Development and Assessment of an Interactive Training Tool to Help Reduce Error Rate Associated With Shared Infusion Volume Management Tasks

by

Kyle Chi Yui Tsang

A thesis submitted in conformity with the requirements for the degree of Master of Health Science in Clinical Engineering

Institute of Biomaterials and Biomedical Engineering
University of Toronto

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Abstract

Nurses often do not understand nor consider the presence of shared infusion volume (SIV) in their practice and there are currently no explicit training methods to address this issue. This research aimed to design and assess an effective interactive training tool (ITT) to help improve a clinician’s ability to deal with SIV management. Recommendations from a heuristic evaluation and two cycles of usability testing helped develop an ITT in the form of a computer-based module. A cognitive task analysis elicited knowledge behind the mental model that critical care nurses and anesthesiologists use when delivering intravenous (IV) infusions. In a high-fidelity simulation experiment, participants performed significantly better for both skill/rule-based and knowledge-based SIV tasks after using the ITT intervention in terms of theoretical comprehension and practical performance. Results of this work can help guide the development of ITTs to address medical administration errors in the context of multiple IV infusions.
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1 Introduction

Preventable medical errors have been estimated to account for $29 billion US annually and cause between 44,000 and 98,000 annual deaths in the United States alone\(^1\). Each year in Canadian hospitals, nearly half of adverse events reported are considered avoidable\(^2\). Reports from the Institute of Medicine (IOM) estimate that each year at least 1.5 million people are negatively affected from preventable adverse drug events\(^3\). It is clear that patient safety issues account for a significant portion of problems related to healthcare systems.

In particular, medication administration errors are the most difficult to be intercepted compared to errors related to the ordering and prescription stages\(^5\). Healthcare providers are more likely to correct for mistakes found in the ordering and prescription stages because the drug of interest has not reached the target patient\(^4\). There are multiple checkpoints at which the clinician or pharmacist can intercept the medication error. However, the administration stage is the last stage of the medication delivery pathway and therefore the chance for interception of errors is significantly reduced. Enhanced safety measures need to focus at the medication administration phase to have the greatest impact in improving the medication delivery process.

The most common medication administration procedure for 90% of hospitalized patients involves intravenous (IV) infusion\(^5\). IV medications are delivered through a patient’s vein either continuously or over a short period of time. Primary infusions are set-up simply with a single medication bag that is delivered by means of gravity-drip or with an infusion pump that can set a more accurate, desired flow rate (Figure 1, left). If a clinician wanted to add a second type of IV medication, they can deliver the intended dose through a secondary line (also known as piggybacking) connected to the primary infusion set-up (Figure 1, right). One advantage of using a secondary infusion line is that the clinician does not need to find another suitable vein for a new access point. Using a combination of carefully placed clamps, correctly positioned medication bags, and properly programmed infusion pumps, it is possible for a nurse to systematically control the delivery rate of multiple medications to achieve the intended dose.
However, in a critical care setting, it is common for a patient to be connected to ten or more infusions bags through a complex combination of infusion pumps, channels, and IV access points\textsuperscript{10}. Managing multiple infusion lines can become extremely disorganized and is often associated with a wide variety of risks as a result of human error where patients have died from incorrect medication administration\textsuperscript{10,16-18}. Common human-related errors include: failure to open the secondary clamp, shared infusion volume management, connection error, and incorrect positioning leading to inappropriate pressure differential\textsuperscript{10,16-18}. These types of errors can be attributed to the increasing complexity of multiple IV administration infusion set-ups to a single patient (Figure 2) leading to estimated error rates of 48–81\%\textsuperscript{4,6-9}. Specifically, the concept of shared infusion volume (SIV), which refers to the common volume shared by 2 or more infusions in the IV tubing between the patient’s vein and the point of medication delivery (Figure 3), is often incorrectly accounted for, which can result in unpredictable and hard to detect medication errors (e.g., delays in therapy, medication incompatibilities).

\textbf{Figure 1:} Primary infusion setup (left); Secondary Infusion Setup (right)\textsuperscript{19}
Figure 2: Components of Secondary Infusion Setup

Figure 3: Shared infusion volume for multiple intravenous infusion setup is highlighted in red
Medical device design flaws are often the root cause of adverse events and thus device re-design can be an optimal solution. Although training should not be used as a resolution for poor design, when deficiencies in device design do exist, users must be trained to overcome or compensate for them. However, previous research has shown that there is an absence of training or a lack of standardized training and education about principles such as hydrostatics, fluid mechanics, and SIV\textsuperscript{10}. The technical aspects of IV infusion are taught to nurses with significant variation ranging from self-directed methods (e.g. simulations) to didactic methods (e.g. lectures, demonstrations)\textsuperscript{10}. Nurse interviewees have also stated that there is rarely any explicit safety training preventing SIV errors with multiple infusions\textsuperscript{10,53}. Students gain experience from their specific instructors during clinical placement, but there is no formal error prevention curriculum prior to deployment. Nurses often rely on their previous experience and encounters, which may limit their ability to quickly adapt to problems found in unforeseen situations. Researchers have concluded that nurses have poor SIV-related practices\textsuperscript{10,36,37,53}. However, little research has been conducted on creating strategies to manage or reduce SIV. Thus, the overarching objective of this thesis is to develop and test an educational tool to increase clinicians’ knowledge of shared infusion volume principles and risks, and to provide training on how to manage SIV, in an attempt to reduce medication administration errors.

Having a standardized training method to help nurses gain a strong foundation in fundamental infusion theoretical principles (e.g. hydrostatics, fluid mechanics) can potentially reduce the number of errors found in novel scenarios. Furthermore, it may be possible to help alleviate the error rate associated with IV infusions by taking a more proactive approach. This method would involve explicit preparation of standardized safety procedure lessons to prevent errors related to SIV that would have resulted in the delivery of harmful medication dosages.

It is important to design new education tools and resources for IV infusion administration and management that is not only cost-effective, validated, and easily deployable, but also with a proper human factors lens. Human factors engineering is a discipline that aims to improve performance by designing devices and systems that take into account both the capabilities and limitations of humans\textsuperscript{11}. The application of human factors to healthcare delivery, a field associated with frequent interruptions and high volume/intensity of information and management, may improve clinical performance\textsuperscript{12}. Specifically, tackling the challenge of
reducing errors associated with IV medication administration may be accomplished with the development of an innovative training tool where clinicians can build upon basic skills and apply them to novel situations.
2 Background

2.1 Preventable IV Medication Administration Errors

Intravenous (IV) infusion systems involve the delivery of medication through the patient’s bloodstream and other body compartments. Proper management of this procedure requires an understanding of the type of medication being delivered and its purpose. The clinician must be able to adjust the dosage based on the physiological changes detected (e.g. blood pressure) as well as resolve unexpected complications that may arise including respiratory distress and cardiac arrest.\(^\text{22}\) Infusions can be categorized based on the duration of administration: intermittent or continuous. For example, infusions of anesthetic agents are only required for the duration of surgery (a few minutes to hours) while infusions of subcutaneous insulin for diabetes mellitus require an indefinite duration.\(^\text{22}\) Further analysis of the data collected is used to design an appropriate course of action for the patient. The complexity of steps involved in IV infusion allow for a significant possibility for the clinician to commit human errors.

The general components of an intravenous infusion system consists of the following items: a) a reservoir of liquid (bag or syringe), b) tubing to transport the liquid to the patient, c) a control mechanism to adjust the flow rate, and d) a percutaneous catheter to deliver the drug into the bloodstream.\(^\text{22}\) In addition, there may include back check valves to prevent backflow, side ports or manifolds to allow for secondary infusion, and drip chambers for visualization of flow. The pressure for the infusion system to drive the delivery of medication can be generated either through the use of gravity or a mechanical pump device. A thorough understanding of how each component contributes to IV infusion is necessary for safe and proper drug administration.

Traditionally, continuous infusion was achieved using the force of gravity as the propulsive force. Based on the height difference between the reservoir and the point of insertion of the catheter, a pressure differential is created, which determines the flow rate of medication.\(^\text{22}\) Because of the simplicity of a gravity-driven system, it is often used in clinical settings where there are limited financial resources and technical support available. Alternatively, a mechanical propulsive device can be used to deliver liquid into the patient by generating a positive pressure using a variety of propulsion mechanisms. The size of mechanical pumps can range from ‘large volume’ mechanical pumps, used in conjunction with reservoirs with volume capacities of 50 to
1000mL, to syringe pumps, designed to propel liquids of 3 to 60mL. Mechanical pumps have the ability to overcome backpressure and unintended resistances from tubing while maintaining a very consistent performance. In addition, modern mechanical pumps have the inclusion of a drug-library and are recognized as ‘smart’ infusion pumps. Ideally, these pumps are designed to help prevent drug dose miscalculations and keystroke errors.

2.2 Common Intravenous Infusion Medication Errors
Intravenous infusion is a complex process and there are many steps where an error can occur. The US Institute for Safe Medication Practices (ISMP) have reported that 54% of potential adverse drugs effects and 56% of medication errors are associated with intravenous infusions. These errors can be attributed to flaws found in two general categories: a) the technical design of infusion systems or b) the practical design of the infusion systems.

2.2.1 Potential Errors with the Technical Design of Infusion Systems
If the clinician decides to use a gravity-driven infusion method, the standard practice is to determine flow rate by counting the number of drops in the drip chamber over a set time interval. This method assumes that the rate of drops will be consistent throughout all infusions regardless of medication. However, in an older study, La Cour compared different infusion sets and found large variations in drop size with a given flow rate. Measuring the flow rate based on this metric can be inaccurate and clinicians may fail to recognize the difference between the relationships of such parameters between different manufacturers. In addition, the resistance in fluid pathway has a significant impact on intravenous infusion. For example, the diameter and length of the vascular access catheter can change the resistance and flow of drug delivery based on Poiseuille’s Law that states that resistance is inversely proportional to diameter raised to the fourth power while scaling linearly with the length of the tube. Therefore, a long catheter with a small diameter may potentially increase the resistance of the flow to a significant enough amount such that there would be an adverse clinical outcome. The design of the catheter or tubing could prove to be highly influential when dealing with intravenous infusion. There are several other design modifications that could be introduced into current infusion systems, however, the more impactful area that could be explored is the second category of changing the practical design of the intravenous infusion process method. The importance of clinicians understanding
the equipment they are being asked to use is paramount especially in cases where the technology may fail during critical moments.

2.2.2 Potential Errors with the Practical Design of Infusion Systems

Several studies have shown that despite the introduction of different smart-pump technologies that are meant to reduce the number of infusion errors through various failsafe mechanisms, an alarming amount of incidents still occur. This can be attributed to the possibility that these technologies may in fact introduce new forms of failure and increase rates of mortality. It is therefore important to characterize the work environment that the clinicians face and develop a system that can accommodate for their cognitive processes. Designing a safer health care environment requires a thorough understanding of the types of medication administration errors that are primarily related to the set-up of the infusion system as opposed to simply the technical design of individual components.

Table 1: Administration errors associated with IV infusions

<table>
<thead>
<tr>
<th>Type of Administration Error</th>
<th>Description</th>
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<tr>
<td>• Incomplete/incorrect labeling of IV tubing&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Tubing was only labeled with partial information; bag was not labeled with name of medication or concentration</td>
</tr>
<tr>
<td>• Inappropriate Y-site or manifold connection&lt;sup&gt;a,b,c,d&lt;/sup&gt;</td>
<td>Products being infused together were not compatible resulting in precipitate formed in the IV tubing or bag</td>
</tr>
<tr>
<td>• Inappropriate infusion rate programmed&lt;sup&gt;a,b,d&lt;/sup&gt;</td>
<td>Pump cannot control flow rate of secondary infusate allowing for free-flow into patient</td>
</tr>
<tr>
<td>• Inappropriate IV access&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Failure to open secondary roller clamp resulted in primary infusion to be delivered at secondary infusion rate</td>
</tr>
<tr>
<td></td>
<td>Infusion rate programmed on pump was not appropriate for type of tubing</td>
</tr>
<tr>
<td></td>
<td>Conversion calculation error in programming sequence resulted in drug delivery delay</td>
</tr>
<tr>
<td></td>
<td>Based on medication and concentration, the type of tubing was chosen inappropriately</td>
</tr>
</tbody>
</table>
• Misplacement of IV bags\textsuperscript{c,d}  
• Shared infusion volume management\textsuperscript{e,f}

| Pressure differential error occurred due to misplacement of IV bag allowing for mixing and concurrent delivery at inappropriate rates  
| Volume between the point of entry of a secondary infusion into the main fluid pathway and the point of exit from the infusion system into the bloodstream is mishandled resulting in drug delivery lag times and unintended drug boluses |

Sources:  
a) Summa-Sorgini et al\textsuperscript{29}  
b) ISMP Canada\textsuperscript{16}  
c) Nunnally & Bitan\textsuperscript{17}  
d) Trbovich et al\textsuperscript{18}  
e) Lovich et al\textsuperscript{34}  
f) Peterfreund & Philips\textsuperscript{22}  

Using this vast amount of knowledge we have regarding the IV infusion process, several technologies and systems have been designed to reduce the chances of preventable medical errors. However, these failsafe mechanisms (e.g. smart pumps, alarms) that have been incorporated into these technologies have limited effectiveness and studies have shown mixed results.\textsuperscript{4,18,25-27} The increasing complexities of IV infusion administration require clinicians to not only understand the functionalities of the technology, but the underlying fundamental principles. One area that requires specific attention relates to shared infusion volume management.

2.3 Shared Infusion Volume Management

The concept of “shared infusion volume” (SIV), more commonly known as “dead volume”, is critical when handling two or more medications. SIV refers to the common volume shared by 2 or more infusions in the IV tubing between the patient’s vein and the point of medication delivery\textsuperscript{10}. Interferences with the accuracy of IV therapy are difficult to detect and are generally noticeable after a change in a patient’s physiological status (e.g. rise in patient’s blood pressure)\textsuperscript{10}. The inputted flow rate and size of the SIV are important factors when adjusting for the concentration of each IV medication. Errors in the management of IV infusion occur when the patient experiences delays and unintended boluses (large dose of substance given intravenously) of IV medication are delivered. Consider the following example adapted from Cassano-Piché et al:

Suppose two fluids (e.g. norepinephrine and normal saline) are given to a patient through a common IV catheter via a Y-connector (Figure 4a). Assume the volume inside the shared tubing
is approximately 2mL before reaching the patient’s bloodstream. The combined flow rate of both fluids is 36mL/h (Figure 4a). At this point, if the clinician decides to give the patient only the medication (i.e. norepinephrine) by stopping the flow of normal saline, the new flow rate will be 6mL/h (Figure 4b). However, the desired rate of norepinephrine would not be achieved for another 20 minutes due to the shared infusion volume of 2mL containing the remaining fluid.

**Figure 4a:** Normal saline and norepinephrine infusing through Y-connector

**Figure 4b:** Normal saline stopped

**Figure 4c:** Norepinephrine concentrates in dead volume over 20 minutes
Alternatively, once the system has stabilized (Figure 4c), if the clinician decides to restart the normal saline at 30mL/h, the 2mL of epinephrine in the SIV will be delivered in a mere 3.33 minutes as opposed to the intended 20 minutes (Figure 4d). The flow rate is 6 times faster than intended despite the small 2mL unintended bolus of norepinephrine. It is important to note that this example has already been simplified to 1 medication, 1 hydration fluid and a simple Y-connector, while in practice, clinicians are often given much more complex scenarios (Figure 5). However, this fundamental principle of SIV is often not explicitly taught in certified training programs, which affect the clinician’s ability to deliver the proper concentration of mixed medications\textsuperscript{10,53}. Principles of infusion therapy associated with the fluid mechanics of IV medication must be fully understood by the clinician to mitigate the prevalence of such errors.
The overall literature on the extent of SIV in short-term infusions has been primarily focused in the design of equipment that could potentially reduce the chance of IV administration errors related to SIV. Lovich et al have performed multiple studies to better understand the fluid dynamics of drug administration by deriving complex mathematical models. Using their quantitative assessment, they and other groups have attempted to design various low SIV infusion sets. For example, Foinard et al demonstrated that multilumen infusion devices were able to minimize the contact time between drug-concentrated solutions until their dilution at the point of entry in the patient. Other infusion set characteristic modifications include shortening tubing length, using antireflux valves, and reducing the volume of manifolds, which have also been shown to impact the flow change efficiency during drug administration.

The majority of research done in this field has been directed towards solving the SIV management issue by changing the technology that clinicians use to deliver medication. There are a few studies that have attempted to survey hospital departments regarding the extent and awareness of SIV management. Plagge et al have concluded that significant loss of drug at
the end of an infusion session is a result of a lack of awareness of SIV.\textsuperscript{37} Although the specific clinical consequences were out of the scope of Plagge’s study, it was noted that this situation could be harmful to both patient safety and effectiveness of intravenous infusion therapy.\textsuperscript{37} An observational study by Wotten et al at an Australian hospital demonstrated that a majority of nurses actually had little awareness regarding the concept of SIV.\textsuperscript{53} In addition, Peterfreund and Philip have published a review on the critical parameters in drug delivery by intravenous infusion.\textsuperscript{22} Based on their expert opinion, they also believe that infusion of drugs cannot be considered a simple, passive process. Having a proper understanding of intravenous infusion principles will ultimately help reduce the number of administration errors. Thus, an alternative approach to address the SIV management situation is to use an educational intervention.

A recent study performed by Pinkney et al\textsuperscript{51}, aimed to identify the risks associated with IV infusions by conducting simulations of infusion related tasks and to evaluate nurses’ ability to safely administer IV medication using an education module. One of the major themes they looked at was SIV management. As mentioned previously, patients often are administered multiple IV infusions connected through a single port, and therefore, a time lag must be accounted for when clearing out the resultant SIV in order to reach an appropriate change in dosage. For this particular theme, Pinkney et al used two tasks associated with SIV management to measure the impact of an education intervention on nursing practice after viewing a SIV education module. One of the tasks involved the administration of medication through a manual IV push into the IV tubing of a pre-existing infusion (Figure 6). To ensure the patient receives the proper dose at the intended rate, the nurse must have accounted for the SIV by flushing the IV tubing with the appropriate volume.

![Figure 6: Manual IV push into IV tubing of existing infusion\textsuperscript{51}](image)
Pinkney et al chose to target this specific theme in patient safety with an educational intervention in the form of a computer-based module, a tool that would be scalable to several learners\(^5\). This multimedia platform included explanations of fundamental infusion principles related to SIV and detailed examples of SIV in common infusion setups. Although there was no significant improvement in overall knowledge-based test scores after completing the module, there was significant improvement in participant performance for the simulated tasks compared to nurses where no intervention was used. Significantly more participants who viewed the education module flushed the residual medication in the SIV compared to baseline (\(P=0.02\))\(^5\). Additionally, although the number of participants that committed a flush rate error when performing the manual IV push was similar in both experimental groups, the mean magnitude of the error dropped significantly (from 3,401mL/h to 1,383mL/h; \(P = 0.03\)) for participants who viewed the educational module.\(^5\) It was clear that the education module caused participants to become more aware of the need to clear the SIV and more conscious of the impact that flush rate has on the delivery of medication during a manual IV push task.

Through Pinkney et al’s study, they also discovered new issues regarding SIV management that were previously not discussed in past literature and therefore not included in their training module. One of the key issues involved the fact that out of the 62 flushes observed, a variety of different practices were used to prevent residual medication. This lack of standardization regarding the appropriate method to deliver a flush can contribute to SIV errors as observed in their study\(^5\). It was concluded that participants do have a basic SIV knowledge foundation, but the underlying problem involves the difficulty in translating and applying this knowledge effectively during clinical practice. Participants may in fact respond differently to various scenarios (e.g. adults versus children, unfamiliar drug orders, changing flush rates) and their mental thought process to proactively tackle these complex SIV situations is currently unknown.

Not all administration errors are easily detectable, specifically errors associated with SIV management, due to their complex nature. In particular, there are few visual cues to assist clinicians. When clinicians make changes to a patient’s infusion set-up, there is a substantial chance for a SIV error to occur, as most IV fluids are transparent in colour making it difficult to detect changes. Despite the correct dosage of medication administered, it is possible for a bolus of medication to remain within the SIV, and thus be delivered to the patient at a slower or faster
rate than expected. Major consequences from this type of SIV mismanagement can lead to sudden adverse changes to a patient’s health. SIV education must go beyond the teaching of fundamental principles and instead provide clinicians with interactive examples and case studies that can help improve their decision-making skills. Therefore, it is worthwhile to uncover the cognitive (as opposed to the technical) aspects of this phenomenon using methods such as cognitive task analysis (CTA).

2.4 Improving Clinician’s Decision-Making Capabilities through Cognitive Task Analysis
Cognitive task analysis (CTA) is a set of methods often used by human factors professionals to better explain and represent the mental processes involved in performing a task. People use their cognitive abilities to make key judgments and decisions when solving challenging problems. When we want to evaluate these cognitive skills, it requires unique methods for assessment. In particular, CTA allows researchers to identify ambiguous, context-bound processes that traditional task analysis is unable to achieve.

Traditional task analysis involves the investigation of the certain steps a person should follow to achieve a certain goal. In essence, it focuses on observable behavior that can be easily recorded through means of shadowing a professional in their natural setting. Behavioral task analysis helps document the objective nature of a certain task focusing on clear and unambiguous cues. Klein and Militello describe this method of task analysis as a means to produce an orderly hierarchical account by decomposing tasks into smaller components. Although this decomposition into a task list can be useful for highly proceduralized tasks, the underlying cognitive processes are often missing resulting in a partially misleading account of performance. There is often a broken link between the steps described in behavioral task analysis that could be repaired by a thorough exploration of the connecting cognitive skills.

It is important to understand that CTA is not fundamental research in the field of cognition or a prescription of how people should think. Although the insights gathered from basic cognitive research involving working memory or attention can be useful to the development of CTA methods, CTA tries to understand certain phenomena that cannot be explained in terms of simple
rules. CTA does not try to impose a framework on a person’s method of completing a task, but instead gathers information regarding the cognitive processes of decisions and judgment when performing such task. The knowledge gained can then be applied to building training modules that would better fit the professional’s way of thinking.

Developing a successful CTA study requires the team to have discovered something important about key judgments and decisions in a particular area (in this case, SIV management). This can range from designing mental models for effective troubleshooting to balancing resources and tradeoffs when making a critical decision. Depending on the scenario, the cognitive discoveries can help directly lead to a better decision support or training system. Applying such knowledge to development of new strategies must be followed by gathering data regarding the intervention’s actual value and describing such impact in a meaningful way.

CTA moves beyond the simple application of a particular rule and delves into the exploration of cognitive elements required for dealing with real world constraints. A wide variety of CTA methods have emerged to manage such complex cognitive processes, which include: interview, observation, modeling, and experimental methods. Choosing an appropriate method requires a careful understanding of which types of cognitive processes will be most likely encountered during investigation. For example, a study of pilots and their ability to target certain controls on their highly complicated dashboards would require a thorough examination of their attention seeking and control abilities. Alternatively, a study of librarians and their ability to recommend books to patrons would require an examination of their perceptual skills. Furthermore, selection of a suitable CTA method also needs to take into account how the information gathered will be used for the improvement or design of a new decision making training system.

In regards to nursing education specifically, the ability to make rapid and accurate assessments given a patient’s status is cultivated through experienced-based knowledge (i.e. hands-on involvement). Achieving a proficient level of clinical skill and intuitive judgment requires a significant amount of practical experience. This type of expertise is thus difficult to characterize, as there is no standard curriculum when a nurse attempts to learn and build upon his or her critical decision making abilities. Crandall and Getchell-Reiter suggest that at a certain point in an expert’s career, they may not be consciously aware of the particular cognitive skills required
to perform a complex task. Their study on expert neonatal intensive care unit (NICU) nurses utilized a particular CTA method known as the critical decision method (CDM) to identify and document key elements for delivering care for critical incidents (e.g. early detection of sepsis). CDM is a knowledge elicitation method that employs the use of semi-structured interviews with specific, focused probes designed to extract information from particular incidents from the interviewee. Although it was difficult for nurses to initially articulate their assessment cues, the researchers went over the described scenario again using their CDM model of semi-structured interviews. It was found that CDM was better able to help nurses explain in detail surrounding cues, judgments, decisions and actions in the nurse’s initial account. Additionally, CDM has the ability to solicit information regarding the particular goals during the incident and the various options considered to circumvent any further crisis. Therefore, it may be highly beneficial to employ CDM to extract hidden information from other areas of nursing (i.e. SIV management) to help build suitable training methods.

The steps of the CDM are outlined below and the framework is based around Crandall et al and Baxter et al’s research around neonatal intensive care unit nurses

<table>
<thead>
<tr>
<th>Phase</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instruction</td>
<td>Rationale of study is explained and participants are probed as to their knowledge regarding SIV</td>
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<tr>
<td></td>
<td>Participants are also given a general introduction around the ideas of the critical decision method</td>
</tr>
<tr>
<td>Incident identification/selection</td>
<td>Participants are asked to identify any IV infusion incidents they were involved in</td>
</tr>
<tr>
<td></td>
<td>Participants are asked to place specific attention to detail where SIV was a significant issue</td>
</tr>
<tr>
<td>1st event recall</td>
<td>Participants are asked to describe a selected SIV incident in detail and the interviewer records in detail critical events, decisions, and actions when such challenge was encountered</td>
</tr>
<tr>
<td>Timeline verification</td>
<td>Notes taken by the interviewer are verified with the participant</td>
</tr>
<tr>
<td></td>
<td>Any outstanding information missing from the timeline/decision-making events are appended</td>
</tr>
<tr>
<td>2nd Event recall</td>
<td>For each event, the interviewer asks in detail what was happening in the participant’s mind to extract information about the cognitive</td>
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</table>
A set of questions is used to help probe for additional information regarding the cues, judgments, decisions, and actions contained in the nurse’s description that may have not been identified in the initial event recall.

Data analysis and verification

Data is analyzed and transformed to generate an inventory of information cues, a situation assessment record, and a list of SIV issues identified by the participant.

The type of judgment used in the situation assessment recorded is divided into three categories: normative (comparison between similar cases), ipsative (comparison between present/previous status of patient), or cue discrepancy (apparent discrepancies among warning signs).

Once an understanding of the mental processes involved in performing IV administration tasks is achieved, it is important to consider the different types of errors that can be made to better identify the content to be covered in educational training tools.

2.5 Training using a Skills, Rules, and Knowledge-based framework

In the area of intravenous medication, many studies have discovered an alarming rate of preventable errors.\footnote{\ref{1,2,4,6,7,9}} Some studies have suggested that these errors derive from a multitude of factors including equipment problems, communication problems, lack of experience and knowledge, and most notably a lack of training.\footnote{\ref{7,24,39}} Taxis et al have previously discovered that nurses are in fact unaware of the occurrence of medication errors.\footnote{\ref{7}} In Taxis’ ethnographic study, they demonstrated that administration errors occurred in 36% IV doses.\footnote{\ref{7}} In their observations of two study hospitals, it was noted that mistakes were frequent due to the complex design of the infusion equipment. Additionally, student nurses were occasionally given tasks without any supervision. It was unlikely that the novices were left unattended intentionally, but was instead put into the situation due to the high workload and distractive environment. Nevertheless, adequate training for intravenous drug administration needs to be offered for a safe environment. Current training methods for nurses regarding the practical aspects of IV drug preparation and administration are often taught through apprenticeship rather than in a formal setting.\footnote{\ref{7}} The content and quality of training programs were unregulated and uncommon preparation.
techniques were not covered. Safe IV medication delivery was considered a low priority in both hospitals. Taxis suggests that further studies are needed in which the application of a framework on human error theory could be used to design better equipment. Taking this one step further, it would be ideal if training methods were also designed with concepts derived from Rasmussen’s framework on human error.

Rasmussen’s conceptual framework for human performance revolves around three basic types of errors: skill-based (execution failure), rule-based (errors in applying a rule), and knowledge-based mistakes (human bias leading to incorrect situational solutions). While mechanistic tasks require minimal stored knowledge and are more often prone to skill-based errors, abstract tasks are often prone to rule- and knowledge-based errors. This is because the latter type of tasks requires the integration of multiple data sources that the human must perform based on the current situation. Training tools that address rule-based and knowledge-based errors may prove to be more effective in reducing errors in IV medication administration.

Changing behavior associated with rule-based errors for basic IV infusion principles has been previously tackled through the introduction of smart pumps with bar coding that possess computer-automated safeguards against dosing errors. Automation of mechanistic tasks (e.g. recognizing mismatch in drug label and patient armband), which compare two tangible sources of information, has been shown to significantly decrease the rate of IV infusion process errors. However, non-mechanistic (i.e. abstract) components of this procedure (e.g. recognizing an incorrect drug due to inappropriate recommendation from a physician order) require critical thought and higher cognitive functions, which cannot always be solved with simply technological solutions. Unexpected situations in healthcare environments require clinicians to be able to draw from their previous understanding of basic medical principles to make a proper judgment regarding the situation. Developing an adaptive strategy requires the person to not only identify the key issues, but also the ability to select and implement the appropriate solution. It may be possible to enhance the clinician’s critical reasoning skills in training by incorporating a tool that allows learner participation in knowledge construction through practice-based techniques and self-paced training with learn-tailored feedback. This tool would be able to take these human factor principles into consideration and explicitly characterize experts’ experience-based knowledge.
2.6 Combining e-Learning approaches and constructivism

Health care professionals are required to develop their basic clinical skills before interacting with an actual patient. In particular, intravenous skills are taught in medical and nursing schools through a series of specific tasks, which include: venipuncture procedure, catheter placement, evaluation, and discontinuation. However, standardization of the training methods used to teach these skills is lacking. It was demonstrated that less than 50% of students had limited exposure to placing a peripheral intravenous catheter. Ruiz et al have suggested that health care delivery and advances in medicine have increased at a rapid rate over the past few decades, resulting in less time for teaching than previously. It has been difficult for medical curriculum to cover the immense amount of new information that becomes available from advancing medical technologies and growing clinical safety policies. There is also the additional factor of designing a training style that is compatible with human cognitive learning processes.

Fortunately, with the advancement of technology, specifically in the field of virtual reality (VR) and interactive programming, training has excelled for the teaching of certain intravenous skills. For example, an interactive, multimedia, computer-based intravenous simulator called CathSim has been widely used in various training settings and has shown significant improvement in learner satisfaction for medical students. CathSim has also been shown to be a viable learning process for students learning intravenous catheterization. Johannesson et al discovered that integration of simulation skills training as part of the curriculum offered students the opportunity to work on a broad range of cases. Furthermore, the CathSim offered visual, auditory, and touch components allowing students to be engaged in an educational tool with a high level of realism. Computer-based simulators could potentially help with the standardization of training methods for a variety of clinical skills. A study by Youngblut have found that teachers have actually stated they would be inclined to use virtual reality technology if certain limitations of VR were addressed in terms of affordability, availability and ease of use. Some of these limitations are further reiterated by Chen where she explains that although VR is an impressive learning tool, issues that require further investigation involve identifying appropriate theories and/or models for effective design and development. Other disadvantages of using VR are primarily focused on cost and time necessary for learning how to use the new hardware and software. Virtual reality for the purposes of improving SIV management for nurses is simply too expensive to justify.
Another method of standardization for intravenous skills is the use of e-learning approaches, which try to integrate electronic technologies to enhance knowledge and performance. E-learning is often cited as an advantage due to increased accessibility to information, personalized instruction, ease of distribution, standardization and accountability. This type of technology can enhance learning through an adaptive process by recognizing the user’s level of expertise and knowledge. Specifically in health care, Gibbons and Fairweather demonstrated that e-learning is at least as good as, if not better than, traditional didactic approaches. They discovered that computer-based instruction can in fact increase both the efficiency and retention rate in learning. Ruiz et al believe that e-learning can help transform the role of the teacher from disseminator to facilitator, an idea that is closely related to the theory of constructivism.

Constructivism is a learning theory that encourages learners to develop their own ideas based on individual experience, which can be directly applied to their learning environment. The educator facilitates learning by keeping the student engaged through consistent interaction during training. There are several methods to incorporate constructivism with e-learning. Moderated online discussion boards help promote collaboration and cooperation between peers. Self-reflective activities through questioning and tasks can help users connect existing knowledge with new information. Computer technology allows the teacher to shift e-learning experiences towards a student-centered environment. Conceicao and Taylor found that nurses were better able to integrate prior knowledge and validate current knowledge after taking online courses, which were designed with constructivism. Failure to use an appropriate learning theory when designing an e-learning experience can potentially have negative outcomes.

Kala et al have recently published a model for nursing education when electronic learning and constructivism are used as summarized in the following table.
Table 3: Model for integrating electronic learning for nurse education derived from Kala et al.47

<table>
<thead>
<tr>
<th>Integration of Electronic Learning and Constructivism</th>
<th>Educator’s role</th>
<th>Course effectiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-learning uses technologies as cognitive tools</td>
<td>Enhance active learning by:</td>
<td>Evaluate the effectiveness of the e-learning solution by:</td>
</tr>
<tr>
<td>Constructivism is a learning theory based on the idea that learners should develop their own knowledge within the learning environment</td>
<td>a) Allowing students to articulate their current knowledge and reflect on how they can combine new knowledge with their basis</td>
<td>1. Surveying learners on the accessibility, ease of use, appropriateness, and helpfulness</td>
</tr>
<tr>
<td></td>
<td>b) Utilize problem-based learning, case-studies, gaming, concept-mapping, or simulated-based learning tasks</td>
<td>2. Evaluate learning outcomes through pre- and post-questionnaires, simulation testing</td>
</tr>
<tr>
<td></td>
<td>Create quality learning materials based on their target audience:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>c) Content and multimedia components should increase in breadth and depth as the learner progresses</td>
<td></td>
</tr>
<tr>
<td></td>
<td>d) Opt for an interactive media rather than simply prescriptive content</td>
<td></td>
</tr>
<tr>
<td></td>
<td>e) Appropriate materials should be evaluated prior to implementation</td>
<td></td>
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</table>

In summary, the constructivism learning theory can be applied to e-learning in an effective manner when the teacher utilizes active learning tasks such as patient care scenarios, blog-writing to express their understanding of nursing knowledge, problem-solving, and participation among peers. In addition, Kala et al recommend that the quality of learning materials are developed at a high standard, which are expected to be reviewed by nursing colleagues for validity.47
Despite the many advantages of e-learning and its growing presence in all forms of training (11% to 36.5% from 2001 to 2010 based on ASTD State of the Industry Report, 2010), there still remain several limitations of current e-learning tools. Organizations are using e-learning to save both training time and travel costs that are generally associated with traditional person-to-person learning. However, the quality of instruction embedded in these e-learning tools may not always effectively build the required knowledge and skills intended for a successful outcome, which thus reverses any cost savings produced. The challenge remains that e-learning tools are often not designed with a specific instructional strategy. Technology may in fact deliver sensory data at a rate that the human nervous system can simply not process. It is not beneficial for the learner to be overloaded with an excess of audio and visual elements such that interference with human cognition occurs. Simultaneously, learning also requires a consistent level of interactivity such that the user has an opportunity to process the content through practice exercises and simulations. To fully maximize the potential that e-learning has to offer, there exists a need to have a strong understanding of the human cognitive processes involved with the type of learning required for the intended task.

To facilitate meaningful learning, Clark and Mayer have emphasized the need to incorporate four broad features in e-learning tools. Activities that are designed to help the self-explaining of a complex visual or summarizing a portion of a lesson can promote human cognitive processes that stimulate better knowledge construction. E-learning tools should not be a collection of slides that simply require mundane actions to progress through. Instead, if e-learning is to be utilized as a method to teach a complex task requiring the user to build a complete mental model, the tool needs to include the following features:

1. **Customized Training:** Content must be tailored to the needs of the individuals based on their prior knowledge. Adaptive e-learning can be incorporated in an asynchronous fashion in which the program customizes content dynamically based on the user’s response and background knowledge. Finding an appropriate balance between learner control and program control is an important feature to consider when designing an e-learning tool. A thorough understanding of the type of audience the tool needs to teach and the complexity of the content is required when considering the type of customized training one wants to deliver.
2. *Engagement in Learning*: The two types of engagement that can be employed when delivering content is either “behavioral” or “psychological” engagement. Behavioral engagement triggers the user to take a certain action after given a certain cue. An example of this would be pressing the forward arrow button after completing an exercise on a computer-based module. Psychological engagement triggers the user to acquire new knowledge and skills by activating certain cognitive processes. This type of engagement is much more effective in meaningful learning as the user is driven to integrate the new information with existing knowledge into long-term memory.

3. *Multimedia*: A well-balanced combination of text and audio can lead to enormous benefits when communicating new content. Various e-learning principles outlined by Clark and Mayer may be applied to the development of a new training tool to fully maximize its teaching potential. This feature may include the following principles:
   a. Balance between the amount of text and graphics
   b. Balance between the positioning of text and graphics
   c. Choice of audio versus narration
   d. Use of a conversational style and virtual coaches
   e. Complexity of breaking a lesson into parts

4. *Acceleration of Expertise through Scenarios*: Rather than waiting several months for an opportunity to arise where certain thinking skills can be trained, e-learning tools offers the ability to accelerate this process and directly immerse the user in a job-realistic environment. The two types of thinking skills that would heavily benefit the training of SIV management are critical thinking and problem solving. Critical thinking involves the evaluation of a new product and/or idea while problem solving refers to the ability of a how a user can adjust a certain approach to solve a particular problem based on what scenario he or she has been monitoring. One can use cognitive task analysis (see Sections 2.4 and 4.3) to identify these job-specific thinking skills and incorporate them into an e-learning tool to help accelerate expertise.

A primary objective of my thesis will be to utilize these key features on the development and evaluation of an interactive training tool for SIV management.
3 Objectives

3.1 Gap in Knowledge
Many of the concepts found in constructivism can be potentially incorporated in a computer-based training module about SIV management previously developed by the HumanEra team at the University Health Network. The team created a prototype of a touchscreen user interface with the use of narration, graphics, and animations. A research study was conducted to evaluate the effectiveness of the computer-based tool compared to baseline (no training) on intensive care nurses’ ability to perform common nursing tasks involving shared infusion volume (SIV) management in a high-fidelity simulation laboratory. The results of that research showed that the computer-based training was especially effective in improving SIV management practices when the module explicitly targeted specific tasks and associated recommendations. However, the computer-based training was not effective in helping nurses perform tasks that required them to translate the knowledge gained to untaught (novel) tasks. Therefore, the overarching purpose of this thesis is to design, develop, and evaluate an interactive training tool (ITT) that incorporates knowledge gained through various methods and theories including: cognitive task analysis, Rasmussen’s framework for human performance, and principles from constructivism. The effectiveness of this ITT on improving nurses’ understanding and management of SIV was assessed through multiple usability and validation phases in the form of simulation studies.

This thesis project aims to answer the following research question:

*Can an interactive training tool developed with CTA help clinicians perform better in the shared infusion volume management of IV infusion systems for skill based, rule based and knowledge based tasks compared to a baseline condition of no training?*

3.2 Approach
A computer-based training module on SIV management was developed and evaluated in a previous phase of a larger initiative to improve the safety associated with the administration of multiple intravenous (IV) infusions. Although some improvement in safety was recognized, the HumanEra group identified further areas of improvement involving the addition of an interactive component to training modules. Specifically, participants were not provided a means to apply their knowledge gained and build skills towards solving certain IV infusion tasks and case
A four-phased approach was used to address the above objectives:

1. A heuristic evaluation was performed on a previous prototype of the e-learning module designed by HumanEra, based on good training design. It is an inexpensive method of systematically evaluating the design of a user interface to assess whether aspects of a design are in agreement or in violation of established training (i.e. ease-of-use) principles or heuristics.

2. An interactive training tool (ITT) was developed with a human factors approach to help clinicians prepare better for both routine and novel tasks involving SIV management. Two cycles of usability testing on the ITT were performed with a mix of 15 critical care student and experienced nurses. Modifications regarding the design and content of the ITT were performed based on participant feedback and observer notes.

3. A cognitive task analysis was performed with critical care nurses and anesthesiologists in regards to their knowledge of SIV management. Specifically, semi-structured interviews were conducted to better understand the cognitive processes required during the administration of multiple intravenous infusions. Interviews were transcribed and structured into different types of cognitive elements (e.g. cue, appraisal, action). An inventory of cues from critical care nurses were then developed using an affinity diagramming technique.

4. Lastly, an experimental study using a high-fidelity simulated critical care environment was conducted to assess the effectiveness of the newly developed ITT compared to a baseline condition of no training. During the simulation phase, participants were given four intravenous infusion scenarios, each with certain sub-tasks related to SIV. Additionally, each participant underwent a cognitive walkthrough process to reveal whether or not a deeper understanding of shared infusion volume concepts were learnt. The cognitive walkthrough consisted of a series of questions asked at the end of each scenario to help probe the nurse’s mental model regarding the tasks s/he performed.
4 Heuristic Evaluation

4.1 Objective and Methods
Heuristic evaluation (HE) is an inexpensive method of systematically evaluating the design of a user interface to assess whether aspects of a design are in agreement or in violation of established usability (i.e. ease-of-use) principles or heuristics. Usability heuristics were used as a framework of reference to evaluate the design of the computer-based module that was previously used to help train nurses with intravenous infusion. The heuristic report contains information regarding key areas of improvement, key design elements that support usability, and any limitations that hinder usability. Any specific issues discovered were matched with a relevant heuristic and classified under a certain category of importance (i.e. minor, moderate, major).

Similar to Nielsen’s previously published set of 10 usability heuristics for user interface design, a new set of heuristics has been established by Peters, described in “Interface Design for Learning”, geared specifically towards learning interfaces. The computer-based training module built by HumanEra was evaluated using this set of 11 heuristics as outlined in the following table:

<table>
<thead>
<tr>
<th>Heuristic Principle</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>1. Relevance of media</td>
<td>Causes for extraneous cognitive load, such as imagery, visual and decorative detail, and other media elements that do not directly support the learning objective or required interactions should be avoided</td>
</tr>
<tr>
<td>2. Learner control and freedom</td>
<td>The level of learner control afforded by navigation, architecture, and interaction design should be appropriate to audience characteristics and pedagogical approach</td>
</tr>
<tr>
<td>3. Support for learning objectives</td>
<td>Interface graphics, content graphics, and interaction design should support the learning objectives as defined by educational designers or instructors</td>
</tr>
<tr>
<td>4. Alignment with specific learner needs</td>
<td>The design should be influenced by specific audience characteristics such as prior knowledge, culture, literacy, computer literacy, visual literacy, age, professional, or subgroup culture, and any other aspects that can affect design decisions</td>
</tr>
<tr>
<td>5. Appropriateness of look and feel</td>
<td>The look and feel should reflect an image appropriate to the audience, message, and content of the learning experience (for example, neither too childlike to be patronizing to experts, too serious to depress engagement in children, nor</td>
</tr>
</tbody>
</table>

Table 4: List and description of heuristics for user interface design for e-learning modules by Peters.
6. Cognitive aspects of learning

The design should support the cognitive aspects of learning relevant to the experience (for example, reasoning, cognitive load, problem solving, social interaction) as defined by one or more theories of learning psychology. Obstacles to the cognitive aspects of learning should be treated as errors in learning interface design.

7. Affective aspects of learning

The design should support the affective aspects of learning relevant to the learning objectives within the constraints of available research evidence. Obstacles to the affective aspects of learning should be treated as errors in learning interface design.

8. Appropriateness of media and tools

The design should use media, devices, and tools appropriate to the type of learning or activity.

9. Accessibility

The design should be accessible to all learners within its scope, regardless of disability, device type, or technological literacy.

10. Usability

The design should conform to usability guidelines and best practices.

11. Feedback and responsiveness

The design should permit both operational and instructional feedback. Feedback should be intrinsic where possible and, when extrinsic, it should be placed near the relevant item and leave room for instructionally “rich” responses. Operational feedback should be provided instantaneously.

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**Figure 7:** Screenshot of previous e-learning video
4.2 Results

Issue 1: Lack of Labels

In the e-learning module evaluated (see Figure 7), there were certain connectors in the SIV infusion set up that were unlabeled. It was therefore difficult to determine, which particular component was being referred to based on simply the narration. From a usability perspective, grasping new concepts should be accomplished in a non-distracting setting. If any cognitive process is used to solve an issue unrelated to the targeted concept (i.e. SIV management), there will be a lower retention rate in material.

Relevant Heuristics Violated: Usability, affective aspects of learning

Severity: Minor

Recommendation: Adding labels for the user to easily identify the various sections of the infusion set-up will naturally help the usability of the module.

Issue 2: Lack of interactivity

The video had no area of interactivity with the user in terms of controlling the pace of the e-learning module and engaging the user. It can be difficult for the user to grasp the new material without any natural pauses, as s/he may be unable to absorb the complex information. Having the ability for learner control and freedom is a critical aspect to incorporate when designing an e-learning tool. The designer should not predetermine the amount of time a user requires to understand new information. Additionally, throughout the video, the user never had an opportunity to be engaged (e.g. probed with questions) with the material being taught. A lack of engagement within the module can also hinder the user’s learning proficiency. If users are more engaged with the content, it’s more likely that they can start developing their own mental model around SIV management due to a higher level of interest. Allowing engagement activities such as questions also allows user to recognize if they have a gap in their own knowledge.

Relevant Heuristics Violated: Learner control and freedom, support for learning objectives, feedback and responsiveness

Severity: Critical

Recommendation: Since there is no particular time constraint for the user to complete the e-learning module, it was advised that future iterations allow users to view the tool at their preferred pace. This can be accomplished by including previous and next buttons, in which the user can navigate through the content accordingly. Previous and next buttons would also allow
people to learn at different speeds. Finally, an additional recommendation was to increase the level of interactivity by incorporating engagement questions, which would help set the tone of the e-learning module. By introducing this type of interactivity, users will either become aware of their potential lack of knowledge in SIV management or confirm their existing knowledge and treat the e-learning module as a good refresher.

**Issue 3: Overloading of text**

There are generally two groups of learning styles that users identify themselves with: visual and audio learner. Achieving a balance between the amount of text and speech given in any learning tool is an important heuristic to follow. In this e-learning tool, it was found that certain sections had an overwhelming amount of audio that did not explicitly correspond to the overwhelming amount of text. The user may be inclined to read the information in the video as opposed to listening to the narration or vice versa. This is especially problematic when the visual and narration are not congruent. The overloading of sensory inputs during the explanation of a new topic may result in decreased knowledge construction.

*Relevant Heuristics Evaluated: Relevance of media*

*Severity: Moderate*

*Recommendation:* When the video is explaining concepts, it was advised that the e-learning module should highlight the key points regarding SIV by using short key phrases. This would allow the user to quickly read the most important take-away message and then listen to the rest of the narration for any other supplementary information. If large blocks of texts are determined to be an absolute necessity, it is paramount to match the narration with the text on screen. It is recommended that heavy text only be used at the end of an e-learning module where there are specific recommendations (rules) for best practice.

**Issue 4: Lack of case studies**

Many of the concepts provided in this e-learning module were very informative and the content was heavy on the theoretical underpinnings of multiple intravenous infusions. However, it is possible that the module focused too much of its effort in explaining the theory behind SIV management. This may not be of value and/or interest to the end-user who may only want to know how this concept of SIV applies to his or her work. Alternatively, it may be more appropriate to present the concept of SIV by including concrete case studies in which the nurse
The teaching theory known as constructivism, which encourages learners to develop their own ideas based on individual experience, can be directly applied to the module. The education module can facilitate learning by keeping the user engaged through a series of relevant case scenarios.

**Relevant Heuristics Violated:** Cognitive aspects of learning, alignment with specific learner needs

**Severity:** Minor

**Recommendation:** By integrating a relevant clinical scenario, users may find it easier to help add information onto an existing framework of knowledge. It was suggested to introduce a case study scenario in the beginning of an e-learning module as an engagement piece before providing the theory behind the particular incident. However, it is also important to not introduce a case study with questions that are too complex to avoid the possibility of shunning the user from continuing with the module. Simpler case studies can be introduced at the beginning of the training tool while more complex case studies can be used at the end of teaching section.

### Time to Clear Dead Volume Approximation Table

| Flow Rate Through Dead Volume (mL/h) | 5     | 10    | 20    | 30    | 40    | 50    | 60    | 70    | 80    | 90    | 100   | 110   | 120   | 130   | 140   | 150   | 160   | 170   | 180   | 190   | 200   | 210   | 220   | 230   | 240   | 250   |
|-------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 5                                   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 10                                  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 20                                  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 30                                  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 40                                  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 50                                  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 60                                  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 70                                  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 80                                  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 90                                  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 100                                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 110                                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 120                                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 130                                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 140                                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 150                                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 160                                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 170                                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 180                                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 190                                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 200                                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 210                                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 220                                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 230                                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 240                                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 250                                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 260                                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 270                                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 280                                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 290                                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 300                                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |

**Figure 8:** Shared infusion volume (or dead volume) approximation table used in the e-learning video

**Issue 5: Look-up table has limited utility in a real-world setting**

Despite the potential benefits of the SIV approximation table presented in the video (Figure 8), there was a concern that it might have little value in a real-world setting. At first glance, the table is very complicated and could potentially detract a user’s interest in learning the material. When using such a complex tool, it would be useful if the user were given a particular incident to solve.
that required the use of the look up table to figure out the SIV time. This would also help incorporate an interactive component to the e-learning module. The incorporation of the look-up table is meant to teach the user how to calculate the exact time lag amount when delivering an infusion through a particular volume of tubing. However, the module never explicitly mentioned the rationale for knowing how to calculate the exact time lag amount. There seems to be a missing link between understanding how to calculate this value and the potential consequence of not knowing this value. Recommendations on how to avoid or reduce this time-lag were needed for this section. Thirdly, it is unlikely that a clinician would carry this look-up table with them in their practice. Overall, this look-up table is extraneous information that could potentially confuse users and thus reduce their ability to properly perform their clinical duties.

Relevant Heuristics Violated: Relevance of media, cognitive aspects of learning
Severity: Critical
Recommendation: It was recommended to simply remove the look-up table as method to understand the time lag associated with SIV. An alternative tool or simpler method to explain the underlying formula to calculate the time-lag issue may be needed.

Issue 6: Mathematical explanations feel rushed
Being able to teach such complex material related to SIV management requires lessons to be taught at a slower rate. There was little time for the user to absorb the amount of mathematical information being presented. For example, when the video began to delve into the mathematics behind the changing of infusion rates, the equations on screen would appear and disappear too quickly. The user was not given any control on the pace at which the equations were being used to calculate the flow rates.

Relevant Heuristic Violated: Cognitive aspects of learning, learner control and freedom
Severity: Moderate
Recommendation: Modifying the e-learning module to be more user-controlled was recommended. For example, adding user-controlled buttons (e.g. previous, pause, next, replay) in the e-learning module to navigate through the training tool was recommended to improve the level of knowledge absorption. This is particularly important when explaining mathematical equations, as it is likely that this subject matter is not as commonly taught in a nurse’s curriculum. Additionally, a user may want to attempt to perform his or her calculations to verify that they have understood the mathematics behind the changing flow rates.
Issue 7: Passive Learning

Many of the previous issues discussed have briefly touched upon the passive nature of this e-learning module. Learning passively through watching a video may not be engaging enough for a user to draw conclusions and build knowledge. Videos may be of more use when trying to teach users skill or rule-based information. However, active learning that can stimulate a person’s cognitive processes is required for successful knowledge construction.

Relevant Heuristic Violated: Cognitive aspects of learning, support for learning objectives

Severity: Critical

Recommendation: By incorporating some aspect of problem solving or reasoning, the user will have a higher chance of linking their previous knowledge foundation to this new information. It was advised that future iterations of the training tool have a significantly higher level of interaction and case studies.

4.3 Summary of Heuristic Evaluation

From the HE, it was determined that the ITT required a significant level of learner control to allow the user sufficient time to build upon their existing knowledge framework. This e-learning video module appears to provide users with relevant and useful information regarding issues that arise due to SIV when performing multiple intravenous infusions. However, based on Peter’s set of heuristics for an e-learning tool, several heuristics were improperly addressed ranging from minor to critical importance. Two of the eleven heuristics that require the most significant attention involve a) learner control and freedom, and b) cognitive aspects of learning.

It was found that the interactivity of the video is already being directed without any natural pauses. This means that the user would not actually have time or require any effort to think about a particular solution to a given incident. In addition, the use of a video does not aid the user in terms of activating the cognitive process of learning. SIV management is a complex issue that requires critical thinking to solve. Learning passively without an engagement piece may hinder the ability for the user to draw conclusions and gain knowledge.

The SIV management training tool provides a large amount of useful and relevant information that may not have been explicitly taught in a nurse’s previous education. Previous research has demonstrated that the rationale behind certain procedures in multiple intravenous infusions is
missing from a nurse’s knowledge\textsuperscript{7,24,39}. The HumanEra e-learning module hopes to address SIV related issues. After performing a HE on this training tool, it was found that the two major heuristics that required attention involved a lack of learner control and freedom and little integration of the cognitive aspects of learning. Overall, it is recommended that future versions of the e-learning modules incorporate features that allow for natural pauses to provide users with sufficient time to build upon his or her existing knowledge framework. In addition, incorporating an explicit list of recommendations for best practices in relation to SIV may prove to be more applicable for clinicians as opposed to learning how to use a look-up table for SIV calculations. Lastly, the introduction of relevant clinical scenarios that the user can work through can serve as useful engagement pieces.

HE is a powerful method to understand and identify areas of improvement regarding a particular interface. This low cost and relatively quick method to uncover potential issues has revealed multiple heuristics that have been violated. However, HE has its limitations in terms of the lack of involvement with actual end users. Therefore, the next method in which representative end-users perform tasks to uncover whether issues raised in the HE are relevant was conducted subsequently. The recommendations for this HE were used as a guideline when probing users for their feedback regarding the ITT during the subsequent usability-testing phase.
5 Design and Testing of the Interactive Training Tool

Once the design modifications based on the heuristic evaluation were established, a usability testing session was conducted on the developed interactive training tool (ITT) to discover potential issues regarding the intervention. The objective of the usability tests was to assess the ease of use (in terms of how well users can understand the material being presented) and the satisfaction and acceptability of the ITT.

5.1 Methodology for Usability Test (First Iteration)

5.1.1 Location and Materials

The usability testing was conducted in a low-fidelity simulation environment at the Centre for Global eHealth innovation, based at the University Health Network (UHN) in Toronto, Ontario. The set-up was modest and simply included a desk at which the participant interacted with the ITT. Observational rooms with one-way glass were used to actively monitor the participant’s actions and record feedback. Overhead ceiling mounted cameras and audio recording systems in the room were used to monitor the usability tests.

5.1.2 Sampling and Recruitment of Participants

Ten participants were recruited for the first round of usability testing. Nurses were recruited for the study using a sign-up sheet for interested individuals and announcements during morning nursing rounds in the cardiovascular intensive care unit (CVICU) and medical surgical intensive care unit (MSICU) at Toronto General Hospital. Research Ethics Board approval (Appendix A) from the University Health Network (REB 14-7881-BE) was obtained prior to the study being undertaken. Interested individuals were subsequently contacted through e-mail or phone to confirm an appointment for the research study. Prior to confirming an appointment, study participants were asked a series of questions to ensure that they met the following criteria in order to be eligible for this study:
   a) Registered nurses who work at UHN in a critical care environment as staff or student
   b) Have been trained to use infusion pumps
   c) Fluent in English in reading, speaking, and understanding
   d) Have the intent of actively participating in this study and willing to sign the consent form
The purpose of the usability testing was not to establish statistical significance but rather to identify design-related issues with the training tool. The sample size was sufficient to provide enough information regarding 75-90% of usability issues (i.e. issue saturation) based on Figure 9 for each usability cycle.

![Figure 9: Relationship between the number of users and the percentage of usability issues found during usability testing.](image)

Participants provided voluntary consent. Participants were notified of the implications of their involvement, their right to withdraw, and that their participation was entirely voluntary. Nurses participated in the study outside of their working hours, thus, there was no impact on patient care. Nurses were directly remunerated $125 for their time based on the following approximate calculation:

- Hourly rate of senior nurse: $44.22/h (source: ONA Hospital Central Agreement, Exp Mar 31, 2016. Note: the rate for a senior nurse for April 1, 2014 was used as we do not want to discriminate against this group of nurses)
- Premium pay: 150% (source: ONA Hospital Central Agreement, Exp Mar 31, 2016)
- Study duration: 2 h
- Compensation: $44.22/h * 150% * 2 h = $132.66

5.1.3 Procedure

When the participant first arrived, s/he was greeted by the study facilitator and was introduced to the overall mission of the Centre for Global eHealth Innovation. The participant was introduced to their role in the study and asked to complete a demographics questionnaire (Appendix B)
consisting of questions regarding specialization, age, sex, weekly hours, and level of experience. The consent form (Appendix C) was then reviewed with the participant. To ensure the participant felt comfortable, the facilitator emphasized that the purpose of the study was not to evaluate their clinical knowledge but rather to understand the extent to which the training tool required design or content improvements. It was also emphasized that any positive or negative comments regarding the training intervention would have no effect on their employment. Additionally, participants were asked to verbalize their thoughts and actions while watching the ITT regarding shared infusion volume. The facilitator explained that by “thinking aloud”, the observers would be able to better understand possible usability issues and end-user experiences. For example, if a particular navigation sequence was confusing, observers asked the participant to inform them and explain where exactly in the module the problem was arising. Some nurses were more talkative than others and provided a significantly higher amount of criticism. For example, one nurse provided feedback at the end of each slide (before clicking the next button) commenting on either the content presented or the design of that particular slide. Participants were asked to ensure the module’s narration was complete before providing their thoughts on the module. Once the participant was notified that his or her comment was recorded, the participant continued onto the next slide of the module. Other nurses were less talkative and were more focused on understanding the content of the module rather than providing feedback. For the latter group of nurses, the study facilitator asked the participant to pause the ITT after each major section and reminded them to communicate their current thoughts.

Behind a one-way mirror, the test facilitator and another human factor analyst recorded any issues that were noticed or mentioned by the participant. Data was collected through direct observation and post-test review of audio and video recordings of each session. Observations included, but were not limited to, the time it took for the participant to complete each module, navigation difficulties, and ability to understand content. The overall time was recorded to gain a rough estimate of the module’s completion time. It is important to highlight that this time measurement has its limitations as it also included the time used for participants to verbalize their thoughts regarding the module. Comments regarding the overall design and usefulness of the content presented were also recorded in the data collection templates (Appendix D)
After the participant finished viewing the ITTs, an informal debrief session occurred where the test facilitator helped clarify any comments or address any concerns the participant had about the study. The participant was thanked and handed a cheque for $125 for his/her time and was reminded not to discuss the contents of the ITT with other colleagues until after it was ready for release so as to not bias other participants.

5.2 Results and Recommendations

5.2.1 Participant Demographics

Table 5: Participant demographics of the first cycle of usability testing

<table>
<thead>
<tr>
<th>Predominant Critical Care Unit</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CVICU</td>
<td>8</td>
</tr>
<tr>
<td>MSICU</td>
<td>2</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Sex</th>
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</tr>
</thead>
<tbody>
<tr>
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<td>0</td>
</tr>
<tr>
<td>Female</td>
<td>10</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Age Range</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>18-29</td>
<td>6</td>
</tr>
<tr>
<td>30-39</td>
<td>2</td>
</tr>
<tr>
<td>40-49</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Years of Experience in Nursing</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1</td>
<td>0</td>
</tr>
<tr>
<td>1-3</td>
<td>4</td>
</tr>
<tr>
<td>4-10</td>
<td>4</td>
</tr>
<tr>
<td>&gt; 10</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Years of Experience in Critical Care</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1</td>
<td>5</td>
</tr>
<tr>
<td>1-3</td>
<td>2</td>
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<tr>
<td>4-10</td>
<td>2</td>
</tr>
<tr>
<td>&gt; 10</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Average Number of Shifts Per Week</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3-4</td>
<td>9</td>
</tr>
<tr>
<td>&gt;4</td>
<td>1</td>
</tr>
</tbody>
</table>

During the first cycle of usability tests, 10 participants provided much positive feedback regarding its overall strong visuals and simple navigation layout. However, critical usability
issues were discovered regarding the content of modules in terms of presentation and difficulty. Descriptions of identified issues are provided below along with the accompanying design changes.

5.2.2 Reducing the amount of content

Based on the feedback given by the participants, observers identified that there was simply too much content presented in the ITTs about SIV for a user to appreciably absorb the information. Several participants either mentioned that the second module was too long or that it was too repetitive (5/10; 50%). The average time to complete the two shared infusion volume ITTs was 22 and 38 minutes, respectively, even though the expected time to finish each module was 20 minutes. It is important to acknowledge the fact that participants did spend time “thinking aloud”, which increased the overall completion time. However, the completion time for the second module, which took an average of 38 minutes, was still vastly different than the expected completion time, even when taking into consideration the time it took for participants to provide feedback.

To address the complexity of SIV management, our team decided to remove extraneous information from the module. For example, the majority of participants (6/10; 60%) had some difficulty understanding the explanations regarding the interactions of a two IV infusion system when making a change to the flow rate of a connected infusion. Due to the SIV, an increase (or decrease) of a flow rate is not instantaneously reflected at the patient’s bloodstream, as there is a time lag before the expected change occurs. Instead, other connected infusions will temporarily increase (or decrease) since the proportion of drugs in the SIV has not been adjusted yet. The ITT followed this lesson with an even more complex example of how 3 connected infusions would interact when making a change in flow rate. It was found that more time was required to focus on explaining the fundamental concept of changing connected infusions in a 2-infusion system rather than discussing a more complex case of a 3-infusion system. This issue is in accordance with heuristic #6 regarding the cognitive aspects of learning and the sixth issue in the heuristic evaluation regarding “mathematical explanations being rushed”.

Recommemndation: The observers recommended removing some content from the longer ITT to increase the amount of time available to explain the more fundamental concepts more explicitly.
In the example described above, three sets of rules were added to the ITT to simplify the take-away message from the lesson regarding making a flow rate change to a connected infusion. These rules were expected to synthesize the complex content into a toolset that nurses could apply in their own practice.

5.2.3 Connecting the audio narration with the text on the screen

While watching the ITT, some nurses (4/10; 40%) commented that the audio didn’t match the text on the screen causing confusion. During the final recommendations slide, one nurse stated, “There’s so much extra he’s saying, I’m not sure what I should be listening to ... I found the narration very confusing in this module”. This issue is in accordance with heuristic #1 (see Table 4) regarding the relevance of media and the third issue in the heuristic evaluation regarding “overloading of text”.

*Recommendation:* The observers recommended that the audio narration should be identical with the text on the screen for slides. Two small modifications were made to the ITT in terms of a) changing the script to be congruent with the visual bullet points on the information slides and b) adding a closed captioning function.

5.2.4 Modifications to navigation

Due to the heavy content in the interactive training tool, nurses wanted to review a particular slide more than once or re-answer an engagement question (8 occurrences). The training module, however, only included a previous and next button to navigate through the ITT. Participants would have to click the ‘previous’ button, which would take them to the previous screen, then click the ‘next’ button, to repeat the intended slide she wanted to replay (6/10; 60%). This usability issue is in accordance with the usability heuristic #2 regarding learner control and freedom and the second issue in the heuristic evaluation regarding “lack of interactivity”. Additionally, some nurses (4/10; 40%) were unclear as to when the next slide was ready to be viewed. For example, the animations in the ITT would continue to play even after the audio narration had stopped prior. Nurses would therefore sit patiently for more audio to sound resulting in awkward pauses.

*Recommendation:* The observers recommended that a simple navigation feature of adding a ‘replay’ button is necessary to enhance the usability of the ITT. Furthermore, the addition of a
blue flashing sign around the ‘next’ button was recommended to indicate when the next slide was ready for viewing.

5.2.5 Engagement questions reduce nurse confidence due to complexity

The ITT was designed to incorporate questions at the beginning of each shared infusion volume management topic to engage the user. The intent of adding engagement questions prior to teaching the material was that participants who were unfamiliar with the content would become more engaged with the ITT. This was received with mixed feedback as some nurses mentioned that they had a lack of confidence with learning the new material due to answering the engagement question incorrectly. Some nurses suggested that to move all questions to the end of the module as test questions, while others appreciated knowing at the beginning there was a piece of information missing from their own knowledge of intravenous infusions.

Recommendation: Based on the participants’ feedback, observers recommended to modify the engagement questions such that each question had a specific focus. For example, for one of the most difficult engagement questions, 7/10 nurses found it to be too confusing and only 1/10 participant answered it correctly in the module. The question involved understanding how to calculate the amount of SIV given a set of infusion equipment volumes. Due to the confusing and busy nature of the slide, participants had a difficult time identifying which volumes should be used to calculate the SIV. Therefore, observers recommended to simplify the diagram and reduce the amount of volume numbers on the question slide to help the user focus on the fundamental method of adding different volume sets that corresponded to the correct SIV.

5.2.6 Changing the term “dead volume”

One of the interesting findings from the usability testing was the reception from the nurses regarding the term “dead volume”. Originally coined by Lovich et al.\textsuperscript{34}, this term was used throughout the e-learning modules, but one of the participants found the term too similar to another medical term “dead space”, which refers to the volume of air that is inhaled into the lungs but does not participate in gas exchange. In addition, a survey was sent to various leaders in the infusion therapy industry (e.g. pharmacists, clinical educators, anesthesiologists), and it was found that majority of respondents (13/25; 52%) of respondents preferred the term “shared volume” as opposed to “dead volume” (7/25; 28%) or “common volume” (1/25; 4%).
**Recommendation:** After much internal discussion with the HumanEra team, observers recommended to change all subsequent references from “dead volume” to “shared infusion volume”. One of the primary reasons for this recommendation is that the term dead volume suggests that the volume is stagnant and not moving. Since fluids are moving through the infusion line, that particular space is certainly not “dead”, and our team believed “shared infusion volume” more accurately describes what is happening in the tubing. This volume is essentially a shared space for multiple medications. Furthermore, the term “dead volume” may be inappropriate for a clinical environment due to the negative connotation associated with the word “dead”.

### 5.2.7 Summary of Design Changes

Using the information gathered from the heuristic evaluation and the first round of usability testing, the ITT was updated accordingly by a member of the HumanEra team based on the discovered design and functionality improvements. The changes involved increasing the amount of cognitive aspects of learning through the implementation of relevant clinical scenarios and recommendation slides, increasing the level of learner control and freedom through the addition of a replay button, and reducing the amount of overall content of the modules such that the ITTs could focus on the more fundamental aspects of SIV (e.g. changing flow rates from multiple infusions, performing a proper line change). Other modifications as a result of the usability test included: changing the phrasing of narration and adding a visual cue for when the next screen was ready. A second usability test was conducted with a slightly modified methodology to test whether the changes made to the ITT were effective based on improvement of theoretical knowledge using a pre- and post-knowledge questionnaire. Additionally, the second usability test was also used to assess whether performance on the theoretical knowledge test was associated with practical performance (i.e. how well participants performed during applied high fidelity simulation).

### 5.3 Methodology for Usability Test (Second Iteration)

The methodology for the second cycle of usability testing was similar to the first cycle of usability testing, but with an added component of a pre and post knowledge questionnaire (Appendix E) and a post-intervention simulation phase (described in sections 5.3.1 and 5.3.4 respectively). In the post-intervention simulation phase, participants were instructed to perform certain intravenous infusion tasks related to SIV in a high-fidelity simulation at the Centre for
Global eHealth Innovation. This facility includes patient beds, typical hospital furniture, computerized physician order entry (CPOE) system, IV infusion equipment, and paperwork. Observational rooms with one-way glass were used to actively monitor the participant’s actions. There were video and audio systems in the room to monitor the simulations. The updated version of the SIV ITT in the modification phase was used for testing.

5.3.1 Pre- and Post-Knowledge Questionnaires

A pre-knowledge questionnaire was designed to measure the participant’s baseline knowledge of SIV management. Participants were given 15 minutes to complete the pre-knowledge questionnaire. Upon completion of the training condition, participants were given a post-training written knowledge test to evaluate the amount of knowledge they have gained through using the ITT. Participants were also given 15 minutes to complete the post-knowledge questionnaire. Both tests were designed to be equivalent in difficulty and content (e.g. use different case examples, but both requiring the same decision making elements). The tests were counterbalanced to minimize any order effect and to ensure no bias was introduced because of differences in the level of difficulty of the tests. That is, half the participants were given Test A to complete first and Test B after, while the remaining participants were given Test B to complete first and Test A after.

5.3.2 Overall Design

Participants were expected to complete the following:

1. Introduction: Review their role and complete a background demographic questionnaire and a consent form
2. Baseline Theoretical Knowledge: Complete a written knowledge test
3. Training phase: Train with the ITT to learn about SIV
4. Theoretical comprehension: Complete a written knowledge test
5. Post-Training Simulation: Perform a series of tasks simulating SIV management

The initial intent of this phase was to include both a pre-training simulation step and a post-training simulation step, but due to time restrictions we opted to remove the pre-simulation step and only included it in the subsequent validation phase.
5.3.3 Procedure

When the participant first arrived, s/he was greeted by the study facilitator and was introduced to the overall mission of the Centre for Global eHealth Innovation. The participant was introduced to his/her role in the study and asked to complete a demographics questionnaire (Appendix B) consisting of questions regarding specialization, age, sex, and level of experience. The consent form (Appendix C) was then reviewed with the participant. A pre-knowledge questionnaire (Appendix E) was then administered to measure the participant’s baseline knowledge of SIV management. To ensure the participant felt comfortable, the facilitator emphasized that the purpose of the study was not to evaluate their clinical performance but rather to understand the extent to which the training tool helped them in their clinical decision-making. It was also emphasized that the comments regarding the training intervention and the results from the knowledge questionnaires would have no effect on their employment. Participants were informed that they had 15 minutes to complete a pre-knowledge questionnaire. When 5 minutes were remaining, a verbal warning was given. If the participant finished prior to the 15 minutes, the facilitator continued to the next part of the study. At the end of the 15 minutes, participants were asked to stop working on the questionnaire.

Afterwards, participants were asked to use the ITT regarding shared infusion volume while verbalizing their thoughts and actions. The facilitator explained that by “thinking aloud”, the observers would be able to better understand possible usability issues and end-user experiences. For example, if a particular navigation sequence was confusing, we asked the participant to inform us and explain where exactly in the module the problem was arising. Similar to the first cycle of usability testing, some nurses were more talkative than others and provided a significantly higher amount of criticism while other nurses were less talkative and were more focused on understanding the content of the module. The talkative participants made sure that the module’s narration was complete before providing their thoughts on the module. Once the participant was notified that his or her comment was recorded, the participant continued onto the next slide of the module. For less talkative nurses, the study facilitator asked the participant to pause the ITT after each major section and reminded them to communicate their current thoughts.
Behind a one-way mirror, the test facilitator and another observer recorded any issues that were noticed or mentioned by the participant. Data was collected through direct observation and post-test review of audio and video recordings of each session. Observations included, but were not limited to, the time it took for the participant to complete each module, navigation difficulties, and ability to understand content. Additionally, comments regarding the overall design and usefulness of the content presented were also recorded in the data collection templates. After the participant finished viewing the ITTs, a post-knowledge questionnaire (Appendix E) was administered to test whether the training intervention had any effect on the participant’s understanding of SIV. The next phase involved a pilot simulation phase where participants were instructed to perform intravenous infusion tasks related to SIV management.

5.3.4 Simulation Phase
The simulated intensive critical care unit consisted of one mock patient played by a mannequin. End tables were located at the end of each bed and provided gloves, hand sanitizer, alcohol swabs, swab caps, a flush syringe, and a multi-connector. A laptop placed on a nearby desk was used to simulate a MOE/MAR that provided patient information and physician orders. Additionally, a binder was provided that included both hospital standard and restricted nursing IV drug list.

All props involved in the simulation were replicated from those used in an actual clinical environment, which included: medication IV bags, syringes, IV tubing sets, medication orders, labels, Graseby IV pumps, multi-connectors, and extension tubing. All medication protocols and intravenous infusion tasks used in the experiment were previously consulted with a hospital pharmacist and three ICU clinical nurse educators to ensure realism. Medications in the clinical setting were substituted with water.

Participants were exposed to the patient mannequin with prior knowledge regarding their medical history and physician orders for IV infusions. Participants were allowed to communicate with the confederate nurse (i.e. actor playing the role of a nurse) at any time if they required help. Physician orders, change in physiological status, and instructions from the confederate nurse helped guide the simulation phase. Their actions helped observers evaluate their level of knowledge in SIV management. Specifically, to test the participant’s knowledge during the
simulations, four scenarios involving the concept of SIV for IV infusions were designed as described below:

1. Delivering a rate-sensitive IV push medication
2. Doubling the concentration of a previously connected infusion
3. Performing a proper tubing change
4. Changing the rate of a connected infusion in a multiple intravenous infusion system

The scenarios for the experiment were divided into sub-tasks that were designated as a skill-, rule-, or knowledge-based task (see Table 5 below). For example, a task that required little to no attention and can be performed automatically when an intention is formed was considered a skill-based task. A task that involved performing a set of actions based on a set of rules was considered a rule-based task. A task that involved integration of multiple data sources and required heavier cognitive thinking was considered a knowledge-based task. The designation of task type was based on the facilitator’s understanding of the SRK framework. Participants were asked to conduct the tasks while verbalizing their actions and thought process (think-aloud protocol). Only the scenarios of the simulation portion of the usability test could be divided into skill, rule, or knowledge-based tasks (e.g. the delivery of an IV push would be consider a skill/rule task, while flushing the residual medication at the correct volume and rate would be a knowledge task) because the participant is observed performing these various sub-tasks.

Table 6: Example of skill/rule-based tasks versus knowledge-based tasks

<table>
<thead>
<tr>
<th>Skill- or Rule-based Tasks</th>
<th>Knowledge-based Tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Delivering an IV Push</td>
<td>• Flushing residual medication in the SIV at the correct volume and rate</td>
</tr>
<tr>
<td>• Using new IV tubing when doubling concentration of medication</td>
<td>• Understanding why a temporary change in blood pressure may occur</td>
</tr>
<tr>
<td>• Changing the flow rate of an infusion pump</td>
<td>• Considering the clinical implications of two or more infusions being delivered at different rates</td>
</tr>
<tr>
<td>• Removing unnecessary extension tubing to minimize SIV</td>
<td></td>
</tr>
</tbody>
</table>

Summaries of each scenario along with its objective are outlined in the next section while the full script and protocol is provided in Appendix F.
5.3.5 Scenario Descriptions

The participant was placed in a role as a resource nurse in a simulated intensive care unit. After being introduced to the confederate nurse, the participant was instructed to take care of a 64-year old female vascular patient who recently had an open abdominal aortic aneurism repair performed on her. The mock patient was hooked up to three medications with specified rates (i.e. norepinephrine, vasopressin, and a saline chaser). She was also connected to a central venous pressure monitoring line and had an extra medication line for any intermittent IV push orders. The multiple IV infusion system was connected through a bridge connector. The target mean arterial pressure (MAP) was 65 mmHg.

5.3.5.1 Delivering an IV push

The participant was informed that a physician wanted to reduce the amount of ankle swelling the patient was experiencing using an IV push of furosemide. A prepared furosemide syringe was handed to the participant and s/he was reminded that it needed to be pushed in longer than one minute as specified in the computerized physician order entry (CPOE).

Objective: The objective of this scenario was to evaluate whether or not the participant would administer the medication at the specified rate and follow the IV push with a saline flush. To deliver a proper saline flush, nurses needed to be cognizant of the amount of SIV in the infusion set-up and the correct rate of the subsequent flush.

5.3.5.2 Doubling the concentration of a previously connected infusion

The participant was informed that a physician wanted to double the strength of the norepinephrine by replacing the currently hung medication bag (8 mg in 250 mL) with a medication bag that had twice the concentration (16 mg in 250 mL) while maintaining the same dose rate. A previously spiked medication bag with the new concentration was given to the participant.

Objective: The objective of this scenario was to evaluate whether or not the participant was able to properly double the concentration of the medication while reducing the amount of SIV in the system. Participants were expected to lower the current flow rate on the infusion pump to half of the original rate such that the dose rate would remain constant with a doubly concentrated medication bag. However, participants were also expected to ask for new IV tubing to properly perform this scenario to avoid giving the patient the old concentration of medication at the slower rate for an extended period of time. This is because in the SIV the old concentration of
medication would still remain. To minimize the SIV, nurses needed to change the IV tubing and flush it with the new concentration of medication before attaching it to the infusion set-up. Once the system was reconnected and nurse pressed start on the infusion pump, the physiological monitor would alarm the nurse indicating a drop in blood pressure. Participants were expected to understand that this drop in blood pressure would only be temporary and was a result of the remaining SIV requiring time to be cleared of the old medication. Titration of medication was not necessary, as the blood pressure would return to normal after a few minutes once the SIV was cleared.

5.3.5.3 Performing a proper tubing change
The participant was informed that the patient was due for a tubing change. The confederate nurse told the participant that she had finished changing the tubing for 2 of the 3 ports connected to the patient. The last port that needed a tubing change was connected to a bridge connector supplying the three infusions of norepinephrine, vasopressin, and the saline chaser. The participant was provided with the 3 new infusion pumps with medication bags already spiked to complete the tubing change.

*Objective:* The objective of this scenario was to evaluate whether or not the participant would properly switch the three old infusions with the three new infusions. To perform a proper tubing change, nurses needed to program the new infusion pumps at the correct rate and gravity prime each medication. The infusion lines would then be connected to a new bridge connector. At this point, nurses needed to be cognizant of the amount of SIV in the bridge connector and ensure that it would be primed with the same proportions as the previous three infusions. Participants were expected to allow the drugs to mix over at least 15 minutes to ensure the slowest infusion had cleared the SIV. After this time period, the nurse would pause the old infusion pumps, detach the 3 original infusions, attach the 3 new infusions, and then press start on the 3 new infusion pumps.

5.3.5.4 Changing the rate of a connected infusion in a multiple IV infusion system
The participant was informed that a physician wanted to decrease the normal saline flow rate from 30 mL/h to 10 mL/h on an infusion pump to reduce the amount of fluid intake by the patient. The normal saline was acting as the chaser fluid in a multiple IV infusion set-up and was connected to two other infusions (norepinephrine and vasopressin) through a bridge connector.
Once the participant decreased the flow rate to the infusion pump delivering saline, the physiological monitor would alarm the nurse indicating a drop in blood pressure.

**Objective:** The objective of this scenario was to evaluate whether or not the participant was able to understand the relationship between why the blood pressure would suddenly drop after making a change to the infusion pump delivering saline. Participants were expected to understand that this drop in blood pressure would only be temporary and was a result of the infusion system requiring time to readjust the drug proportions in the SIV. For a temporary time period, the norepinephrine and vasopressin in the SIV would be delivered at a slower than expected dose rate to the patient due to the decreased total flow rate. This is because by decreasing the flow rate of one of the connected infusions, a change in the drug proportions in the SIV would be required. Therefore, a temporary delay in therapy would be expected, as the SIV would need time to reestablish itself to match the corresponding new ratio of flow rates. Titration of medication was not necessary, as the blood pressure would return to normal after a few minutes once the old drug proportions in the SIV was cleared and the SIV was filled with the new drug proportions.

### 5.3.6 Data Collection and Analysis

Evaluation behind a one-way glass door was conducted. The number of errors the nurse committed for each given task helped determine the level of success or failure for a certain task. A data collection template (Appendix D) was created to ensure that details (e.g. programmed flow rates) were collected for each participant. All comments made by the participant were recorded during the simulation phase. Additionally, any workflow deviations or other observations were noted. Ceiling mounted cameras were used to record the session and track the participant’s actions as they moved throughout the simulation. Discrete communication between the test facilitator and confederate nurse via wireless microphone and radio was allowed such that observers could verify any missed actions.

### 5.4 Results for Usability Testing (Second Iteration)

#### 5.4.1 Participant Demographics

<table>
<thead>
<tr>
<th>Predominant Critical Care Unit</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CVICU</td>
<td>2</td>
</tr>
<tr>
<td>MSICU</td>
<td>2</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
</tr>
<tr>
<td>-----------</td>
<td>-------</td>
</tr>
<tr>
<td>Male</td>
<td>0</td>
</tr>
<tr>
<td>Female</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age Range</th>
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</tr>
</thead>
<tbody>
<tr>
<td>18-29</td>
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</tr>
<tr>
<td>30-39</td>
<td>1</td>
</tr>
<tr>
<td>40-49</td>
<td>1</td>
</tr>
<tr>
<td>50-59</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Years of Experience in Nursing</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1</td>
<td>0</td>
</tr>
<tr>
<td>1-3</td>
<td>1</td>
</tr>
<tr>
<td>4-10</td>
<td>0</td>
</tr>
<tr>
<td>&gt; 10</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Years of Experience in Critical Care</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1</td>
<td>1</td>
</tr>
<tr>
<td>1-3</td>
<td>0</td>
</tr>
<tr>
<td>4-10</td>
<td>2</td>
</tr>
<tr>
<td>&gt; 10</td>
<td>1</td>
</tr>
</tbody>
</table>

A total of four participants participated in the second round of usability testing although 5 participants were wanted for recruitment. A 5th participant was not recruited as the observers felt there was enough information gained from the usability tests to reach saturation after the first 4 participants.

### 5.4.2 Pre and Post-knowledge Questionnaire

From these preliminary results, we were able to see that there was an increase from pre to post intervention condition for the majority of SIV management questions (with the exception of 3 questions, see Figure 10). Although we weren’t able to conduct any statistical analysis on the knowledge test scores (due to small sample size), these pilot results demonstrated a positive trend in increasing theoretical knowledge due to the ITT. All 4 participants did not answer the complex flow rate change question correctly either pre or post intervention and this may have been a reflection of improper question design as opposed to a lack of effectiveness in our ITT. The question was designed such that two individual flow rates were changed simultaneously, however, the challenge here is that the total flow rate remained constant. This meant that immediately after the change, the drugs being delivered to the patient would still correspond to
the previous drug dose rate. In the ITT, it was taught that a single flow rate change (increase/decrease) in a multiple IV infusion system would cause other connected infusions to temporarily exhibit that change (increase/decrease) due to the temporary delay in the changing proportions of drugs in the SIV. It is important to realize this concept (or rule) is only valid for a single flow rate change meaning the total flow rate must have changed as well. Therefore, the knowledge gained from the ITT was applied inappropriately when answering the multiple flow rate change question. It can be assumed that nurses were unable to extrapolate how to apply this concept when the total flow rate remained constant and unable to make the distinction between single flow rate changes and multiple flow rate changes.

Two of the questions (i.e. using proper connectors and adding flow rates) had no increase in score due to the ceiling effect, where participants could no longer obtain higher than a perfect score. Overall, there was an increase of overall average score for the knowledge test from 57% to 86%. Further modifications to our knowledge test questions were made for the subsequent simulation study to avoid potential ceiling effects and to improve clarity of questions.

![Knowledge Test Results](image)

**Figure 10:** Theoretical knowledge results post-intervention

### 5.4.3 Results from Simulation Phase

From the post-performance results (see Figure 11), the average performance score for skill-rule based tasks was 100%. All nurses had a very strong performance when conducting the more automatic tasks (e.g. using new IV tubing when doubling the concentration of a medication) after
viewing the intervention. However, there were mixed results for knowledge-based tasks (e.g. understanding why a temporary change in blood pressure may occur due to SIV) even after viewing the intervention with an average overall score of 62.5%. The ITT seems to have ensured strong performance on skill or rule based tasks, but it appears that the ITT may not have achieved maximum success on knowledge-based tasks. During the simulation phase, participants were not performing the knowledge-based tasks correctly, but observers were unable to identify “why” they were making errors despite the applicable content being explained from the intervention. For example, when delivering the tubing change (or line change), only half the nurses considered mixing the multiple medications in the SIV of the bridge connector post-simulation. The experiment design for this phase did not include any means of probing the nurse about their thought process regarding the reasoning of why they were using a bridge and the types of SIV issues that may have occurred. Essentially, we were unable to understand the cognitive processing that nurses were experiencing.

![Figure 11](image)

**Figure 11**: Post-performance results for skill-rule- and knowledge-based SIV management tasks

### 5.4.4 Recommendations

During the second round of usability testing, the 4 critical care nurses had fewer criticisms regarding the engagement questions in the ITT compared to the 10 participants in the first usability testing. Additionally, one major change we included in the ITT was the addition of three rules to explain how changing the flow rate to an IV infusion affects other connected infusions in a multiple IV system. These rules were intended to help synthesize the complex
information into a toolset that could be applied in the nurses’ practice. Specifically, participants (3/4; 75%) enjoyed this addition and one of them even noted that she would apply it in her workplace. Another important change that we included for the ITT was modifying the content and placement of the engagement questions such that there was always at least some fundamental background information. The feedback regarding these new questions was mixed. Some nurses (2/4; 50%) appreciated the “question-first” method as they felt it help set the tone of the module or that seeing their mistakes early on heightened their awareness levels and were enthusiastic to rectify them in future practice. All participants commented positively regarding both the audio and visual aspects of the ITT. One of the most interesting findings from the usability testing was that a lot of the information wasn’t necessarily entirely new, but all participants (4/4; 100%) noted that the information presented was only taught through transfer of knowledge directly from nurses. There currently exists no explicit training method that touches upon shared infusion volume and the potential effects it has when delivering multiple intravenous infusions.

While no major usability issues were identified with the ITT, nurses still had some criticism for the ITT. For example, the addition of the blue flashing light to signal the next slide of the module was not easily noticeable. The choice of colour was not distinct enough to signal availability of the next slide as it was camouflaged with the background theme color, which also was the same shade of blue. Therefore, when the next slide was ready for viewing, the signal was changed to a green flashing light.

5.4.5 Limitations
During the design process of the ITT, we were able to improve upon many of the functional aspects of what a successful e-learning module required. Our modifications from the first cycle of usability testing proved to be effective as all four nurses performed well on the theoretical questionnaire. The second round of usability testing also included a pilot simulation phase where participants were asked to perform SIV management tasks. Overall, nurses performed excellent on skill-/rule-based tasks.
However, despite these positive outcomes, nurses still seemed to have difficulty performing knowledge-based tasks correctly. We were unaware as to why nurses performed these tasks with actions that were misaligned with the information provided by the ITT. Essentially, the design process of the ITT was missing a critical component. We did not yet obtain any knowledge regarding the cognitive processes behind a critical care nurse’s thinking. By conducting a cognitive task analysis (Chapter 6), it may be possible to further improve upon the ITT to address the issue of nurses performing worse on knowledge-based tasks. Additionally, the cognitive task analysis can be conducted on SIV experts (e.g. anesthesiologists) who may possess a different mental model around multiple IV infusions that can be taught to critical care nurses through our ITT.

Secondly, tasks in this usability cycle were designed to have some element of Rasmussen’s skill-, rule-, knowledge (SRK) framework, but were rated only by a single human factor analyst. Thus, there was no inter-rater reliability when designating sub-tasks to be SRK-based. Future designation of SRK to SIV management tasks requires the input of multiple human factor experts.

Lastly, we were unable to evaluate the cognitive aspect of what nurses were thinking when performing tasks in a given scenario. Some comments were recorded during the simulation, but no explicit methodology was developed to understand their cognitive thinking. A cognitive walkthrough phase (explained in Chapter 7) was thus developed to understand this aspect.
6 Cognitive Task Analysis

6.1 Objective
A cognitive task analysis (CTA, see Section 2.4) was performed to help elicit knowledge from shared infusion volume (SIV) experts and front line nursing staff in the ICU. Specifically, the CTA was used to help reveal the underlying cognitive processes that clinicians use when performing intravenous infusion tasks related to SIV. To make rapid, accurate assessments when managing SIV, often under conditions of time pressure and high risk, requires expertise. Although essential, this expertise is difficult to characterize or to communicate to others. That is, experience-based knowledge that leads to “expertise” is usually difficult for the proficient operator to articulate because it involves skills that are so ingrained that the expert may not be consciously aware of them. Consequently, knowledge elicitation methods that attempt to make experienced-based knowledge explicit are needed to provide information on what leads to expertise. Past CTA studies cited from Klein and Militello have often tried to capture certain knowledge aspects of expertise including mental models, perceptual discriminations and skill aspects of expertise including the ability to spot anomalies, perform workarounds, and achieve rapid decision making. By understanding the cognition of subject matter experts (SMEs), it is possible to assist with enhancing patient safety through the application of the lessons learned from previous errors or accidents. The objective of performing a CTA for this research was to reveal how experienced clinicians deal with intravenous infusion scenarios with shared infusion volume (SIV) issues. Additionally, analysis of the CTA data uncovered key cognitive elements of SMEs in terms of the types of the mental models, perceptual skills (i.e. ability to notice subtle cues and patterns), and routines they use to solve critical situations related to SIV.

Medication administration errors represent a substantial proportion of hospital based adverse events. This is partially due to the increasing complexity of medical technology and abundance of procedures required to deliver first-rate healthcare to patients. These technologies place higher demands on cognitive skills such as decision making, planning and managing. Effective training methods are needed to ensure that clinicians are able to perform at a high level while avoiding preventable human related errors. Changes in our society have shifted the learner’s role from a traditional passive role to a preference towards participatory knowledge construction. Through the use of cognitive task analysis (CTA) methods, I hope to inform the design of training and
decision support systems for clinicians during the management of shared infusion volume.

6.2 Overview of Critical Decision Method
For the purposes of my research on SIV management, a CTA method known as the critical decision method (CDM) was used to discover the type of skills and knowledge aspects subject matter experts (SMEs) and front-line critical nurses use when performing intravenous infusion tasks. This method of “storytelling” is especially effective as the CTA researcher can discover different types of details, challenges, subtle cues, and strategies through the SME’s experiences. The unique aspect of CDM is the fact that it deliberately avoids generic questions such as, “Can you tell me everything you know about shared infusion volume?” Instead, important cognitive elements are revealed during moments that require a critical decision. This knowledge elicitation method is employed through the use of semi-structured interviews. Barriball describes semi-structured interviews as a method that is especially useful for exploring the perceptions and opinions of participants regarding complex cognitive processes and allows for better clarification of answers. 49

A standard set of questions is developed prior to the interviews, which helps form the framework of themes that is discussed. The format of the session allows for open-ended ideas to be shared with a framework of themes that may be discussed. CDM has been previously used in several high-risk settings to investigate the diagnosis of sepsis in a neonatal hospital department 50 or to study the tactical decision making of urban fire ground commanders 61. In the neonatal study, it was previously found that nurses had a difficult time describing aspects of their clinical judgment. However, the CDM helped elicit specific cues and assessment parameters from them due to its more structured outline. Of the 33 incident accounts, sepsis was found to be the most frequently discussed topic. Interestingly, nursing experts revealed many sepsis indicators that were absent in nursing literature. It was inferred that nurses were able to detect early onset indicators of sepsis that were not strictly defined as symptoms of advanced sepsis. The elicited knowledge helped the design of a sepsis guide, which could be used as a training method during orientation for novice nurses. For the purposes of this thesis, utilizing the CDM helped explore and understand the cognitive processes that SMEs and front-line critical care nurses use when managing SIV.
6.3 Methodology
This phase of CTA was performed after the first two iterations of usability testing to gain a better appreciation for clinicians’ current level of understanding of shared infusion volume to help supplement the ITT.

6.3.1 Recruitment of Participants
Semi-structured interviews with 5 intensive critical care unit nurses and 2 domain experts (i.e. anesthesiologists and/or shared infusion volume researchers). Nurses with at least 10 years of experience in a critical care setting were recruited using a sign-up sheet for interested individuals and announcements during morning nursing rounds in the cardiovascular intensive care unit (CVICU), coronary intensive care unit (CICU), and medical surgical intensive care unit (MSICU) at Toronto General Hospital. Research Ethics Board approval from the University Health Network (REB 14-8493-BE) was obtained prior to the study being undertaken. Interested individuals were subsequently contacted through e-mail or phone to confirm an appointment for the research study. Participants provided voluntary consent. Participants were notified of the implications of their involvement, their right to withdraw, and that their participation was entirely voluntary. Nurses participated in the study outside of their working hours, thus, there was no impact on patient care. Nurses were directly remunerated $50 for their time based on the following approximate calculation:

Hourly rate of senior nurse: $44.22/h (source: ONA Hospital Central Agreement, Exp Mar 31, 2016. Note: the rate for a senior nurse for April 1, 2014 was used as we do not want to discriminate against this group of nurses)

Premium pay: 150% (source: ONA Hospital Central Agreement, Exp Mar 31, 2016)

Study duration: 45 minutes

Compensation $44.22/h * 150% * 0.75 h = $49.75

Interviews were also conducted with published authors of SIV management research papers who were the domain experts. Two groups of clinicians were interviewed in order to gain different perspectives regarding SIV in a hospital setting. The sample size of 7 participants was used based on Klein et al’s overview of CDM\textsuperscript{63}. It reflects the fact that CDM is used to identify
marginal knowledge of experts and not to elicit an exhaustive catalog of an expert’s knowledge base. Front-line nurses may not have a definitive understanding of SIV in their mental model, but may rely on other cues or assessment parameters to solve a particular critical situation. Eliciting knowledge from SIV experts, however, may reveal certain techniques that have helped them diagnose intravenous infusion related issues and attribute them to a SIV problem.

6.3.2 Interview Logistics

Prior to the interview, participants were asked to complete a demographic questionnaire (Appendix G). After this, semi-structured interviews were conducted individually in a one-on-one setting and lasted roughly 45 minutes. Participants were encouraged to focus on specific incidents related to SIV in which they felt their presence made a difference to the patient’s outcome. Note that all interviews were audio-recorded while handwritten notes by the interviewer were taken. These recordings were divided amongst a team of three human factor analysts, who independently transcribed them word for word immediately following the sessions. The transcriptions were used to more easily compare information amongst this team to elicit knowledge regarding the cognitive elements involved in the participants’ incident recalls. Participants were asked to refrain from revealing any personal information that may identify themselves (e.g. name of patient, care team members). In the event that personal information was accidentally released, it was removed from the study data (i.e., we would not transcribe personal information). Surveys, recordings, and transcripts were stored and protected on UHN servers with adequate security measures (i.e. password protected). Each participant was given a unique identifier to help maintain his or her anonymity. During the reporting of findings, participants were only referred to by their position (i.e. nurse, anesthesiologist, SIV researcher). A slightly modified procedure was used with the anesthesiologists versus the critical care nurses.

6.3.3 Materials

Participants were asked to complete a skill-, rule-, and knowledge (SRK) worksheet with an interviewer. In each worksheet, four different scenarios were described and each participant was asked to describe how she would complete the scenario in order to minimize shared infusion volume errors. Below is an example of one of the scenarios the participant had to complete.
Figure 12: A page taken from the SRK worksheet about administering a manual IV push of furosemide

The purpose of the handout was to learn about the typical tasks the nurse would perform when administering IV medications at the bedside in a critical care unit. They were asked to categorize tasks based on four scenarios according to Rasmussen’s definition of skills-, rules- and knowledge-based behaviour explained in the following table below.
**Table 8:** Categories of skill-, rule-, and knowledge-based tasks

<table>
<thead>
<tr>
<th>Task Type</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skill-based</td>
<td>Skill-based tasks require little to no attention when performed. Performance should come automatically when an intention is formed.</td>
<td><em>Checking your blind spot before making a turn when driving a car</em></td>
</tr>
<tr>
<td>Rule-based</td>
<td>Rule-based tasks involve performing a set of actions based on a given set of rules (if-then scenarios). The rules can be developed through experience or given by an instructor.</td>
<td><em>If all traffic lights are malfunctioning at an intersection, then treat oncoming traffic as a four-way stop.</em></td>
</tr>
<tr>
<td>Knowledge-based</td>
<td>Knowledge-based tasks involve integration of multiple data sources that one must perform given a complex situation. These types of tasks require heavier cognitive thinking and a more advanced level of reasoning to make an informed decision.</td>
<td><em>Planning an alternate route when there is traffic accident on your way to work.</em></td>
</tr>
</tbody>
</table>

### 6.3.4 Procedure with Critical Care Nurses

A 45-minute interview was conducted with critical care nurses at the Centre for Global eHealth Innovation.

#### 6.3.4.1 SRK Worksheet Procedure

During the first half of the interview, nurses were asked to complete the SRK worksheet by describing the tasks they would carry out to accomplish the required goal in a given scenario. When describing a task, nurses were explicitly told to keep in mind that each scenario involved some aspect of SIV management. Additionally, they were asked to identify the reasoning behind the task and which task type (skill, rule, or knowledge) they would associate it with. For example, one of the scenarios involved describing the steps to deliver an IV push. One of the nurses described the first task as “to check the control line port which is not being used,” which meant she wanted to find an available IV infusion line. Specifically, she wanted to find a dedicated medication line, such that the IV push would not interfere with potentially other medications that were already being delivered continuously. She then identified that this task would be a rule-based task that she was explicitly taught in training.
Table 9: Example of filling out the first row of an SRK worksheet.

<table>
<thead>
<tr>
<th>#</th>
<th>Task Description</th>
<th>Why?</th>
<th>S</th>
<th>R</th>
<th>K</th>
</tr>
</thead>
</table>
| 1  | Check control line port which is not being used | Because med line is the preferred line  
Don’t interfere with other lines (different medications) |   |   | X |

6.3.4.2 Procedure of Critical Decision Method Interview with Critical Care Nurses

During the second half of the interview, participants were encouraged to focus on specific incidents on SIV they could vividly recall in their career. The table below describes the data gathering process for the critical decision method (CDM):

Table 10: Summary of the phases of the critical decision method\textsuperscript{50,52}

<table>
<thead>
<tr>
<th>Phase</th>
<th>Description</th>
</tr>
</thead>
</table>
| Instruction                          | Rationale of study is explained and participants are probed as to their knowledge regarding SIV  
Participants are also given a general introduction around the ideas of the critical decision method |
| Incident identification/selection    | Participants are asked to identify any IV infusion incidents they were involved in  
Specific attention to detail will be used where SIV was a significant issue |
| 1\textsuperscript{st} event recall   | Participants are asked to describe a selected SIV incident in detail and the interviewer records in detail critical events, decisions, and actions when such challenge was encountered |
| Timeline verification                 | Notes taken by the interviewer are verified with the participant  
Any outstanding information missing from the timeline/decision-making events will be appended |
| 2\textsuperscript{nd} Event recall   | For each event, the interviewer asks in detail what was happening in the participant’s mind to extract information about the cognitive process  
A set of questions is used to help probe for additional information regarding the cues, judgments, decisions, and actions contained in the nurse’s and/or experts description that may have not been identified in the initial event recall |
A list of prepared questions was used to help guide the second half of the interview.

Table 11: Questions used to guide the critical decision method

<table>
<thead>
<tr>
<th>Available and alternative options</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. How did you come up with this option? Were you conscious of making this particular decision? Was there any specific rule you were following?</td>
</tr>
<tr>
<td>a. How much time pressure was involved in making this decision? How long did it take you to come up with this decision?</td>
</tr>
<tr>
<td>2. What other options do you think were available or would have considered in hindsight?</td>
</tr>
<tr>
<td>a. If the decision was not optimal, what knowledge available do you think might have helped?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. What were your specific goals at this point? What was the primary objective you were trying to achieve at this decision point?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Situational Awareness</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. If you had to describe the situation to someone taking over on the next shift how would you summarize it?</td>
</tr>
<tr>
<td>5. How might a novice have behaved differently?</td>
</tr>
<tr>
<td>6. What mistakes do you think would have likely occurred for a less experienced nurse?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Information Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. What training or experience was necessary or helpful in coming to this decision? Where did you derive the information used to make this decision?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>8. How confident were you in this information?</td>
</tr>
<tr>
<td>9. Is this case a typical scenario? Is it the sort of scenario you are trained to deal with?</td>
</tr>
<tr>
<td>10. How many incidents per month or year like this have you been involved with?</td>
</tr>
<tr>
<td>11. What type of learning method do you use to expand your existing nursing or medical knowledge?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>General Probing Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Can you elaborate on that idea?</td>
</tr>
<tr>
<td>2. Would you explain that further?</td>
</tr>
<tr>
<td>3. I’m not sure I understand what you’re saying.</td>
</tr>
<tr>
<td>4. Is there anything else you would like to add?</td>
</tr>
<tr>
<td>5. What were you seeing or hearing?</td>
</tr>
<tr>
<td>6. Were you reminded of previous similar experiences?</td>
</tr>
</tbody>
</table>
After the interview, participants were thanked and handed a cheque of $50 for their time.

6.3.5 Procedure of Critical Decision Method Interview with Anesthesiologists

45-minute interviews with the anesthesiologists were conducted over the telephone. The primary difference regarding the interview procedure with critical care nurses and the anesthesiologists was that an SRK worksheet was not filled out with the anesthesiologist. Only the CDM procedure was conducted over the entire session. There were several reasons for this difference in procedure. Firstly, it would not be feasible to complete a worksheet over the telephone. Secondly, the SRK worksheet was specifically developed based on scenarios that critical care nurses would be more familiar with. Lastly, and most importantly, the level of expertise regarding SIV was much greater for the anesthesiologists due to their extensive research in this domain, and thus more revealing incidents were discussed using the CDM.

6.3.6 Data Analysis

6.3.6.1 Analyzing the SRK Worksheets

The SRK worksheets were used as a method to get participants comfortable with the topic of SIV. Each scenario discussed revealed the set of steps nurses are currently trained to perform when delivering an intravenous infusion. The three scenarios in the SRK worksheets that were explored included:

1. Delivering a rate-sensitive IV push medication
2. Performing a proper tubing change
3. Changing the rate of a connected infusion in a multiple intravenous infusion system

6.3.6.2 Analyzing the CDM Interviews

There are several different methods to analyze CTA data including: cue inventories, narrative formats, decision requirement tables, chronologies, situation assessment records, and process maps. These qualitative methods of analysis provide CTA practitioners the ability to discover new insights and relationships using a more flexible approach. This type of analysis is especially useful in behavioral or cognitive research where data is difficult to be reduced to simply...
numbers. Essentially, the information collected can be processed such that trends can be revealed without the requirement of finding a p-value.

Not all of these methods were used to represent the findings, but only those that suited the data captured. The methods used to analyze the CDM interviews included the development of a critical care inventory to discover the types of cues that trigger a critical care nurse’s cognition, an affinity diagramming technique to organize these cues and discover general themes, and the use of a situation assessment record to discover the decision points during a critical incident experienced by an SME. In any CTA, analysis involves the following four phases: a) preparation, b) data structuring, c) discovering meaning, and d) communicating results.

a) Preparation: To prepare the data from the CDA interviews, a team of 3 human factors researchers transcribed the semi-structured interviews into a consistent format. The team divided the task of transcribing 7 interviews as evenly as possible (2-3 interviews per member). Each interview was listed with complete identifying information including participant ID, date of data collection, and relevant time stamps. By transcribing the interviews, the analysis team was able to more easily review the data in a text format and make notes in the transcriptions if any particular incident was of interest. Afterwards, the study facilitator reviewed the transcripts for accuracy, as team members may have had difficulty with medical acronyms or vernacular.

b) Data Structuring: Structuring the data involved pulling the data apart and decomposing it for better organization of ideas. The team divided the task of coding the 7 interviews as evenly as possible (2-3 interviews per member). The transcriptions were coded into 10 different cognitive elements based on previous research:

- Action (ACT)
- Action-Deliberation (ACT-DEL)
- Anticipation (ANT)
- Appraisal (APP)
- Contingency (CON)
- Cue (CUE)
- Cue-Deliberation (CUE-DEL)
- Goal (GOA)
- Knowledge (KNO)
- Metacognition (META)

These categories were used to understand the different types of cognition used during a critical care multiple IV infusion incident involving SIV. The definitions of each cognitive element (Appendix H) were discussed prior to the coding step to ensure that each member had a clear
understanding of how a particular statement in the interview would be coded. To ensure inter-rater reliability, each member reviewed another person’s coding, independently. After each interview was reviewed twice, the team analyzed the coding together and any discrepancies amongst the identification of cognitive elements were discussed until a common decision was reached.

Below is an example of how a typical transcript was coded into different cognitive elements:

**[Transcribed data before coding]** “We have a drug called “levophed” which is norepinephrine and we have a drug called “fentanyl” which is a pain killer. Each of these drugs are covered with a brown bag to protect from the light. And I was in a situation, where I was helping someone and the patient was on each of those drugs, which is fairly common. But the patient’s blood pressure was falling and she was going up and up and up [on the pump] with what she thought was levophed and it was in fact the fentanyl. Laughs. So she was going up on a painkiller and the patients blood pressure kept continuing off and she was going up. And I noticed that it was actually the fentanyl she was putting up rather then the levophed. And I think part of the problem was they both had a brown bag to cover them from light. So if you are on a situation that is happening very quickly and people start to panic a little bit. You just kind of go to the one that has the brown bag on it.”

**[Organized data after coding]**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>P3-15</td>
<td>KNO</td>
<td>We have a drug called “levophed” which is norepinephrine and we have a drug called “fentanyl” which is a painkiller.</td>
</tr>
<tr>
<td>P3-16</td>
<td>KNO</td>
<td>Each of those drugs is covered with a brown bag to protect from the light.</td>
</tr>
<tr>
<td>P3-17</td>
<td>ACT</td>
<td>And I was in a situation, where I was helping someone</td>
</tr>
<tr>
<td>P3-18</td>
<td>KNO</td>
<td>And the patient was on each of those drugs, which is fairly common.</td>
</tr>
<tr>
<td>P3-19</td>
<td>CUE</td>
<td>But the patients blood pressure was falling</td>
</tr>
<tr>
<td>P3-20</td>
<td>ACT</td>
<td>She was going up and up and up [on the pump] with what she thought was the levophed</td>
</tr>
</tbody>
</table>
It was in fact the fentanyl.

She was going up on a pain killer and the patient’s blood pressure kept continuing off.

And she was going up I noticed that it was actual the fentanyl she was putting up rather then the levophed.

I think part of the problem was they both had a brown bag to cover them from light.

So if you are on a situation that is happening very quickly and people start to panic a little bit.

You just kind of go to the one that has the brown bag on it.

c) Discovering Meaning: The 3 human factors researchers identified central questions, issues, and emergent themes by integrating data together and describing regularities between individual interviews that were consistently present. From the critical care nurse interviews, a total set of 138 cues were organized into groups based on their similarities and differences using a method known as affinity diagramming\(^6^4\). Affinity diagramming is a technique that helps organize a large number of ideas (e.g. cues) into more coherent themes. This method is extremely useful when you are confronted with many facts or ideas in apparent chaos, when issues seem too large and complex to grasp, and when group consensus is necessary. For verbal data, such as those collected in a cognitive task analysis, this was an appropriate method to use to discover meaning.

**Cue statements** were laid out on a table and 3 human factor researchers pinned the cues on a wall based on similarity. A cue was defined as any statement that triggered a cognitive element (e.g. “the patient’s blood pressure kept continuing off”). Once all the cues were pinned on the wall, discussion took place regarding the placement of the cues and any surprising patterns. Any cue statements that seemed to be closely related in some fashion were grouped together side by side and were labeled with a particular **heading**. For example, in the interviews, many of the nurses identified that a sudden drop in blood pressure signaled them that the patient was in distress. These types of cues were subsequently grouped under a heading called “blood pressure falling may change my patient’s status”. This heading acted as the representative cue for all cues related to blood pressure dips and helped build a cue inventory. Using this inventory, **central cue**
Statements were formed to further categorize these headings. For example, the central cue statement “changes in blood pressure affect my decision making and thinking process” was used to represent the following three headings:

a) “Blood pressure falling may change my patient’s status”
b) “Blood pressure rising may change my patient’s status”, and
c) “Blood pressure values outside my target change are critical”

Lastly, the central cue statements were used to discover overarching themes related to intravenous infusion delivery. For example, the overarching theme related to “patient-related cues” was used to represent the following central cue statements:

a) “Changes in blood pressure affect my decision making and thinking process”
b) “I notice abnormal features in my patient’s condition”
c) “If a patient is on several medications, you have to be aware of concentration and compatibility issues”

Figure 13: Diagram describing the analysis of affinity diagramming

The two anesthesiologists interviewed had much more precise incident recalls related to SIV. This can be attributed to the fact that both participants have extensive knowledge regarding not only multiple intravenous infusions, but also the concept of SIV. Therefore, due to their detailed recollections, a situation assessment record (SAR) could be created (originally developed by Klein et al.). An SAR helps define the types of cues, knowledge, expectations, appraisals, and
goals necessary for an expert to reach a particular decision point. For each decision point, particular cues and goals must have been established prior. As new information becomes available in an incident, the situation assessment will change along with types of goals and expectations necessary to resolve the incident. An SAR allows human factors researcher to better understand the different cognitive elements required to make a decision. Therefore, further insight can be gained regarding the mental models clinicians use when managing SIV problems.

6.4 Results and Discussion

6.4.1 Participant Demographics

All 5 critical care nurses recruited for the CTA were staff nurses and reported to work on average 3-5 times a week (5/5; 100%). All participants were female (5/5; 100%) with the majority of them falling under the age range of 45-54 years (4/5; 80%) with the remainder in the 25-34 year range (1/5; 20%). All participants reported they worked as a as a critical care nurse with the following distribution of years of experience: 11-15 years (1/5; 20%), 16-20 years (2/5; 40%), and >21 years (2/5; 40%).

6.4.2 SRK Worksheets

Each nurse participant had similar responses for each given scenario regarding the type and order of tasks they would perform. The standard procedures at UHN described by the nurses were consistent throughout all 5 participants, although there were slight differences in their approach. For example, for the first scenario of delivering a rate-sensitive medication, all nurses described the first task as checking for a dedicated line used for push medications in order not to push the continuous medications into the patient at an increased rate. The other medications in the given scenario were inotropes and the nurses were very cognizant of its potential effects if bolused to a patient. The next step would be to push the medication in the dedicated line over the specified time due to the rate-sensitive nature of the specified drug (i.e. furosemide). 3 of the 5 nurses specifically discussed the clinical side-effect of pushing furosemide too quickly, which could cause temporary deafness. Finally, the last major step that was described by all participants was to deliver a saline flush in order to get the medication into the patient’s bloodstream. All nurses mentioned that a flush was necessary to prevent the medication from lingering in the tubing. One nurse even used the term shared infusion volume to describe the volume in which residual
medication could be left behind. Interestingly, in a previous related study by Pinkney et al, 40 nurse participants were also asked to perform a manual IV push in a simulated environment. However, 13 of the 40 (32.5%) participants did not use a flush syringe after delivering the medication. The reason for this could be due to the difference in critical care nursing experience. The primary difference in the SRK worksheets between nurses for this scenario occurred during the description of this final step. Nurses were asked whether or not there was a particular rate she would deliver the flush syringe. Three of the 5 nurses indicated that the flush syringe would have to be delivered at the same rate as the original IV push while the other 2 nurses did not indicate that the flush syringe needed to be pushed at the same rate. This discrepancy in knowledge is one of the issues that the ITT would like to address. Despite having over 10 years of experience in critical care, there remained a gap in knowledge for 2 of the 5 nurses regarding how to deliver a proper IV push medication taking into consideration the SIV.

The next scenario involved a doctor ordering the flow rate of a patient’s saline line to be dropped from 30mL/h to 10mL/h. This infusion was connected to another infusion of norepinephrine (used to increase a patient’s blood pressure). The result of decreasing the flow rate of saline would have caused the delivery of norepinephrine to also decrease. This is because the proportion of norepinephrine in the SIV would not have adjusted yet, and the lower carrier flow rate would cause the patient to temporarily have a decreased amount of norepinephrine. The resulting response in the scenario caused the patient to have a sudden drop in blood pressure. Nurses were asked to describe and resolve the situation. 2 of the 5 nurses indicated that they would never drop the patient’s saline line immediately from 30mL/h to 10mL/h and would instead use a step-wise method to slowly wean the patient off of the 30mL/h saline line by decreasing it incrementally by 5mL/h. The reasoning behind this was because both nurses thought that changing the rate of the saline would also affect the rate of the norepinephrine. However, they were unable to provide a strong description as to the exact interaction between the two infusion lines. This gap in knowledge regarding SIV was addressed in the ITT in terms of “how” multiple drugs are given proportionally through a shared infusion line. Furthermore, 4 of the 5 nurses indicated that to rectify the situation, they would adjust the vasopressors being delivered to the patient within a target range to bring the blood pressure back to the desired level. Constant titration of drugs to maintain a particular blood pressure seems to be a common practice amongst critical care nurses. Only one of the critical care nurses indicated that the drop in blood
pressure might in fact be a temporary issue due to the readjustment of drug proportions in the SIV. The time lag involved in clearing the SIV of the old proportion of drugs must be accounted for and any further change in medication may be harmful to the patient.

The last scenario discussed involved delivering a proper tubing change for a three-infusion line system. Performing a tubing change is a common practice amongst critical care nurses and is a mandated policy to decrease the risk of infections. Similar to previous scenarios, all nurses had a consistent method of performing a tubing change. The first common step in performing a tubing change indicated by the nurses was to grab new tubing and prime them with the new bags of medications. Using the primed lines, 4 of the 5 nurses indicated they would connect them together using a bridge connector as the use of a bridge connector helps minimize the SIV compared to chaining the three infusions through their y-connectors. Three of these 4 nurses then said they would run the drugs between half an hour to an hour into a sterile plastic bag because they wanted the bridge connector to be the same concentration of drugs as previously. Finally, the infusions connected through the bridge would then be attached to the patient. Based on the nurses responses, 3 of the 5 nurses were cognizant of the fact that it takes time for the medications in the SIV of the bridge to be at the right proportions.

When nurses were asked to classify the task types, there was a lot of inconsistency between participants. For example, when delivering an IV push, all nurses indicated that a flush was needed to clear the SIV. However, when asked to classify the task type (skill, rule, or knowledge), some nurses indicated that it was a skill-based task as they believed it was a very automatic procedure they would perform while other nurses indicated that it was a knowledge-based task since one would have to figure out the proper rate and size of SIV. Overall, nurses were inconsistent regarding the classification of tasks. Due to the wide variety of responses, these same scenarios were given to three human factors researchers to analyze. Each member of the team independently classified the task types based on their deeper understanding of the SRK framework. Afterwards, any discrepancies between classifications were resolved amongst the team and a final consensus regarding the task type within each SIV related scenario was resolved (see Section 7.1.6).
6.4.2 Cognitive Cues and Themes Revealed from Critical Care Nurses

The cue inventory below describes the types of cues nurses use to identify and solve a critical situation in their line of work.

Table 12: Cue inventory while delivering multiple intravenous infusions

<table>
<thead>
<tr>
<th>Central Cue</th>
<th>Descriptors (Headings)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abnormal physical features</td>
<td>Patient is experiencing pain</td>
</tr>
<tr>
<td></td>
<td>Patient’s physical condition is deteriorating</td>
</tr>
<tr>
<td>Blood pressure changes</td>
<td>Blood pressure needs to be maintained within a target range</td>
</tr>
<tr>
<td></td>
<td>Blood pressure rising may change my patient’s status</td>
</tr>
<tr>
<td></td>
<td>Blood pressure falling may change my patient’s status</td>
</tr>
<tr>
<td>Multiple medications</td>
<td>Delivering multiple drugs raises awareness levels regarding particular side effects and/or compatibility issues</td>
</tr>
<tr>
<td></td>
<td>Mixing-up medication bags happens occasionally</td>
</tr>
<tr>
<td>Complex IV Infusion Sets</td>
<td>Using lines that have already been previously used can result in incompatibility</td>
</tr>
<tr>
<td></td>
<td>Multiple pumps running simultaneously can be difficult to handle</td>
</tr>
<tr>
<td></td>
<td>Frequent concentration changes for medications cause confusion</td>
</tr>
<tr>
<td>Checking device parameters</td>
<td>Noticing different concentration listed on the medication bag versus the corresponding concentration programmed in the pump</td>
</tr>
<tr>
<td></td>
<td>Programmed pump is incorrect in terms of dosage and/or rate</td>
</tr>
<tr>
<td></td>
<td>Accuracy of monitoring data</td>
</tr>
<tr>
<td>Information exchange between clinicians</td>
<td>Special attention for patient’s status when transferred from a different department (e.g. operating room)</td>
</tr>
<tr>
<td></td>
<td>Unfamiliar patients at the beginning of a shift require a new assessment of condition</td>
</tr>
<tr>
<td></td>
<td>Care instructions from physicians can heighten awareness levels</td>
</tr>
<tr>
<td>Deviations from normal work environment</td>
<td>Handling patients outside of the intensive care unit (e.g. inside an elevator during transfers)</td>
</tr>
<tr>
<td></td>
<td>Time pressure situations affect my ability to concentrate (positively or negatively)</td>
</tr>
</tbody>
</table>

The 5 CDM interviews yielded a total of 8 incidents. The incidents described did not result in any immediate, life-threatening crisis, but instead involved near-miss type of events. The accounts consisted of the following clinical events: medication concentration mismatch (4), compatibility issues (2), bolusing drugs to adjust BP (1), and hanging incorrect medication bag.
When nurses were asked to reveal a critical incident they were involved in or witnessed, 4 of the 5 nurses chose an incident in which they discovered that the programmed concentration of a pump was different from the listed concentration on the medication bag. For example, in one of these 4 incidents, a patient was transferred from the operating room (OR) where they were running a high concentration of milrinone (an inotrope that helps the right ventricle function). Usually in the ICU, nurses mix 20mg in a 100cc bag, however, the OR prepares the same medication with 40mg in 100cc. During the hand off of patients, there was a miscommunication between the receiving nurse and the physician as the concentration information was missing. It was only two days later when the nurse was ordered to lower the dose rate did she notice that the patient’s pump was programmed with a 40mg per 100cc setting despite the fact that the medication bag being delivered was 20mg per 100cc. Essentially, the patient had been receiving half the ordered dose rate over the past 2 days. The physician told the nurse that since the patient was tolerating the lower dose rate for the previous 2 days to simply keep the patient at the same dose rate instead.

Events related to the difference in medication concentration for a particular IV bag between the critical care unit and a different department (e.g. OR or emergency) were prevalent in 4 of the 5 participant’s incident recalls. Incidents related to the proper dose rate occurred due to subsequent miscommunication. Although none of the incidents related to this phenomenon resulted in any immediate critical consequence to a patient, the events did result in an undesirable adverse drug event and a delay in the expected treatment. In these incidents, participants mentioned that whenever they are handed a new bag of medication, that it is imperative to not only change the IV bag, but also the tubing and pump. Changing the concentration of a medication is a common event for nurses and it is a type of cue that triggers them to be aware that a tubing change is required due to the old drug concentration remaining in the SIV.

In 2 of the incident recalls, nurses mentioned that the situation was related to medication incompatibilities. For example, one nurse described an incident where she was ordered to deliver an antibiotic medication by replacing a previously hung empty secondary bag. Once the antibiotic reached the main existing infusion line, the tubing started to become cloudy. Her immediate action was to stop the infusion and diagnose the cause of the precipitate. It turned out that the previous secondary bag was filled with Dilantin, a drug known for its high level of
incompatibility. From this point forward, the nurse recognized that every time this particular drug was being administered, to always ensure a 50mL saline flush was delivered in order to prevent any chance of incompatibility in the SIV.

However, when it comes to events related to a change in blood pressure, in a multiple IV infusion system, results of the cognitive task analysis reveals that nurses do not actively think about SIV and may rely too heavily on adjusting drug dosages to stabilize a patient’s status. Nurse participants often cited a blood pressure change as the most frequent cue that affected their decision-making. Critical care nurses seem to be trained extensively on ensuring that a patient’s blood pressure is maintained within a target range. The immediate action that followed this cue would often be accompanied with a titration of medication. One nurse mentioned that titration of medication to reach a particular blood pressure is almost an art form. However, it was rare for nurses to consider whether or not the change in blood pressure may have been caused due to a SIV related issue.

While assessing a critical situation in the ICU, the nurses’ cognition is often oriented towards dealing with medication related issues as opposed to an issue with the intravenous infusion system (e.g. SIV). Nurses did recognize that having multiple pumps and lines in their work environment can lead to confusion, but referred to the problem simply as a memory issue. Preventative measures, such as being cognizant of the SIV, were not always mentioned throughout the interviews. Essentially, the critical care nurses only thought of the multiple pumps as a means to deliver multiple medications to the patient. Their mental model was heavily focused on potential medication incompatibilities and did not include any reference to how the different flow rates could interact with each other due to the SIV.

Overall, three overarching themes were discovered: a) patient-related, b) equipment-related, and c) workflow-related. Table 13 (below) shows a summary of all the cue statements in the form of central cue statements and overarching themes.

Table 13: Summary of cues from semi-structured interviews into three overarching themes

<table>
<thead>
<tr>
<th>Overarching Themes</th>
<th>Central Cue Statements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient-related Cues</td>
<td>I notice abnormal features in my patient’s condition</td>
</tr>
<tr>
<td></td>
<td>Changes in blood pressure affect my decision making and</td>
</tr>
<tr>
<td></td>
<td>thinking process</td>
</tr>
</tbody>
</table>
If a patient is on several medications, you have to be aware of concentration and compatibility issues.

The handling of complex IV infusion sets requires a significant level of attention. Checking and double checking devices are crucial for a safe work environment.

Information exchange between me and another clinician affect my awareness levels. I often experience deviation from my normal work environment.

6.4.3 Situation assessment record revealed from anesthesiologists

2 anesthesiologist participants (Expert A and Expert B) were individually interviewed using the critical decision method (CDM) to share their experience regarding SIV incidents. The perspectives gained from the two participants reflect the importance of managing SIV in an operating room as opposed to a critical care unit.

Expert A mentioned that SIV related incidents probably occur a few times a week in the operating room. One major theme that was discussed in his incident recalls was the idea of delivering vasoconstricting and vasodilating drugs to the same line. By not keeping track of the SIV in these types of situations, it is very common for clinicians to accidentally bolus a drug with an opposite effect. Swings in blood pressure or heart rate are not often (10% of the time) due to a sudden change in a patient’s vascular tone or contractility, but rather a simple mismanagement of the SIV by the anesthesia team. In addition, expert A commented that he has often heard an ICU nurse telling a surgeon that fluctuations in a patient’s vital was simply due to the patient being very labile. Expert A immediately quickly dismissed the validity of the nurse’s statement pointing out that a patient’s instability is often due to a misunderstanding of the SIV and the types of medications that are being delivered to the patient. Unfortunately, expert A was not able to share specific incidents in which a SIV related issue was the cause of a detrimental outcome as he repeatedly stated that due to the high frequency of SIV related cases, all the incidents start to “mix up” in his mind after a while.
Expert B also suggested that SIV related issues happen once a day in a large operating room with multiple cases occurring. However, he was able to provide a few different memorable scenarios in which he had witnessed or been apart of in which a patient was negatively affected due to mismanagement of SIV. Each scenario he described can be broken down into a situation assessment record (SAR) in terms of how certain cues and goals trigger a particular decision point.

**Table 14: SAR-1 for SIV-related critical incident reported by expert B**

| SA-1 | Patient brought from neurosurgical ICU with ruptured cerebral aneurysm  
Carrier for the infusion was gravity driven |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Expectations</strong></td>
<td>Blood pressure (BP) should continue to be stable</td>
</tr>
<tr>
<td><strong>Goals</strong></td>
<td>Control her BP with nitroglycerin (NG)</td>
</tr>
<tr>
<td><strong>DP-1</strong></td>
<td>Begin administering new bag of IV fluid as a new carrier</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SA-2</th>
<th>Patient’s BP immediately dropped to an extremely dangerous level</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Expectations</strong></td>
<td>If BP does not rise back up soon, the patient would die</td>
</tr>
<tr>
<td><strong>Goals</strong></td>
<td>Raise BP back up to an appropriate level</td>
</tr>
</tbody>
</table>
| **DP-2** | Stop administration of nitroglycerin and start patient on vasopressors  
Patient’s BP continues to drop drastically. |

**Table 15: SAR-2 for SIV-related critical incident reported by expert B**

| SA-1 | Patient has 2 IVs, 1 in each arm  
Vascular patient was receiving a muscle relaxant called cisatracurium (CA) in one arm  
To reach the main line of the IV, there is a stopcock manifold upstream of the IV catheter  
CA infusion was driven by a pump considerably upstream |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Expectations</strong></td>
<td>Drug is known to have a paralytic effect to facilitate endotracheal intubation</td>
</tr>
<tr>
<td><strong>Goals</strong></td>
<td>At the end of procedure, administer reversal agent to wake up the patient</td>
</tr>
</tbody>
</table>
| **DP-1** | Use other arm to provide reversal agent to avoid mixing of drugs  
Turn stopcock at the manifold to stop delivery of CA |
In the 1st situation assessment record (SAR), Expert B described a patient in the OR whose blood pressure (BP) was being controlled using nitroglycerin (NG). However, when a new IV fluid carrier was administered, the patient’s BP started to drop immediately. To combat this issue, he decided to stop the nitroglycerin infusion and begin the patient on a vasopressor. Using this new medication, the patient’s BP dropped even further. In retrospect, combatting the drastic drop in BP with additional medication was the incorrect decision. The expert realized that there was accumulated NG in the SIV of the IV infusion system due to a carrier bag that had been lying on the bed the entire time. The fluid from the carrier bag had not been flowing and therefore the system was set up such that a bolus of NG could easily be delivered. This situation was the first critical incident in which Expert B realized that residual medication in the SIV could pose a serious threat to patient safety. From this point forward, expert B was always cognizant of this particular volume. He mentioned that once a particular process (e.g. SIV management) has been experienced enough times it naturally becomes part of his mental model as a set of patterns. By matching the facts up with the available templates, an expert can react according to that individual template. He started conducting further research into this topic using mathematical models to better understand the fluid mechanics behind drug delivery in a multiple intravenous infusion system. The context in which he conducted this research was in anesthesiology.
However, soon after, as described in the 2nd SAR, a similar incident occurred but in the critical care department as opposed to during a surgery. During an operation, a vascular patient was receiving cisatracurium (CA) in one arm as a muscle relaxant. Near the end of the operation, a reversal agent was administered in the other arm to avoid medication incompatibilities while the IV infusion entering the other arm is capped off. In the post-anesthesia care unit (PACU), a nurse takes off this cap and administers an alternate IV medication. Within 2-3 minutes, the CA that remained in the SIV was flushed into the patient’s system and the patient became paralyzed. Similar to the previous situation, residual medication left in the SIV caused an adverse drug event. From this incident recall, SIV management not only needs to occur in the anesthesia, but in any context that involves IV infusions where multiple medications are being delivered to a patient.

6.5 Key Findings from CTA
From the CTA, it was discovered that although experienced nurses have a strong knowledge basis of the types of medications they deliver and their clinical effects, considering the SIV as a potential source of error is a rarity. Many of the critical incidents discussed during the critical decision method involved equipment-related issues where a mismatch between bag concentration and pump programming occurred. It is possible that SIV was not brought up during the critical incident recalls due to the notion that SIV-related issues do not arise during events with serious consequences. Instead, SIV related errors might be more common in everyday infusion tasks where the effects of a temporary delay in therapy or a sudden bolus of medication are not entirely apparent. Interestingly, the critical incidents that the nurses did choose to discuss were primarily a result of miscommunication regarding the concentration of a particular IV medication between different departments. Future research based upon improving communication amongst hospital staff members could prove to be a worthwhile endeavor in decreasing preventable medical adverse events.

Despite the lack of critical incidents that resulted in an immediate patient consequence, the types of cues that do trigger a nurse to become aware of a potential critical situation were recorded. Specifically, blood pressure changes seem to be the most obvious cue that triggers a critical care nurse’s cognitive thinking. The idea that a particular blood pressure range must be maintained at all times can in fact overcome a nurse’s ability to think holistically about a situation. When
making a change to a connected infusion in a multiple IV system, nurses immediately start titrating drugs rather than evaluating how a temporary change in blood pressure may be caused by the SIV needing time to clear. Due to a nurse’s mental model revolving around blood pressure stability, it is possible that involving additional case studies in the ITT based around a patient’s change in blood pressure would help engrain the concept of SIV management more explicitly.

Furthermore, patient lability is one of the most common reasons used in both nursing and anesthesiology to rationalize a patient’s status changes. However, as stated by Expert A, patient lability may not be the actual reason for these changes, but instead can be a result of mismanagement of the SIV. It is possible for future iterations of the ITT to highlight that a patient’s lability is unlikely to fluctuate very drastically and often times, vital signs rise or drop due to SIV-related issue.

Only in the anesthesiologist’s experience has a mismanagement of SIV resulted in critical incidents. This could possibly be attributed to the fact that the anesthesiologists have witnessed a wider variety of cases with higher chances of involving SIV-related errors. Additionally, SIV related critical incidents might go undetected to clinician’s who lack awareness regarding this issue. SIV is not a concept that these two experts actively think about, but instead is simply a toolset that they use to diagnose a particular intravenous infusion system problem. Transferring this toolset of knowledge to critical care nurses, such that it can become an instrument within their mental model, could potentially reduce the amount of SIV related issues.

The CTA conducted in this phase helped broaden the knowledge behind the cognitive processes required when administering multiple IV infusions. Many of the types of cues (e.g. blood pressure changes) that front-line critical care nurses are most cognizant of should be incorporated into the design of the ITT. It was discovered from the interviews that the experienced nurses have a strong understanding of the clinical effects of multiple medications, but do not necessarily consider their interactions in the SIV in the context of flow rates and volumes. Therefore, to improve the ITT, it would be ideal to have a particular emphasis on how the fluid mechanics of a multiple IV infusion system can affect the timing of drug delivery. Lastly, the incidents described by the anesthesiologists were very descriptive and would act as excellent case studies for nurses to experience through the ITT. For example, using one of their critical incident
scenarios related to SIV, a user of the ITT would have to answer a series of questions as the scenario progresses. The questions asked would be based around the cognitive processes found in the SIV researcher’s mental model and would appear around the decision points discussed in the CTA interviews.
Cognitive Walkthrough Simulation: Validation Phase

A cognitive walkthrough was conducted to understand how end users make clinical decisions involving tasks related to SIV management before and after viewing the interactive training tool (ITT). The ultimate goal of the ITT is to help clinicians not only perform multiple IV infusion tasks with fewer preventable errors, but also to incorporate SIV management concepts into their mental model. To achieve this goal, a validation study was conducted to determine the effectiveness of the ITT in terms of improvement in theoretical knowledge and practical performance.

The overall design and procedure of the cognitive walkthrough phase was similar to the previous usability testing cycles (see Chapter 5), but with several added components. The effectiveness of the finalized ITT intervention was evaluated in a high-fidelity simulation. Eight critical care nurses from the University Health Network were recruited to participate in our simulation study. Each participant was asked to perform tasks within four multiple intravenous infusion scenarios to evaluate their skills and knowledge regarding shared infusion volume management in a pre-post intervention experiment. The scenarios included: a) delivering an IV push of a rate sensitive medication, b) doubling concentration of an IV bag, c) performing a proper tubing change, and d) changing the flow rate on an IV pump connected to multiple infusions. For each scenario, nurses were evaluated based on skill/rule-based tasks (e.g. automatic execution, application of a rule) versus knowledge-based tasks (e.g. integration of multiple data sources). Knowledge-based tasks required participants to explain their cognitive thinking behind a certain procedure in the given scenario. By verbalizing their thoughts, human factors evaluators were able to evaluate participant’s understanding of the relevance and consequences of SIV associated with each task. A set of different but equivalent questions to test the user’s theoretical knowledge was given before and after the intervention. Additionally, a set of different but equivalent scenarios to test the user’s performance and evaluate his/her cognitive thinking was used before and after the intervention.

7.1 Methodology

Eight critical care nurses were recruited to participate in the study by carrying out their normal tasks associated with shared infusion volume management. All participants were introduced to
their role and completed a background demographic questionnaire. Participants were then introduced to the simulation area where they had to perform a series of tasks involving SIV management for 4 different scenarios (i.e. pre-intervention simulation phase). After completing the pre-intervention simulation phase, participants completed a pre-knowledge questionnaire. The participants were then trained with the finalized ITT intervention. After the participants’ viewing of the ITT, they completed a post-training knowledge test. Finally, nurses participated in a post-intervention simulation that was conducted.

7.1.1 Location and Materials

The cognitive walkthrough simulation was conducted in a high-fidelity simulation environment at the Centre for Global eHealth innovation, based at the University Health Network (UHN) in Toronto, Ontario. This facility includes patient beds, typical hospital furniture, computerized physician order entry (CPOE) system, IV infusion equipment, and paperwork. There were audio and video systems in the room to monitor the simulations. Observational rooms with one-way glass were used to actively monitor the participant’s actions and record feedback. Overhead ceiling mounted cameras and audio recording systems in the room were used to monitor the usability tests.

The finalized ITT modules used in the validation phase underwent multiple usability testing cycles to improve both their design and content. In terms of design, the ITT has a high level of interactivity where users are able to control the pace of their learning using a set of navigation buttons (i.e. previous, next, play/pause and replay). Additionally, users could navigate to a different topic within the module at any time by using the navigation menu on the left side. The ITT also had the option to turn on and off the closed captioning feature if preferred. For the recommendation summary slides, where a larger amount of text was used, the narration of the modules was modified to be identical with the text on screen. Simple and concise graphics were chosen to ensure that the user would not be distracted by any extraneous information. In terms of content, the ITT incorporated several engagement questions after a fundamental knowledge basis was developed. Explanations were presented at a steady pace and users always had the option of replaying a slide. Specifically, mathematical equations were explained thoroughly to ensure users would feel confident in using them in their practice. For the more complex concepts explained (e.g. changing flow rates to a connected infusion), a simplified take-away message was
always included for easier incorporation into the user’s practice. Below is a screenshot of the finalized ITT (Figure 14).

**Figure 14:** Screenshot of the finalized ITT explaining how drug proportions change in the SIV when making a change in flow rate to a connected infusion

### 7.1.2 Sampling and Recruitment of Participants:

Eight participants were recruited for the cognitive walkthrough. This convenience sample was used given that the purpose was to simply obtain a better understanding of how ICU nurses make clinical decisions regarding SIV management pre- and post-intervention (i.e. before and after watching the ITT modules). Nurses were recruited for the study using a sign-up sheet for interested individuals and announcements during morning nursing rounds in the cardiovascular intensive care unit (CVICU), coronary intensive care unit (CICU), and medical surgical intensive care unit (MSICU) at Toronto General Hospital and Toronto Western Hospital. Research Ethics Board approval (Appendix A) from the University Health Network (REB 14-7881-BE) was obtained prior to the study being undertaken. Interested individuals were subsequently contacted through e-mail or phone to confirm an appointment for the research study. Prior to confirming an appointment, study participants were asked a series of questions to ensure that they met the following criteria to be eligible for this study:

- a) Registered nurses who work at UHN in a critical care environment as staff
b) Have been trained to use infusion pumps
c) Fluent in English in reading, speaking, and understanding
d) Have the intent of actively participating in this study and willing to sign the consent form

Participants provided voluntary consent. Participants were notified of the implications of their involvement, their right to withdraw, and that their participation was entirely voluntary. Nurses participated in the study outside of their working hours, thus, there was no impact on patient care. Nurses were directly remunerated $165 for their time based on the following approximate calculation:

Hourly rate of senior nurse: $44.22/h (source: ONA Hospital Central Agreement, Exp Mar 31, 2016. Note: the rate for a senior nurse for April 1, 2014 was used as we do not want to discriminate against this group of nurses)

Premium pay: 150% (source: ONA Hospital Central Agreement, Exp Mar 31, 2016)

Study duration: 2 h

Compensation $44.22/h * 150% * 2.5 h = $165.82

7.1.3 Pre- and Post- Knowledge Questionnaires

A pre-knowledge questionnaire was designed to measure the participant’s baseline knowledge of SIV management. Participants were given 15 minutes to complete the pre-knowledge questionnaire. Upon completion of the training condition, participants would be given a post-training written knowledge test to evaluate the amount of knowledge they have gained through using the ITT. Participants were also given 15 minutes to complete the post-knowledge questionnaire. Both tests were equivalent in difficulty and content, but with non-identical questions (Appendix I). The tests were counterbalanced to minimize any order effect. That is, half the participants were given Test A to complete first and Test B after, while the remaining participants were given Test B to complete first and Test A after.

7.1.4 Simulation Tasks

Two sets of different but equivalent scenarios were designed to represent SIV management. Scenarios were designed with the intent to minimize transitional issues when a change to an
infusion is made. In general, when multiple IV infusions are connected to a single patient access port, nurses often make SIV errors related to a) the time lag before the desired change is reflected in the patient’s bloodstream, and b) the unintended dose rate changes of connected infusions. Throughout the simulation, different types of tasks (skill, rule, knowledge-based) were used to evaluate the nurse’s ability to manage shared infusion volume.

During infusion setup, nurses were expected to connect the IV infusion ports as close as possible to the patient access port. This means that nurses should minimize the number of connectors being used and refrain from chaining IV infusion tubing together.

During an IV infusion change, nurses are expected to group compatible medications by therapeutic class to avoid unwanted clinical effects. Tasks were designed such that nurses may request new IV tubing when initiating a new concentration of a continuous IV medication infusion to prevent infusing of the previous medication that remains in the shared infusion volume. Overall, participants were provided with IV components that should minimize unnecessary priming/shared infusion volume to minimize both the time lag before the intended dose change is delivered and the potentially dangerous reservoir of medication found in the shared infusion volume. Specifically, to test the participant’s knowledge during the simulations, four scenarios involving the concept of SIV for IV infusions were designed as described below:

1. Delivering a rate-sensitive IV push medication
2. Doubling the concentration of a previously connected infusion
3. Performing a proper tubing change
4. Changing the rate of a connected infusion in a multiple intravenous infusion system

A within-participant design was used whereby each participant participated in both the baseline (i.e. no training control) condition and the intervention (i.e. training via ITT) condition. Two sets of scenarios were designed to be equivalent in difficulty and content (e.g. use different case examples, but both requiring the same decision making elements). The sets of scenarios were counterbalanced to minimize any order effect and to ensure no bias was introduced because of differences in the level of difficulty of the simulation set. The first set of scenarios has previously been described in the procedure of the second round of usability testing (see Section 5.3.5).
Summaries of each scenario in the second set along with their objectives are outlined in the next section while the full script and protocol is provided in Appendix J.

7.1.5 Scenario Descriptions

The participant was placed in a role as a resource nurse in a simulated intensive care unit. After being introduced to the confederate nurse, the participant was instructed to take care of two patients, Patient A and Patient B.

Patient A was a 64-year old female vascular patient who recently came in with renal failure and developed aspiration pneumonia. This mock patient was hooked up to three medications with specified rates (i.e. norepinephrine, vasopressin, and a saline chaser) connected through a bridge connector. She was also connected to a central venous pressure monitoring line and had an extra medication line for delivering an antibiotic infusion of Ancef. The target mean arterial pressure (MAP) was 65 mmHg.

Patient B was a 54-year old male patient who recently had a pulmonary thoracic embolus removed from his pulmonary artery. This mock patient was hooked up to three medications with specified rates (i.e. norepinephrine, propofol, and a saline chaser) connected through a bridge connector. The target mean arterial pressure (MAP) was 65 mmHg.

7.1.5.1 Delivering an IV push

The participant was informed that a physician wanted to administer an IV push of diazepam to Patient A that she normally takes to reduce anxiety at home. A prepared diazepam syringe was handed to the participant and s/he was reminded that it needed to be pushed in longer than one minute as specified in the computerized physician order entry (CPOE).

Objective: The objective of this scenario was to evaluate whether or not the participant would administer the medication at the specified rate and follow the IV push with a saline flush. To deliver a proper saline flush, nurses needed to be cognizant of the amount of SIV in the infusion set-up and the correct rate of the subsequent flush.

7.1.5.2 Doubling the concentration of a previously connected infusion

The participant was informed that a physician wanted to double the strength of the vasopressin for Patient A by replacing the currently hung medication bag (20 units in 100 mL) with a
medication bag that had twice the concentration (40 units in 100 mL) while maintaining the same dose rate. A previously spiked medication bag with the new concentration was given to the participant.

Objective: The objective of this scenario was to evaluate whether or not the participant was able to properly double the concentration of the medication while reducing the amount of SIV in the system. Participants were expected to lower the current flow rate on the infusion pump to half of the original rate such that the dose rate would remain constant with a doubly concentrated medication bag. However, participants were also expected to ask for new IV tubing to properly perform this scenario to avoid giving the patient the old concentration of medication at the slower rate for an extended period of time. This is because in the SIV the old concentration of medication would still remain. To minimize the SIV, nurses needed to change the IV tubing and flush it with the new concentration of medication before attaching it to the infusion set-up. Once the system was reconnected and nurse pressed start on the infusion pump, the physiological monitor would alarm the nurse indicating a drop in blood pressure. Participants were expected to understand that this drop in blood pressure would only be temporary and was a result of the remaining SIV requiring time to be cleared of the old medication. Titration of medication was not necessary, as the blood pressure would return to normal after a few minutes once the SIV was cleared.

7.1.5.3 Performing a proper tubing change

The participant was informed that the patient was due for a tubing change. The confederate nurse told the participant that she had finished changing the tubing for 2 of the 3 ports connected to the patient. The last port that needed a tubing change was connected to a bridge connector supplying the three infusions of norepinephrine, vasopressin, and the saline chaser. The participant was provided with the 3 new infusion pumps with medication bags already spiked to complete the tubing change.

Objective: The objective of this scenario was to evaluate whether or not the participant would properly switch the three old infusions with the three new infusions. To perform a proper tubing change, nurses needed to program the new infusion pumps at the correct rate and gravity prime each medication. The infusion lines would then be connected to a new bridge connector. At this point, nurses needed to be cognizant of the amount of SIV in the bridge connector and ensure that it would be primed with the same proportions as the previous three infusions. Participants were expected to allow the drugs to mix over at least 15 minutes to ensure the slowest infusion
had cleared the SIV. After this time period, the nurse would pause the old infusion pumps, detach the 3 original infusions, attach the 3 new infusions, and then press start on the 3 new infusion pumps.

7.1.5.4 Changing the rate of a connected infusion in a multiple IV infusion system

The participant was informed that a physician wanted to switch Patient B off of Propofol and start the patient on Fentanyl and Versed. The Propofol flow rate was running at 2.5 mL/h while the flow rates of Fentanyl and Versed needed to be programmed at 10 mL/h and 4 mL/h, respectively. The participant was handed a set of two new infusion pumps for this scenario that had Fentanyl and Versed already spiked. In this infusion set-up, there was also another connected infusion of norepinephrine running at 6.5 mL/h and a normal saline line running at 10 mL/h. All infusions were connected through a bridge connector, which led into a single lumen percutaneous introducer (a special IV tubing with a large SIV). The total flow rate change was thus increased from 19 mL/h (2.5+6.5+10) to 31.5 mL/h (10+4+6.5+10). Once the participant increased the total flow rate by administering the new infusions to the patient, the physiological monitor would alarm the nurse indicating an increase in blood pressure.

Objective: The objective of this scenario was to evaluate whether or not the participant was able to understand the relationship between why the blood pressure would suddenly increase after adding the two new infusions. Participants were expected to understand that this increase in blood pressure would only be temporary and was a result of the infusion system requiring time to readjust the drug proportions in the SIV. For a temporary time period, the norepinephrine in the SIV would suddenly be bolused to the patient due to the increased total flow rate. This is because the addition of the two new infusions required a change in the drug proportions in the SIV. Therefore, a temporary delay in therapy would be expected, as the SIV needed time to reestablish itself to match the corresponding new ratio of flow rates. Titration of medication was not necessary, as the blood pressure would return to normal after a few minutes once the old drug proportions in the SIV was cleared and the SIV was filled with the new drug proportions.

7.1.6 Designation of Skill-, Rule-, and Knowledge-Based Tasks

The design of each scenario ensured that skill-, rule-, and knowledge-based tasks (SRK) were prevalent throughout. SRK designation for each task was determined with a team of 4 human factor experts. Each person was given a set of scenarios with sub-tasks and was asked to independently identify whether or not a particular task was skill-, rule-, or knowledge-based. For
example, if an expert thought the task, “administrates contents of syringe over 2 minutes as specified in order” was a rule-based task, s/he would give 1 point in the “rule” column of the following table (Table 16).

**Table 16: Example SRK designation scoring for a SIV scenario**

<table>
<thead>
<tr>
<th>SIV Scenario</th>
<th>Sub-Task Description</th>
<th>S</th>
<th>R</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>IV Push for Rate-Sensitive Drug over 2 minutes</td>
<td>Takes IV push syringe and attaches it to the closest available port</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Administers contents of syringe over 2 minutes as specified in order</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Asks what the SIV is</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chooses to flush the medication using an appropriate method (syringe or pump)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Delivers flush at the same rate as the original IV push</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Caps line after finished*</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

After all 4 experts completed the SRK designation table the results were compiled together. For some tasks (e.g. *takes IV push syringe and attaches it to the closest available port*), one expert rated it as both a skill and rule-based task. Therefore, half a point was awarded to both designations during consolidation. Once the results were consolidated, the 4 human factors experts discussed the SRK designations together to reach an agreed upon designation for each task. Table 17 below is an aggregate of how each expert rated the sub-task in each scenario and the final SRK designation of each sub-task.
### Table 17: Aggregate table for SRK designation for the different sub-tasks in each SIV scenario

<table>
<thead>
<tr>
<th>SIV Scenario</th>
<th>Sub-Task Description</th>
<th>S</th>
<th>R</th>
<th>K</th>
<th>Designated Task-Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>IV Push for Rate-Sensitive Drug over 2 minutes</td>
<td>Takes IV push syringe and attaches it to the closest available port</td>
<td>3.5</td>
<td>0.5</td>
<td></td>
<td>Skill</td>
</tr>
<tr>
<td></td>
<td>Administers contents of syringe over 2 minutes as specified in order</td>
<td>1</td>
<td>3</td>
<td></td>
<td>Rule</td>
</tr>
<tr>
<td></td>
<td>Asks what the SIV is</td>
<td></td>
<td></td>
<td>4</td>
<td>Knowledge</td>
</tr>
<tr>
<td></td>
<td>Chooses to flush the medication using an appropriate method (syringe or pump)</td>
<td>1</td>
<td>3</td>
<td></td>
<td>Rule</td>
</tr>
<tr>
<td></td>
<td>Delivers flush at the same rate as the original IV push</td>
<td>1</td>
<td>3</td>
<td></td>
<td>Knowledge</td>
</tr>
<tr>
<td></td>
<td>Caps line after finished*</td>
<td>4</td>
<td></td>
<td></td>
<td>Skill</td>
</tr>
<tr>
<td>Doubling concentration of norepinephrine IV bag while maintaining overall same dose rate</td>
<td>Obtains a new infusion pump</td>
<td>2</td>
<td>2</td>
<td></td>
<td>Skill</td>
</tr>
<tr>
<td></td>
<td>Get new primary IV tubing and attach it to the new infusion bag</td>
<td>2</td>
<td>2</td>
<td></td>
<td>Rule</td>
</tr>
<tr>
<td></td>
<td>Program new pump with same VTBI and half the flow rate to maintain dose rate</td>
<td>2.5</td>
<td>1.5</td>
<td></td>
<td>Rule</td>
</tr>
<tr>
<td></td>
<td>Pause the old infusion and de-attach the old norepinephrine</td>
<td>4</td>
<td></td>
<td></td>
<td>Skill</td>
</tr>
<tr>
<td></td>
<td>Attach the new pump to the same port and start the new norepinephrine bag</td>
<td>4</td>
<td></td>
<td></td>
<td>Skill</td>
</tr>
<tr>
<td></td>
<td>Monitor patient for any drop in BP and recognize this may be due to the SIV having not cleared of the old drug proportions (may not need to adjust infusion therapy)</td>
<td></td>
<td></td>
<td>4</td>
<td>Knowledge</td>
</tr>
<tr>
<td>Line change with three infusions (slowest infusion running at 4mL/h)</td>
<td>Set up and spike new infusion bags and obtain new infusion pumps to match the previous infusions</td>
<td>4</td>
<td></td>
<td></td>
<td>Rule</td>
</tr>
<tr>
<td></td>
<td>Gravity prime each medication</td>
<td>4</td>
<td></td>
<td></td>
<td>Skill</td>
</tr>
<tr>
<td></td>
<td>Attach the three infusions to a bridge connector (SIV = 1mL)</td>
<td>1</td>
<td>3</td>
<td></td>
<td>Rule</td>
</tr>
<tr>
<td></td>
<td>Allow the drugs to mix over at least 15 minutes to ensure the slowest infusion has cleared the SIV</td>
<td></td>
<td></td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Pause and detach the original 3 infusions</td>
<td>3.5</td>
<td>0.5</td>
<td></td>
<td>Skill</td>
</tr>
<tr>
<td></td>
<td>Attach the three new infusions with the bridge to the same port</td>
<td>2.5</td>
<td>1.5</td>
<td></td>
<td>Skill</td>
</tr>
<tr>
<td></td>
<td>Start the 3 new infusions</td>
<td>3.5</td>
<td>0.5</td>
<td></td>
<td>Skill</td>
</tr>
<tr>
<td>Changing infusion flow rate for a patient connected MIVI, results in an immediate drop in patient’s BP</td>
<td>Before making any change to the patient’s infusion therapy, recognize that this symptom may be a result of shared infusion volume</td>
<td></td>
<td></td>
<td>4</td>
<td>Knowledge</td>
</tr>
<tr>
<td></td>
<td>Wait a few minutes for patient to stabilize with new flow rate after the shared infusion volume has cleared</td>
<td></td>
<td></td>
<td>4</td>
<td>Knowledge</td>
</tr>
</tbody>
</table>
7.2 Overall Design
Upon arrival to the facility, the participant was introduced to their role in the study and asked to complete a demographics questionnaire consisting of questions regarding specialization, age, weekly shifts, and level of experience. The design of the simulation involved a within-subjects study design in which participants were required to perform common IV infusion tasks (e.g. delivering an IV push, performing a proper tubing change) that involved SIV management (see Section 7.1.4). The two training conditions were used: a) the baseline condition, which involved no training and b) an intervention training condition using the ITT built by HumanEra. Participants were assessed for theoretical comprehension of the device prior and after the ITT intervention through a multiple-choice knowledge test. Upon completion of both simulation phases, participants were debriefed.

7.2.1 Outline of Procedure
Participants completed the following:
1. Introduction: Review their role and complete a background demographic questionnaire and consent form
2. Baseline Simulation: Perform a series of tasks simulating shared infusion volume (SIV) management (see Section 7.1.4)
3. Baseline Theoretical Knowledge: Complete a written knowledge test
4. Training phase: Train with the ITT to learn about SIV
5. Theoretical comprehension: Complete a written knowledge test
6. Post-Training Simulation: Perform a series of tasks simulating SIV management (see Section 7.1.4)

7.2.2 Introduction
When the participant first arrived, s/he was greeted by the study facilitator and was introduced to the overall mission of the Centre for Global eHealth Innovation. The participant was introduced to their role in the study and asked to complete a demographics questionnaire (Appendix B) consisting of questions regarding specialization, age, sex, weekly hours, and level of experience. The consent form (Appendix K) was then reviewed with the participant. Once the participant completed and reviewed the form, the facilitator informed them that their performance during the simulated tasks or any problems they encounter with the ITT are not be a reflection of their skills. Participants were reminded that the study is a simulation and will not involve any real
patients or drugs. Participants were also reminded that they would be observed, audiotaped and videotaped. Once the written consent was handed over, the participants were given a signed copy.

7.2.3 Baseline Simulation

The simulated intensive critical care unit consisted of one mock patient played by a mannequin. End tables were located at the end of each bed and provided gloves, hand sanitizer, alcohol swabs, swab caps, a flush syringe, and a multi-connector. A laptop placed on a nearby desk was used to simulate a MOE/MAR that provided patient information and physician orders. Additionally, a binder was provided that included both hospital standard and restricted nursing IV drug list.

All props involved in the simulation were replicated from those used in an actual clinical environment, which included: medication IV bags, syringes, IV tubing sets, medication orders, labels, Graseby IV pumps, multi-connectors, and extension tubing. All medication protocols and intravenous infusion tasks used in the experiment were previously consulted with a hospital pharmacist and three ICU clinical nurse educators to ensure realism. Medications in the clinical setting were substituted with water.

Participants were exposed to the patient mannequin with prior knowledge regarding their medical history and physician orders for IV infusions. Participants were allowed to communicate with the confederate nurse (i.e. actor playing the role of a nurse) at any time if they required help. Physician orders, change in physiological status, and instructions from the confederate nurse helped guide the simulation phase required the nurse to perform intravenous infusion tasks. Their actions helped observers evaluate their level of knowledge in SIV management. Participants were asked to conduct the tasks while verbalizing their actions and thought process (think-aloud protocol).

Specifically, at the end of each scenario, participants were asked a few questions by the test facilitator using an overhead speaker regarding the particular tasks they had just completed in order to probe his or her cognitive thinking about the scenario. This helped the researchers gain insight towards the cognitive processes required to complete the SIV management tasks.
7.2.4 Baseline knowledge
A pre-knowledge questionnaire (Appendix K) was then administered to measure the participant’s baseline knowledge of SIV management. To ensure the participant felt comfortable, the facilitator emphasized that the purpose of the study was not to evaluate their clinical performance but rather to understand the extent to which the training tool helped them in their clinical decision-making. It was also emphasized that the comments regarding the training intervention and the results from the knowledge questionnaires would have no effect on their employment.

7.2.5 Intervention training phase
Afterwards, participants were asked to watch the ITT intervention. Behind a one-way mirror, the test facilitator and another human factor analyst recorded any issues that were noticed or mentioned by the participant.

7.2.6 Theoretical comprehension
After the participant finished viewing the ITTs, a post-knowledge questionnaire (Appendix K) was administered to test whether the training intervention had any effect on the participant’s understanding of SIV.

7.2.7 Post Training Simulation
The next phase involved a simulation phase where participants were instructed to perform intravenous infusion tasks related to SIV management. Equivalent, but different, scenarios were used to evaluate a nurse’s performance. The scenarios were counterbalanced to minimize any order effects during the experiment to ensure that performance was not biased. For this validation-testing phase, half the participants were given Scenario Set A to complete first and Scenario Set B after, while the remaining participants were given Scenario Set B to complete first and Scenario Set A after. The scenarios are described in Section 7.1.5.

7.2.8 Debrief of study
After the participant finished viewing the ITTs, an informal debrief session occurred where the test facilitator helped clarify any comments or address any concerns the participant had about the study. The participant was thanked and handed a cheque for $165 for his/her time and was
reminded not to discuss the contents of the ITT with other colleagues until after it was ready for release.

### 7.2.9 Data Collection and Analysis:

Evaluation behind a one-way glass door was conducted. Data was collected through direct observation and post-test review of audio and video recordings of each session. Observations included, but were not limited to, the time it took for the participant to complete each module, navigation difficulties, and ability to understand content. The number of errors the clinician commits for each given task helped determine the level of success or failure for a certain task. A data collection template was created to ensure that details (e.g. programmed flow rates) were collected for each participant. All comments made by the participant were recorded during the simulation phase. Additionally, any workflow deviations or other observations were noted. Observers independently recorded their observations and compared them after the study. Any discrepancies amongst the observer’s notes were resolved by watching the video recording and through discussion.

Ceiling mounted cameras were used to record the session and track the participant’s actions as they moved throughout the simulation. Discrete communication between the test facilitator and confederate nurse via wireless microphone and radio was allowed such that observers could verify any missed actions. Additionally, any comments regarding the overall design and usefulness of the content presented were also recorded in the data collection templates.

To score the participant on each intravenous infusion task, two human factor analysts reviewed the recordings and compared each participant’s actions with an “ideal answer” spreadsheet (Appendix L). This spreadsheet also listed each scenario, associated intravenous infusion task, and SRK designation. If the human factor analyst observed that the participant’s comments or actions followed the ideal correct answer, the participant was given a point; otherwise the participant scored a zero. Table 18 demonstrates the difference between an incorrect and correct answer and the task type designations for the IV Push Scenario.
Table 18: Incorrect versus correct answer for SIV scenario in validation phase

<table>
<thead>
<tr>
<th>SIV Scenario</th>
<th>Incorrect Answer</th>
<th>Correct Answer</th>
<th>Task Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>IV Push for Rate-Sensitive Drug over 2 minutes</td>
<td>Takes IV push syringe and attaches it any available port</td>
<td>Takes IV push syringe and attaches it to the closest available port</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>Administers contents of syringe over the wrong time</td>
<td>Administers contents of syringe over 2 minutes as specified in order</td>
<td>R</td>
</tr>
<tr>
<td></td>
<td>Does not flush the IV push</td>
<td>Chooses to flush the medication using an appropriate method (syringe or pump)</td>
<td>R</td>
</tr>
<tr>
<td></td>
<td>Flushes IV push too quickly</td>
<td>Delivers flush at the same rate as the original IV push</td>
<td>K</td>
</tr>
</tbody>
</table>

As described in Section 7.2.3, probing questions were used to understand the cognitive processes of the participant. The same scoring procedure was used to determine if a nurse fully understood the reasoning behind a particular action (Appendix N). Table 19 demonstrates the difference between an incorrect and correct answer for the three probing questions regarding the IV Push scenario.

Table 19: Incorrect versus correct answer for SIV scenario during cognitive probing

<table>
<thead>
<tr>
<th>Probing Questions</th>
<th>Incorrect Answer</th>
<th>Correct Answer</th>
<th>Task Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Why do you need to deliver a flush?</td>
<td>1. I have delivered a flush because that is my general practice. [No specific reason]</td>
<td>1. I need to deliver a flush because there is medication remaining in the SIV</td>
<td>R</td>
</tr>
<tr>
<td>2. How do you determine how much to flush</td>
<td>2. [Arbitrary value]</td>
<td>2. The flush volume must be equal or greater to the SIV</td>
<td>K</td>
</tr>
<tr>
<td>3. How long do you need to flush for and why?</td>
<td>3. Not sure</td>
<td>3. I need to make sure the flush syringe is at the same rate as the specified order to ensure all the medication is received by the patient at the specified rate</td>
<td>K</td>
</tr>
</tbody>
</table>

In total, there were 11 skill/rule-based tasks and 13 knowledge-based tasks. Some tasks were more difficult to score than others due to the variance in answers. Therefore, half a point was
scored for participant’s who had somewhat of a grasp of the tested concept, but was still missing a complete understanding of the theory or proper practice.

7.3 Results and Discussion

7.3.1 Participant Demographics

Table 20: Participant demographics for validation phase

<table>
<thead>
<tr>
<th>Predominant Critical Care Unit</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CVICU</td>
<td>3</td>
</tr>
<tr>
<td>MSICU</td>
<td>3</td>
</tr>
<tr>
<td>CICU</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sex</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>3</td>
</tr>
<tr>
<td>Female</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age Range</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>18-29</td>
<td>4</td>
</tr>
<tr>
<td>30-39</td>
<td>2</td>
</tr>
<tr>
<td>40-49</td>
<td>2</td>
</tr>
<tr>
<td>&gt; 50</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Years of Experience in Nursing</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1</td>
<td>0</td>
</tr>
<tr>
<td>1-3</td>
<td>2</td>
</tr>
<tr>
<td>4-10</td>
<td>2</td>
</tr>
<tr>
<td>&gt; 10</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Years of Experience in Critical Care</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1</td>
<td>2</td>
</tr>
<tr>
<td>1-3</td>
<td>1</td>
</tr>
<tr>
<td>4-10</td>
<td>2</td>
</tr>
<tr>
<td>&gt; 10</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Average Number of Shifts Per Week</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>1</td>
</tr>
<tr>
<td>3-4</td>
<td>6</td>
</tr>
<tr>
<td>&gt;4</td>
<td>1</td>
</tr>
</tbody>
</table>

7.3.2 Pre and Post-knowledge Questionnaire

All 8 critical care nurses recruited for this study answered a nine-question knowledge test before and after viewing the ITT intervention. Scores on the knowledge test were analyzed in a 2
(condition: pre-intervention vs. post-intervention) repeated measures Analysis of Variance (ANOVA). It is important to note that due to our small sample size of 8, we had not initially planned on conducting statistical analyses. Therefore, a power calculation to determine an appropriate sample size prior to the simulation phase was not conducted.

**Figure 15:** Knowledge questionnaire results comparing pre-intervention versus post-intervention results

Figure 15 shows the average knowledge questionnaire results for the ITT pre- and post-intervention. A significant difference was observed between conditions, $F (1, 7) = 15.6$, $p < 0.01$. After viewing the intervention, nurses scored an average of 67% (SE: 7.3%) compared to the baseline condition with an average of 26% (SE: 5.5%).

### 7.3.3 Pre and Post-Simulation Data

The performances of 7 out of the 8 critical care nurses in managing SIV-related tasks were analyzed for statistical significance a 2 (task type: skill/rule or knowledge) x 2 (condition: pre-intervention vs. post-intervention) repeated measures ANOVA. Pairwise comparisons were made using Bonferroni corrections. 1 participant was excluded from our analyses due to a technical error in the video recording making it difficult to properly analyze whether or not the participant successfully or unsuccessfully completed a particular task.
Figure 16: Practical performance results for skill/rule-based versus knowledge-based tasks comparing pre- and post-intervention conditions

Figure 16 shows the two-way simple interaction between tasks type and condition, $F (1, 6) = 12.4, p < 0.02$. Specifically, nurses scored significantly higher after viewing the ITT, (mean: 94%, SE: 7.5%) for skill/rule-based tasks compared to the baseline condition (mean: 79%, SE: 4.7%). Similarly, nurses scored higher after viewing the ITT (mean: 67%, SE: 10.4%) for knowledge-based tasks compared to the baseline condition (mean: 22%, SE: 7.5%). However, the delta between the pre-post intervention conditions was significantly higher for the knowledge-based tasks (delta: 45%) compared to the skill/rule-based tasks. Thus, although the ITT improved nurses’ performance across both task types, the improvement was significantly better for knowledge-based tasks.

Comparing the theoretical knowledge and the performance scores, it is interesting to note the correlation between the two testing methodologies regarding the intervention’s effectiveness. Overall, the theoretical knowledge test had a very similar outcome compared to the performance score for knowledge-based tasks. The average score for the pre-knowledge questionnaire was 26% compared to the average score for the pre-performance score of 22% while the average score for the post-knowledge questionnaire and the post-performance score were both 67%. A full breakdown of the results from each scenario is in Appendix M.
7.3.4 Key Findings from Validation Phase

The scenario in which nurses had the greatest increase in performance for SR tasks involved doubling the concentration of a medication while maintaining the same dose rate. Nurses were expected to switch the IV medication bag, switch the primary IV tubing, and program the infusion pump with the same volume to be infused (VTBI) and half the original flow rate. The purpose of the scenario was to evaluate whether nurses were aware of the old concentration of medication in the SIV of the primary IV tubing. The SR task that nurses did not generally perform well prior to the intervention involved the second step of switching the primary IV tubing (2/7 performed correctly). However, after viewing the ITT intervention 6 of 7 nurses asked for new IV tubing to account for the old concentration of medication remaining in the SIV. A few nurses (3/7) did mention in the post-simulation phase that switching IV tubing when changing the concentration of an IV bag is a common practice, but they simply forgot to ask for new tubing in the simulation environment. From these comments, it can be assumed that the ITT was able to act as a refresher for the SR based tasks involved with SIV management.

Interestingly, the ITT was able to change the cognitive thinking of nurses regarding shared infusion volume as demonstrated by the significant increase in performance scores regarding knowledge-based tasks from 22% to 67%. At the end of each scenario, participants were asked a few prepared questions (Appendix N) to gauge their cognitive thinking regarding the SIV aspect of the tasks they had just performed. For example, nurse participants at UHN are trained to use a multi-port connector (also known as a bridge) when delivering multiple intravenous infusions as opposed to piggybacking multiple secondary IV tubing set-ups. However, the reasoning behind such procedure was not always explained properly prior to viewing the ITT (3/7 nurses explained incorrectly). After viewing the ITT, 6 of 7 nurses were able to explain why a bridge was used in conjunction with multiple intravenous infusion lines. Thus, it can be assumed that the reasoning behind the use of a bridge was incorporated into the nurse’s mental model. Having this new knowledge may not only help nurses remember to always use a bridge, but may also prompt the nurse to proactively think of alternative methods to reduce SIV in other multiple IV infusion systems.

Despite an overall improvement, critical care nurses still had some difficulty in grasping the ‘why’ behind some of the SIV related tasks. For example, when delivering an IV push with a rate
sensitive medication into an IV infusion system, it is important to follow the administration of such drug with a flush syringe. Although most nurses (6/7; 86%) learned to deliver the flush syringe with the equal or greater flush volume than the SIV, only 2 of 7 nurses were able to fully incorporate the knowledge from the ITT regarding the rate of the flush syringe. The one crucial step that 5 other nurses did not consider relates to the fact that the rate of flush syringe must be equal to the specified rate of the previous IV push. 3 of these 5 nurses demonstrated a partial understanding by verbally stating the importance of the flush rate, but still ended up delivering the flush at a faster rate than the original push medication. These nurses did not perform the proper calculations to ensure the flush rate was equivalent to the specified delivery rate of the push medication. The remaining 2 nurses did not show any signs of improvement neither verbally by stating the importance of flush rate nor performance wise. It was difficult for the ITT to completely change the cognitive thinking of all 7 participants, as it is likely that integrating new information into practice isn’t necessarily an immediate process. Furthermore, it is possible that nurses were simply not patient enough to deliver a slow enough flush syringe to match the specified rate. 3 of the 7 nurses even indicated that delivering a flush syringe over a period of 1-2 minutes felt much longer than in practice and that he or she would normally have finished the flush within a much shorter time period. Emphasizing the importance of patience when administering a flush syringe is crucial for patient’s receiving a rate-sensitive medication due to potential harmful side effects.

Another area of knowledge that was missing in the nurses’ cognitive thinking during the walkthrough is in relation to how they perceive a patient’s change in vital signs. Throughout the simulation, the physiological monitor of the mock patient would be changed based on the actions of the nurse participant. For example, if a particular medication (e.g. norepinephrine) were suddenly bolused to the patient, the heart rate and blood pressure of the patient would also suddenly rise. To evaluate whether or not the nurse had an understanding of the temporary effects of SIV, a human factor expert would probe the participant’s reasoning behind the changes in vitals. Their comments provided the team with a deeper understanding of their cognitive thinking. Both before and after watching the ITT, nurses still had the presumption that changes in vitals were because the patient was labile and required further adjustment of medications. Fine adjustments of IV medication are a necessary skill that critical care nurses and other clinicians are trained to perform. However, often times, changes in a patient’s vital signs may simply be
due to a SIV related issue. The ITT intervention hoped to change this common perception of nurses that changes in the vitals must be followed by immediate changes to their medication delivery. Instead, it is advised to wait for the SIV to clear and not overreact after a medication change has been administered. One reason as to why nurses only scored an average performance score of 69% for knowledge-based tasks after the ITT intervention is due to the fact that changing a nurse’s common practice of constant adjustment of medications is quite difficult. Despite showing a better improvement in the theoretical knowledge test, converting their new knowledge into practice and changing their cognitive thinking may take more time than a 2.5 hour study. It would be interesting for nurses to return back (e.g. 1 month later) to the Centre for Global eHealth Innovation and partake in a follow-up study. It is possible that over time, the knowledge gained from viewing the ITT will be better incorporated into their cognitive thinking after partaking in intravenous infusion deliveries with SIV related issues.

7.4 Summary
The effectiveness of the ITT at improving a critical care nurses thinking regarding shared infusion volume was compared between skill/rule-based tasks and knowledge-based tasks. Both task types were tested using a within-subjects study in a high-fidelity simulation environment. Results revealed that the ITT intervention developed provided significant benefit to critical care nurses in both task types. However, there was a larger increase in average performance score for knowledge-based tasks compared to skill/rule-based tasks. Overall, the ITT was found to have improved both theoretical and practical performance.
8 General Discussion

The overall aim of this study was to design and assess an interactive training tool (ITT) to help reduce errors committed by critical care nurses in the context of shared infusion volume (SIV) management. A training module in the form of a video on SIV management was developed and evaluated in a previous phase of a larger initiative by HumanEra to improve the safety associated with the administration of multiple intravenous (IV) infusions. Despite the benefits that the module demonstrated, areas of improvement were noticeable especially in terms of its interactivity. A more concise heuristic evaluation (HE) was performed on this prototype, based on good training design to systematically evaluate the design of its user interface and determine which heuristic principles were violated.

8.1 Heuristic Evaluation

From the HE, the SIV management training tool was found to provide a large amount of useful and relevant information that may not have been explicitly taught in a nurse’s previous education. However, it was also determined that a successful ITT requires a significant level of learner control to allow the user sufficient time to build upon their existing knowledge framework. The e-learning video did not properly address the cognitive aspects of learning and instead presented the material in a passive manner without any type of engagement piece. Thus, the user was hindered from critically thinking about the topic and it would be difficult to draw any substantial conclusion from the module. To fully maximize the potential that e-learning has to offer, a certain understanding of human cognitive processes must be incorporated. Specifically, to build a complete mental model, it was recommended that future versions of an e-learning module must incorporate features that allow for natural pauses to provide users with sufficient time to build upon his or her existing knowledge framework. In addition, incorporating an explicit list of recommendations for best practices in relation to SIV would prove to be more applicable for clinicians (as opposed to learning how to use a look-up table for mathematical calculations). Lastly, the introduction of relevant clinical scenarios that the user can work through can serve as useful engagement pieces. All of these recommendations are in accordance with Clark and Mayer’s framework on how to facilitate meaningful learning through an e-learning tool\(^60\). In terms of knowledge construction, there is a particular emphasis on including features that deliver content through both behavioral and psychological engagement. Behavioral engagement involves users to physically control the pace at which s/he is progressing through a
particular module (e.g. having the option to replay a slide) while psychological engagement involves having the user to critically think about solving a SIV related issue (e.g. answering a question about the flush rate after delivering an IV push). However, HE has its limitations in terms of the lack of involvement with actual end users. Therefore, the recommendations for this HE were used as a guideline when probing users for their feedback regarding the ITT during a subsequent usability testing phase.

8.2 Usability Testing
Two rounds of usability testing were conducted to discover potential issues regarding the intervention. The objective of the usability tests was to assess the ease of use (in terms of how well users can understand the material being presented) and the satisfaction and acceptability of the ITT. The first cycle of usability testing was geared towards discovering end-user feedback regarding potential design, content and functionality improvements. Based on the results collected from 5 critical care nurses and 5 critical care student nurses, the primary positive feedback received involved the well-balanced combination of text and audio on the screen especially when describing a complex task such as SIV management. However, due to the complexity of the topic, nurses wanted to increase the level of learner control and freedom through the addition of a replay button. Additionally, several nurses considered the content presented in the ITT overwhelming and it was suggested that ITTs could focus on the more fundamental aspects of SIV and their clinical relevance to common scenarios found in the critical care unit (e.g. changing flow rate from multiple infusions, performing a proper tubing change).

A second cycle of usability testing was conducted with a slightly modified methodology to test whether the changes made to the ITT were effective based on improvement of theoretical knowledge using a pre- and post-knowledge questionnaire. Feedback from 4 critical nurses regarding the ITT was overall positive in terms of the visuals and audio. One major modification we included was the content and placement of the engagement questions. Before trying to engage the user, it was ensured that some fundamental background information was presented. This helped introduce the topic of SIV management less abruptly to participants. Some nurses appreciated the “question-first” method as they felt it helped set the tone of the module or that seeing their mistakes early on heightened their awareness levels. Nurses commented that a lot of the information wasn’t necessarily entirely new, but instead the information presented was taught through transfer of knowledge directly from nurses. This is of particular interest because critical
care nurses often need to complete annual e-learning modules to expand their clinical knowledge or knowledge around new IV related equipment (e.g. infusion pumps, syringes). However, a gap in knowledge regarding the dynamics of an IV infusion system is missing from the nurse’s education and is only taught through mentorship. There currently exists no explicit training method that touches upon SIV and the potential effects it has when delivering multiple intravenous infusions. Incorporating topics such as SIV management into a critical care nurses e-learning curriculum is vitally important to reduce preventable medical IV infusion related errors. Rather than waiting several months for a relevant opportunity to arise in the critical care department, the ITT developed can accelerate the learning process by immersing the nurse in relevant SIV-related case studies. To synthesize all this complex knowledge, recommendation slides and easy take-away messages were included throughout the ITT. Specifically, one major change we included was the addition of a set of three rules to explain how changing the flow rate to an IV infusion affects other connected infusions in a multiple IV system. These rules helped nurses develop a toolset that could be applied in the nurses’ practice.

Based on the post-performance simulation, the ITT seemed to have ensured strong performance on skill or rule based tasks, but had difficulty maximizing success for nurses when performing knowledge-based tasks. During the simulation phase, participants were not performing the knowledge-based tasks correctly. Additionally, observers were unable to identify “why” they were making errors or had a gap in knowledge despite the applicable content being explained from the intervention. For example, some nurses had difficulty in understanding that a change in a patient’s blood pressure may be caused by a temporary delay in drug therapy due to changing drug proportions in the SIV. The experiment design for this phase did not include any means of probing the nurse about their thought process regarding the reasoning of why a change in blood pressure may have been related to a potential SIV issue. Essentially, we were unable to understand the cognitive processing that nurses were experiencing, and thus a cognitive task analysis and cognitive walkthrough were performed in subsequent phases.

8.3 Cognitive Task Analysis
A cognitive task analysis (CTA) was performed to help elicit knowledge from SIV experts and front line critical care nursing staff. By revealing the underlying cognitive process that clinicians use when performing intravenous infusion tasks, a mental model was developed regarding their
expertise and ability to spot particular cues in critical situations. In particular, the critical decision method (CDM) was used to discover the types of cues, challenges, and strategies a clinician faces during a critical incident. From the CTA, it was discovered that although experienced nurses have a strong knowledge basis of the types of medications they deliver and their clinical effects, considering the SIV as a potential source of error is a rarity.

The critical incidents discussed during the CDM revolved heavily around communication issues amongst staff members. In particular, the concentration of a medication bag was often miscommunicated when patients were transferred between departments. The lack of communication resulted in equipment-related errors such as mismatch between bag concentration and pump programming. Although these types of incidents did not result in any immediate serious consequence, it does demonstrate that further research in the field of team communication in a hospital setting would be useful to prevent adverse drug events. The types of cues that trigger a nurse to become cognizant of critical situations primarily involved blood pressure changes. In the ICU, maintaining a particular blood pressure is a priority, however, this mental model can in fact overcome a nurse’s ability to think holistically about a situation. When a blood pressure reading rises or dips after making a change to a connected infusion in a multiple IV infusion system, nurses immediately start titrating drugs rather than evaluating whether or not the change in blood pressure may only be temporary due to a SIV related issue. Nurses are not the only clinicians who attribute blood pressure changes to patient lability (high sensitivity to drugs). SIV subject matter experts (SMEs) also commented that even anesthesiologists rationalize a change in the patient’s status due to lability. However, as stated by one of the SMEs, patient lability may not be the actual reason for blood pressure changes, but instead can be a result of mismanagement of the drugs in the SIV. It is possible for future iterations of the ITT to highlight that a patient’s lability is unlikely to fluctuate very drastically and often times, vital signs rise or drop due to a SIV-related issue.

Only in the anesthesiologists’ experiences has a mismanagement of SIV resulted in critical incidents. This could possibly attributed to the fact that the anesthesiologists have witnessed a wider of variety of cases with higher chances of involving SIV-related errors. Additionally, SIV related critical incidents might go undetected to clinicians who lack awareness regarding this
issue. SIV is not a concept that the two SMEs actively think about, but instead is simply a toolset that they use to diagnose a particular IV infusion system problem. Transferring this toolset of knowledge to critical care nurses, such that it can become an instrument within their mental model, could potentially reduce the amount of SIV related issues. In addition, the incidents described by the SMEs were very descriptive and would act as excellent case studies for nurses to experience through the ITT. The questions asked would be based around the cognitive processes found in the SIV researcher’s mental model and would appear around the decision points discussed in the CTA interviews. In conclusion, the CTA helped reveal insights regarding a nurse’s mental model where it was found that they have a strong understanding of the clinical effects of multiple medications, but do not necessarily consider their interactions in the SIV in the context of flow rates and volumes. Future iterations of an ITT should have a particular emphasis on how the fluid mechanics of a multiple IV infusion system can affect the timing of drug delivery.

8.4 Cognitive Walkthrough: Validation Phase

The cognitive walkthrough validation phase was conducted to determine whether or not the ITT was able to improve a critical care nurse’s thinking regarding shared infusion volume for both skill/rule-based (SR) and knowledge-based (K) tasks. Both task types were tested using a within-subjects study in a high-fidelity simulation environment. Results revealed that the ITT intervention developed provided significant benefit to critical care nurses in both task types. In particular, SR tasks showed significant improvement as demonstrated by an average score from 79% to 94%. Prior to using the ITT, nurses generally performed well for these task types, but performed especially well after using the ITT by mitigating the amount of SR errors committed (e.g. remembering to use a flush syringe after delivering an IV push). This can be attributed to the fact that the intervention was able to act as a refresher tool. During the post-simulation, a few nurses commented that the ITT reminded them to perform a particular action that they would normally have done in a real-clinical setting. The ITT was able to modify the nurses’ behavior when performing SR tasks, which are generally easier to perform and require less conscious effort. In terms of K tasks, a significant increase in practical performance was also observed from 22% to 67%. The nurse’s cognitive thinking behind each scenario was explored based on a series of probing questions. Prior to using the ITT, it was clear that the SIV was often mismanaged or simply not considered. For example, although most nurses understood that a tubing change of multiple infusions require the use of a new bridge connector, several of them
simply flushed the bridge connector with saline before reattaching the new infusions to the patient. However, after watching the ITT, nurses were cognizant of the SIV of the bridge connector and realized that in order to minimize any delay in therapy, the bridge connector should be mixed with the multiple infusions for a period of time such that the slowest infusion clears the SIV. This way, when the new lines are connected to the patient, rather than a bolus of saline being delivered, the actual proper mixture of infusions will be delivered. Despite the overall improvement, some areas in which the ITT was not able to address is in regards to the nurse’s performance when she notices a blood pressure change after adjusting the flow rate to an infusion in a multiple IV infusion system. In the ITT, it was explained that an increase (decrease) in flow rate to an infusion pump would actually cause other connected infusions to increase (decrease) temporarily due to the fluids in the SIV not being at the correct drug proportions. There is a time lag before the SIV clears and thus a patient’s vital sign may temporarily change. The recommendation in the ITT explicitly stated that nurses should not overreact and wait for the SIV to clear. However, in the post-simulation phase, several nurses still tended to adjust the blood pressure medications to maintain the target blood pressure. The reasoning for this may be because changing a nurses’ common practice of constant titration of medication may take longer than a 2.5 hour study. The knowledge gained from the ITT may be better incorporated into a nurse’s practice potentially after a certain time period (e.g. 1 month) after partaking in IV infusion deliveries with SIV related issues. In summary, being introduced to a new IV infusion concept (i.e. SIV management) provided nurses with another toolset of knowledge that can build upon their existing mental model when trying to diagnose a particular drug related incident. The ITT increased awareness levels regarding SIV management and through the validation phase it was found to have improved both theoretical and practical performance.

8.5 Limitations to this Thesis Work
The heuristic evaluation conducted in the first phase of this work was a useful systematic method to discover design and content improvements that would affect potential user knowledge absorption. Despite the many important usability issues found with the original e-learning video, further improvements may have been overlooked due to the fact that only one individual performed the evaluation. Traditionally, a HE is conducted by a set of evaluators, as it can be difficult for a single individual to capture all usability issues in an interface. Different perspectives will improve the effectiveness of a HE because a more substantial amount of issues
can be discovered. In addition, by having more than one evaluator, common (or easier-to-find) usability issues will be highlighted based on the frequency that particular issue was raised. Alternatively, some evaluators may only be able to discover a few usability issues, but are able to identify the more obscure usability issues. Nielsen et al. have demonstrated that a group of 3-5 evaluators are sufficient enough to find 50-75% of all possible usability issues during a HE.\textsuperscript{54}

The cognitive task analysis conducted in the third phase of this work helped reveal several important insights regarding the mental model of a critical care nurse. Specifically, the critical decision method was used as the method of choice to allow nurses to share their own experiences regarding a critical incident related to SIV. However, as mentioned previously in this discussion, none of the incidents revealed had an immediate consequence, and thus it was difficult to pinpoint the exact cognitive elements that nurses used around a critical decision point. In addition, the discussed incidents mostly revolved around miscommunication amongst the clinical team rather than a particular SIV-related issue. The two reasons for this finding may include: a) SIV-related issues are more common in ordinary situations that result in non-life-threatening adverse drug events or b) SIV errors often remain undetected and are difficult for critical care nurses to recognize. In future studies, other methods besides the CDM may want to be used to elicit knowledge about SIV from critical care nurses (e.g. focus groups, job observation).

In the second and fourth phases of this work, controlled simulated observations were conducted to evaluate the effectiveness of the ITT intervention. Although they were conducted in a high-fidelity simulated environment, several limitations were apparent. Firstly, many of the steps that critical care nurses needed to perform to complete a task was already pre-prepared by the confederate nurse. For example, all IV push medications were prepared ahead of time, and the only task that the participant needed to perform was the actual delivery of the push medication. In addition, in a critical care environment, it is well-known that the frequency of interruptions are quite high, but we did not include any interruptions in our simulated environment such that the participant would focus directly on addressing the particular SIV issue. Participants were asked to carry out tasks similar to a real clinical setting, but the lack of real patients and staff members may have affected their overall performance. In both the usability testing phase and the validation phase, nurses were asked to verbalize their thoughts and think-aloud. This is typically not how nurses perform in a real-clinical setting. The act of verbalizing their thoughts may have
altered their cognitive processing, as they would potentially be more inclined to double-check their actions and be more vigilant of errors.

Finally, in the cognitive walkthrough portion of the validation phase, nurses were asked the same set of questions after each scenario, pre- and post-intervention. By introducing questions related to SIV, nurses may have gained an increased understanding of the primary objective of the study (i.e. SIV management). The act of discussing one’s cognitive thinking with the study facilitator helped reveal the nurse’s mental model, but may have also affected their approach to handling IV infusion systems. It is rare that in a real-clinical setting, nurses have to justify their actions, and thus the act of justification may have triggered a subsequent action that is not normally seen in his/her typical work environment. Furthermore, the familiarity of the questions in the post-intervention simulation is another limitation of the study, as nurses are more cognizant of the “correct” response the study facilitator was expecting. This idea of familiarity being a limitation is also applicable for the performance tasks as they were designed to be different but equivalent in difficulty and content. To overcome this limitation, the scenarios were counterbalanced to minimize any order effect.
9 Conclusions

Medication administration errors represent a substantial proportion of hospital based adverse events. This is partially due to the increasing complexity of medical technology and abundance of procedures required to deliver first-rate healthcare to patients. Effective training methods are needed to ensure that clinicians are able to perform at a high level while avoiding preventable human related errors. Changes in our society have shifted the learner’s role from a traditional passive role to a preference towards participatory knowledge construction. The design of interactive training tools (ITTs) can help reduce the error rate related to intravenous (IV) infusion systems as demonstrated by the cognitive walkthrough validation phase in this research. Specifically, the ITT was designed with proper critical thinking analysis methods (i.e. heuristic evaluation and usability testing) and was able to train clinicians to better tackle skill-, rule-, and knowledge-based tasks for shared infusion volume management.

The effectiveness of the ITT was tested in a high-fidelity simulation experiment. Nurses were asked to perform a series of tasks in 4 SIV-related scenarios:

1. Delivering a rate-sensitive IV push medication
2. Doubling the concentration of a previously connected infusion
3. Performing a proper tubing change
4. Changing the rate of a connected infusion in a multiple intravenous infusion system

Results revealed that nurses performed significantly better in both skill-/rule- and knowledge-based tasks after using the ITT intervention. Nurses were able to incorporate many of the key recommendations highlighted in the ITTs and subsequently modified their behavior to properly address SIV tasks. Additionally, the cognitive walkthrough portion of this validation phase revealed that the nurse’s cognitive thinking did change as nurses were more cognizant of ensuring that the SIV is minimized, that drug proportions need time to adjust in the SIV, and that a patient’s status can be affected due to mismanagement of SIV. Overall, this type of interactive and practice-based educational approach helped expand the critical care nurse’s current theoretical knowledge in IV infusions as well as improve their practical performance when dealing with SIV-related issues.
9.1 Future Work
Firstly, although a significant difference was detected between pre-intervention and post-intervention for critical care nurses during practical performance, the sample size of this validation phase was eight. In future studies, it is recommended to expand the sample size to increase the power and expand the design to include a longitudinal component. Changes in cognitive thinking and a nurse’s practice may differ over an extended period of time. A one-month post study to determine the long-term effects of the ITT would be appropriate. This can be conducted through either an additional validation phase in a high-fidelity simulation environment or through the administration of a follow-up theoretical comprehension test. Knowledge retention regarding SIV management is an important area that was out of the scope for this thesis, but would prove to be an interesting avenue to explore. Alternatively, a one-month post survey can be sent out to participants regarding their own perception of the prevalence of SIV-related issues in their work environment now that they have been introduced to this new infusion concept.

Secondly, a cognitive task analysis was conducted to elicit knowledge from clinicians regarding their understanding of SIV. From the CTA, it was discovered that although experienced nurses have a strong knowledge basis of the types of medications they deliver and their clinical effects, considering the SIV as a potential source of error is a rarity. This may have been attributed to the fact that SIV errors are hard to recognize and thus often go undetected. The interviews with the anesthesiologists (SIV experts), however, revealed several critical incidents related to SIV. Future iterations of the SIV ITT may want to incorporate these incidents by applying them as interactive case studies that a user would have to problem solve through. Questions based around the cognitive processes found in the SIV expert’s mental model would appear around the decision points of that particular case study. Essentially, in the updated ITT, it would be ideal to transfer the anesthesiologist’s toolset of knowledge to critical care nurses in the context of SIV management.

Finally, while the ITT developed in this work was geared towards shared infusion volume management, there remain other clinical topics in which a gap in knowledge exists. Due to the success of this particular ITT, similar human factors design approaches and evaluation methods
can be applied to the development of future ITTs to help reduce preventable medical errors in other health care domains.
References

59. Pantelidis VS. “Reasons to Use Virtual Reality in Education and Training Courses and a Model to Determine When to Use Virtual Reality” Themes in Science and Technology Education. Special Issue, 59-70.
Appendices

Appendix A: Research Ethics Board Approval for Usability Testing (#14-7881-BE)

<table>
<thead>
<tr>
<th>Date:</th>
<th>September 19th, 2014</th>
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<tr>
<td>To:</td>
<td>Ms. Patricia Trbovich</td>
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<tr>
<td></td>
<td>Toronto General Hospital, 200 Elizabeth St.</td>
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<tr>
<td></td>
<td>Toronto, Ontario, Canada M5G 2C4</td>
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<td>Re:</td>
<td>14-7881-BE</td>
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<td>Mitigating Risks Associated with Multiple Intravenous Infusions: Phase 3b Interactive Training Tools - Formative Usability Tests</td>
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<td>REB Review Type:</td>
<td>Expedited</td>
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<td>REB Initial Approval Date:</td>
<td>September 19th, 2014</td>
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<td>REB Expiry Date:</td>
<td>September 19th, 2015</td>
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Documents Approved:

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<td>Interactive Training Tool - Outline of Module</td>
<td>Received on: September 15th, 2014</td>
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<td>Questionnaire A and B (pre and post)</td>
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<td>Poster</td>
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<td>Background Questionnaire</td>
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<td>Debrief Questionnaire</td>
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<td>Background Questionnaire</td>
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The UHN Research Ethics Board operates in compliance with the Tri-Council Policy Statement; ICH Guideline for Good Clinical Practice E6(R1); Ontario Personal Health Information Protection Act (2004); Part C Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations and the Medical Devices Regulations of Health Canada. The approval and the views of the REB have been documented in writing. The REB has reviewed and approved the clinical trial protocol and informed consent form for the trial which is to be conducted by the qualified investigator named in the letter.

Furthermore, members of the Research Ethics Board who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB.

Best wishes on the successful completion of your project.

Sincerely,

Alan Barbet, MD PhD FRCPC
Co-Chair, University Health Network Research Ethics Board
Appendix B: Demographics Questionnaire for Usability Testing

Background Questionnaire

Participant ID: __________________________

1. What best describes your role in the hospital?
   - Staff nurse
   - Nurse manager
   - Clinical trials nurse
   - Advanced practice nurse
   - Student nurse
   - Other (please specify): _______________________________

2. What age range are you in:
   - 18 – 29 years old
   - 30 – 39 years old
   - 40 – 49 years old
   - 50 – 64 years old
   - 65 years old and over

3. Are you:
   - Male
   - Female

4. Which clinical unit do you predominantly work at?
   - TGH: Medical surgical ICU (MSICU)
   - TGH: Cardiovascular ICU (CVICU)
   - TGH: Coronary ICU (CICU)
   - TWH: Neuro ICU (NICU)
   - TWH: Medical/Surgical/Neurological ICU (MSICU/NICU)
   - Other (please specify): _______________________________

5. How many years of experience do you have working as a registered nurse?
   - Less than a year
   - 1-3 years
   - 4-10 years
   - greater than 10

6. If you work in critical care, how many years of experience do you have working as a critical care nurse?
   - I have only worked in critical care as a student nurse
   - Less than a year
   - 1-3 years
   - 4-10 years
   - greater than 10
   - NA (I have never worked in critical care)

7. If you work in critical care, how often do you work in the critical care on average?
   - Less than once a week
   - 1 to 2 times a week
   - 3 to 5 times a week
   - More than 5 times a week
   - NA (I do not work in critical care)
CONSENT FORM TO PARTICIPATE IN A RESEARCH STUDY

Study Title: Mitigation Risk Associate with Multiple IV Infusions: Phase 3b Interactive Training Tools – Formative Usability Tests

Principal Investigator: Dr. Patricia Trbovich

Contact Information: 416-340-4800 x7180

Funder: Health Quality Ontario

Introduction:
You are being asked to take part in a research study. Please read the information about the study presented in this form. The form includes details on study’s risks and benefits that you should know before you decide if you would like to take part. You should take as much time as you need to make your decision. You should ask the study staff to explain anything that you do not understand and make sure that all of your questions have been answered before signing this consent form. Before you make your decision, feel free to talk about this study with anyone you wish. Participation in this study is voluntary.

Background/Purpose:
Past research has identified that administering multiple IV infusions to a single patient is a high-risk activity. One contributing factor to these errors is that Ontario nurses are not consistently taught fundamental principles associated with administering secondary intravenous (IV) infusions and managing dead volume (the common volume shared by 2 or more infusions).

Researchers at the University Health Network (UHN) are investigating the effectiveness of an interactive training tool (ITT) on improving the safety of administering multiple IV infusions to a single patient. Past research showed that watching a computer-based training module about multiple IV infusions improves safety, but areas for improvement were also identified.

Your participation will help us to determine content and design improvements to the newly developed ITT. The primary audience for the ITT is practicing critical care nurses. However, we are also interested in evaluating the appropriateness of the ITT for use by critical care nursing students and non-critical care nurses that administer multiple IV infusions.
Study Procedures and Visits:
Twenty-five nurses (including students) will be included in this study. Each nurse will participate separately and each session will last no more than 2 hours.

If you agree to participate in the study, you will be asked to come to the Centre for Global eHealth Innovation at UHN to do the following:
1. Complete a background (demographic) questionnaire (e.g., age, sex, years nursing experience)
2. Complete a written test*
3. View the ITT and provide your feedback as you navigate through the ITT. The ITT reviews the fundamental principles associated with administering secondary IV infusions and managing dead volume.
4. Complete a second written test*
5. Complete clinical tasks in a simulated clinical environment (i.e., laboratory facility) to a simulated patient (mannequin and/or actor*). You will be asked to complete common IV-related tasks such as: setting up secondary IV infusions, administering an IV manual push dose, and changing a parameter to a continuous infusion (e.g., increase the flow rate). No actual drugs will be used; instead, water will be used. You will be asked to “think aloud” (i.e., verbalize your thoughts) as you complete the tasks to help us understand what you are doing and why.
6. Complete a semi-structured debrief interview with the study coordinator to clarify and summarize your feedback about the ITT so we can improve its content and design.

*Note: All actors are part of the research team; they are not direct colleagues or management. Your performance/competency is NOT being evaluated in a way that will impact your employment. Any issues or errors observed during the simulation tasks will be noted as related to the evaluation of the ITT to better understand how we can improve it.

Human factors experts (i.e., not direct nursing colleagues or management) will record your feedback and other observations made from behind a one-way mirror. The entire session will be video and audio taped using ceiling-mounted cameras in the simulation laboratory to aid in subsequent analysis.

Risks:
There are no anticipated or known medical risks associated with this study. You may experience discomfort in sharing your opinions with the researchers. You only have to share as much about your opinions as you wish. Your participation will have NO impact on your employment at UHN (or your student evaluation, if applicable).

Benefits:
You may or may not receive direct benefit from participating in this study. Information from this study may help to increase your knowledge about managing multiple IV infusions.
Confidentiality:
If you agree to join this study, you will be asked to provide the following personal information that could identify you:

- name
- address
- phone number
- email

All information obtained during the study, including your personal information, will be kept confidential and will not be shared with anyone outside the study unless required by law. You will not be named in any reports, publications, or presentations that may come from this study. You will be identified with a subject number only. A list linking your study number with your name will be kept by the study Principal Investigator (PI) in a secure place, separate from your study data file. The study PI will keep any personal information about you in a secure and confidential location for at least 5 years and a maximum of 10 years. Any personal identifiable information will be stored and protected on secured servers or kept in a locked filing cabinet and then destroyed by shredding of paper or erasing of digital information.

No information identifying you will be transferred outside the investigators of this study. All results shared outside the study team will be de-identified and aggregated such that no results will be directly associated with you. If the video/audio tapes from the research are shown outside the research team, your face will be blurred, audio modified, and all identifying information will be made anonymous. However, despite best efforts, there is a very small possibility that you may still be identified.

Representatives of the University Health Network (UHN) including the UHN Research Ethics Board may come to the hospital to look at the study records and at your personal information to check that the information collected for the study is correct and to make sure the study is following proper laws and guidelines.

Voluntary Participation:
Your participation in this study is voluntary. You may decide not to be in this study, or to be in the study now, and then change your mind while completing the simulation study. You may also refuse to answer any questions you do not want to answer during the study. Whether you choose to participate or not has no impact on your employment at UHN (or your student evaluation, if applicable).

Costs and Reimbursement:
You will receive monetary compensation in the amount of $125 for your participation in this study.

Rights as a Participant:
If you are harmed as a direct result of taking part in this study, all necessary medical treatment will be made available to you at no cost.

By signing this form you do not give up any of your legal rights against the investigators, sponsor or involved institutions for compensation, nor does this form relieve the
investigators, sponsor or involved institutions of their legal and professional responsibilities.

**Conflict of Interest:**
Health Quality Ontario, the funder of this study, will reimburse the hospital and Principal Investigator for the costs of doing this study. All of these people have an interest in completing this study. Their interests should not influence your decision to participate in this study.

**Commercialization:**
The project sponsor and study team intend to claim sole ownership of any results that would come from this study. You will not receive any financial benefit that might come from the results of this study.

**Questions about the Study:**
If you have any questions, concerns or would like to speak to the study team for any reason, please call the Principal Investigator Patricia Trbovich at (416) 340-4800 x 7180 or the Study Lead, Sonia Pinkney, at (416)-340-4800 x 4766.

If you have any questions about your rights as a research participant or have concerns about this study, call the Chair of the University Health Network Research Ethics Board (REB) or the Research Ethics office number at 416-581-7849. The REB is a group of people who oversee the ethical conduct of research studies. The REB is not part of the study team. Everything that you discuss will be kept confidential.

You will be given a signed copy of this consent form.

**Consent:**
This study has been explained to me and any questions I had have been answered. I know that I may leave the study at any time. I agree to the use of my information as described in this form. I agree to take part in this study.

I allow video clips in which my face is obscured (i.e., blurred) and audio modified to be shown for educational purposes (e.g., illustrate ITT issues):

☐ Yes, video clips may be shared
☐ No, video clips may NOT be shared

Print Study Participant’s Name ___________________________ Signature ___________________________ Date ___________________________

My signature means that I have explained the study to the participant named above. I have answered all questions.

Print Name of Person Obtaining Consent ___________________________ Signature ___________________________ Date ___________________________
**Appendix D: Example of Data Collection Template**

![Data Collection Template Table]

**Figure 17:** Example of Data Collection Template
Appendix E: Pre- and Post-Questionnaire for Usability Testing

Questionnaire A – Shared Infusion Volume

Q1. Participant ID: ______________________

Q2. Circle: Pre or Post

Q3. An IV syringe push of 5 mg of drug in 5 mL is ordered to be administered over 3 minutes to avoid side effects (i.e., speed shock). The nurse administers the syringe dose slowly over 3 minutes into an IV tube that is currently infusing sodium chloride 0.9% at a slow KVO rate (see Figure 1, below). The nurse then administers a prefilled 10 mL syringe of sodium chloride 0.9% slowly over 3 minutes to flush the line. What statement best describes what has just occurred?

a) The patient did not receive all the medication
b) The patient received all the medication as ordered
c) The patient received all the medication too slowly
d) The patient received all the medication too quickly
e) None of the above

Figure 1

5 mL medication syringe (full)

25 mL
Q4. A patient is fluid restricted, so the physician orders the concentration of a continuous infusion of Drug A to be doubled from 8 mg (in 250 mL) to 16 mg (in 250 mL) but the dose rate be maintained. The nurse disconnects the single strength concentration and attaches the double strength concentration to the same primary IV tubing and then reprograms the pump to half the rate. What best describes this scenario immediately after this change?

a) The patient received the medication as ordered
b) The patient received half the dose rate ordered
c) The patient received double the dose rate ordered
d) The patient received a temporary interruption in therapy during the bag change
e) None of the above

Q5. In the scenario in Figure 2 (below), which of the following best describes the exact delivery of Drug B after the flow rates are changed?

![Figure 2]

A patient is currently receiving 2 IV infusions through a single-lumen catheter:
Drug A: 10 mL/h
Drug B: 10 mL/h

Both infusions are then changed to new flow rates:
Drug A: 15 mL/h
Drug B: 5 mL/h

Figure 2

a) Dose rate of Drug B reaching the patient briefly increases and then decreases to the new dose rate
b) Dose rate of Drug B reaching the patient instantaneously decreases to the new dose rate
c) Dose rate of Drug B reaching the patient remains the same momentarily before dropping to the new dose rate
d) Dose rate of Drug B reaching the patient is unaffected by the change
e) None of the above

Q6. Four hours later after the change in Question 5 (above) is made, drug A (Figure 2) is now further increased to 20 mL/h. Which of the following best describes the exact delivery of drug B after this change?

a) dose rate of drug B reaching the patient briefly increases and then returns to the intended dose rate
b) dose rate of drug B reaching the patient steadily increases and then stabilizes at a higher dose rate than intended
c) dose rate of drug B reaching the patient briefly decreases and then returns to the intended dose rate
d) dose rate of drug B reaching the patient is unaffected by the change
e) None of the above
Q7. In Figure 3, which setup minimizes unintended rate changes of connected infusions (when 3 infusions need to share one access site)?

**Figure 3**

- a) Setup 1 or 2, because they are equivalent
- b) Setup 1, because it minimizes the volume in which the 3 infusions mix
- c) Setup 1, because 4 more infusions can be added
- d) Setup 2, because only one y-port is free for IV manual push doses
- e) Setup 2, because infusion 1 is first mixed with infusion 2 before mixing with infusion 3
Q8. In Figure 4 (below), suppose infusion A is programmed at 100 mL/h, infusion B at 50 mL/h and infusion C at 250 mL/h. What is the total flow rate:

![Figure 4](image)

i) Just after the point where drug A and drug B meet (①)?

ii) Just after the point where drug C is connected (②)?

iii) At the tip of the patient catheter (③)?
Q9. A nurse has been asked to add another vasoactive drug (Drug E) to the setup in Figure 5 (below). It is compatible with all drugs. Where should the nurse add Drug E?

Figure 5

a) At ① or ②  
b) At ①  
c) At ②  
d) Neither ① or ②  
e) Depends on when the IV tubings are next scheduled for change
Questionnaire B – Shared Infusion Volume

Q1. Participant ID: ____________________

Q2. Circle: Pre or Post

Q3. An IV syringe push of 3 mg of drug in 3 mL is ordered to be administered over 5 minutes to avoid side effects (i.e., speed shock). The nurse administers the dose slowly over 5 minutes into an IV tube that is currently infusing sodium chloride 0.9% at a slow KVO rate (10 mL/h; see Figure 1, below). The nurse then titrates the infusion pump to 100 mL/h for 5 minute (8.3 mL) to flush the line. What statement best describes what has just occurred?

a) The patient received all the medication as ordered
b) The patient did not receive all the medication
c) The patient received all the medication too slowly
d) The patient received all the medication too quickly
e) None of the above

Figure 1

- 3 mL medication syringe (full)
- 2 mL
- 25 mL

Q4. A patient is fluid restricted, so the physician orders the concentration of a continuous infusion of Drug A to be doubled from 4 mg (in 100 mL) to 8 mg (in 100 mL) but the dose rate be maintained. The nurse disconnects the single strength concentration and attaches the double strength concentration to the same primary IV tubing and then reprograms the pump to half the rate. What best describes this scenario immediately after this change?

a) The patient received a temporary interruption in therapy during the bag change
b) The patient received half the dose rate ordered
c) The patient received double the dose rate ordered
d) The patient received the medication as ordered
e) None of the above

Q5. In the scenario in Figure 2 below, which of the following best describes the exact delivery of Drug A after this change?
Drug A is infusing at 25 mL/h. A separate infusion (Drug B) is then joined to the same catheter.

**Old flow rates**
- Drug A: 25 mL/h
- Drug B: 0 mL/h

**New flow rates**
- Drug A: 25 mL/h
- Drug B: 10 mL/h

**Figure 2**

a) dose rate of drug A reaching the patient briefly increases and then returns to the intended dose rate
b) dose rate of drug A reaching the patient steadily increases and then stabilizes at a higher dose rate than intended
c) dose rate of drug A reaching the patient briefly decreases and then return to the intended dose rate
d) dose rate of drug A reaching the patient is unaffected by the change
e) None of the above

**Q6.** Five hours later after Drug B is added in the scenario in **Figure 2** (above), Drug A is increased to 30 mL/h and Drug B is decreased to 5 mL/h?

a) Dose rate of Drug A reaching the patient briefly decreases and then increases to the new dose rate
b) Dose rate of Drug A reaching the patient instantaneously increases to the new dose rate
c) Dose rate of Drug A reaching the patient remains the same momentarily before increasing to the new dose rate
d) Dose rate of Drug A reaching the patient is unaffected by the change
e) None of the above
Q7. In Figure 3, which setup minimizes unintended rate changes of connected infusions when 3 infusions need to share one access site.

Figure 3

a) Setup 1, because only one y-port is free for IV manual push doses
b) Setup 1, because infusion 1 is first mixed with infusion 2 before mixing with infusion 3
c) Setup 2, because 3 more infusions can be added
d) Setup 2, because it minimizes the volume in which the 3 infusions mix
e) Setup 1 or 2, because they are equivalent
Q8. In **Figure 4** (below), suppose infusion A is programmed at 250 mL/h, infusion B at 50 ml/h and infusion C at 25 mL/h. What is the flow rate:

![Figure 4](image)

i) Just after the point where drug A and drug B meet (①)?

ii) Just after the point where drug C is connected (②)?

iii) At the tip of the patient catheter (③)?

Q9. A nurse has been asked to add another sedative drug (Drug E) to the setup in **Figure 5** (below). Drug E is compatible with all drugs. Where should the nurse add Drug E?
Figure 5

a) At ① or ②  
b) At ①  
c) At ②  
d) Neither ① or ②  
e) Depends on when the IV tubings are next scheduled for change
Appendix F: Experimental Protocol and Script for Usability Testing

General Roles

Person 1

- Meet and greet participant, introduce participant to study and lab
- Facilitation
- Note taking in observation room

Person 2

- Cameras
- Sim Man Control
- Note taking?
- Set-up of labs between protocols

Person 3

- Nurse Actor
PRE-EQUIPMENT SET-UP

Scenario Setup

Lab
- Bring up orders on MOE/MAR computer
- Adjust MOE/MAR cart height for participant
- Paper, pen, pencil, calculator on MOE/MAR cart
- Bring out bins with meds
- Check flush supplies at the bedside
- Check IV collection bags
- Laptop and extension cord (plug in laptop)
- Make sure tubing is primed and IV bags are full
- Garbage can at each bedside
- Start pumps
- Small poster in a visible area to (a) ensure the participant that they are in the correct location for the study and (b) extension to contact study coordinator when they reach the center.
- Check that the drip chambers for all IV sets are not full

Control Room
- Easel pad (write participant name, ID for each experiment, condition number)
- Laptops
- Synch time on laptops with camera recording time
- Put do not disturb signs on lab and control room doors
- Telephone
- SIM Man Controller on
- Replace batteries (Walkie-Talkie, Pager)

Nurse Actor
- Wireless microphone
- Walkie Talkie
- Scrubs and ID badge

Consent Table Set-up
- Have paper questionnaires? (pretest, posttest, debrief)
- Consent forms x2
- Chequebook and/or cheque req
- Receipts (Participant and HTSRT)
- Sign on to computer and bring up demographic questionnaire (and pre/post education test?)
- Lab coat for participant
- Drinks/snacks and water
- Wireless microphone (on Table)
- Laptop
Patient Setup

Pre-experiment Set-up: Ms. Susan Chur

**PATIENT**
- IV access points:
  - Triple Lumen Catheter - Right Internal Jugular Vein (IJ)
    - Brown port:
      - Central Venous Pressure (CVP) Transducer (ICU) or locked (Floor RN)
    - Blue port (with extension set and Bridge):
      - Normal Saline
      - Vasopressin
      - Norepinephrine (Levo)
    - Proximal Line (with extension set): Med Line
      - Normal Saline
- Wig
- Armband
- 10 cc IV flush syringe
- New multiport bridge

**EQUIPMENT SET-UP**
- Physiological monitor

**Bags:**

<table>
<thead>
<tr>
<th>Infusion</th>
<th>Bag volume and type</th>
<th>Number</th>
<th>Label</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVP – brown port</td>
<td>1000 mL NS</td>
<td>1</td>
<td>NA</td>
</tr>
<tr>
<td>Normal Saline – blue port</td>
<td>1000 mL NS</td>
<td>2</td>
<td>NA</td>
</tr>
<tr>
<td>Vasopressin – blue port</td>
<td>100 mL NS</td>
<td>2</td>
<td>RN Med Added: 40 units in 100 mL</td>
</tr>
<tr>
<td>Norepi – blue port</td>
<td>250 mL D5W</td>
<td>4 (1 initial, 2 conc change, 1 line change)</td>
<td>Rx label: 8 mg in 250 mL Baxter: 16 mg in 250 mL</td>
</tr>
<tr>
<td>Normal Saline – white port</td>
<td>1000 mL NS</td>
<td>1</td>
<td>NA</td>
</tr>
</tbody>
</table>

**Bin:**
- Furosemide/Lasix: 5 mL syringe (w 4mL) + med added label
- 16 mg in 250 D5W norepi
- primed primary lv tubing
- extension set

**Initial Pump programming**

**On patient:**

<table>
<thead>
<tr>
<th>Infusion</th>
<th>VTBI</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Saline – blue port</td>
<td>1000</td>
<td>75 ml/h</td>
</tr>
<tr>
<td>Vasopressin – blue port</td>
<td>100</td>
<td>2.5 mL/h (1 unit/h)</td>
</tr>
<tr>
<td>Norepi (8mg) – blue port</td>
<td>250</td>
<td>13 ml/h (0.1 mcg/kg/min)</td>
</tr>
<tr>
<td>Normal Saline – white port</td>
<td>1000</td>
<td>10 ml/h</td>
</tr>
</tbody>
</table>

**Off to side:**

**Pole #1**

<table>
<thead>
<tr>
<th>Infusion</th>
<th>VTBI</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Saline – blue port</td>
<td>1000</td>
<td>10 ml/h</td>
</tr>
<tr>
<td>Vasopressin – blue port</td>
<td>100</td>
<td>2.5 mL/h (1 unit/h)</td>
</tr>
</tbody>
</table>
Pre-experiment Set-up: Mr. Thomas Sim

- IV access points:
  - Single central
    - Normal Saline primary
- Armbands
- IV flush syringe

**EQUIPMENT SET-UP**
- Pumps: 1

**Bags:**

<table>
<thead>
<tr>
<th>Infusion</th>
<th>Bag volume and type</th>
<th>Number</th>
<th>Label</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Saline</td>
<td>1000 mL NS</td>
<td>1 (full)</td>
<td>NA</td>
</tr>
</tbody>
</table>

**Bin:**
- Gravol: 3 mL syringe (w 1mL) + med added label

**Initial Pump programming**

<table>
<thead>
<tr>
<th>Infusion</th>
<th>VTBI</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Saline</td>
<td>1000</td>
<td>10 mL/h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>***clear secondary/flush programming (make secondary default rate 999 and VTBI 999)</td>
</tr>
</tbody>
</table>

Orientation

Meet and greet participant

**Location:** Main office area and innovation lab hallway

"Hi __________________, welcome to the centre! My name is ____________ and I’m one of the study coordinators for the multiple IV infusion study. How are you? [Small talk ... i.e. did you have any problems finding the center etc?] We are really happy that you’re able to participate in this study. Have you ever been to center before? No? All right, let me give you a quick summary of what goes on here."

Introduction to the study and the lab
Lead participant into innovation lab hallway toward lab

[While walking to lab give quick summary of the center]

“So, [Name of Participant] this center was created to improve healthcare for people through safe, usable and effective technologies and processes. A key component of our work is to conduct usability simulation studies on new products so we can understand potential safety and usability issues prior to roll-out. We often require the help of front-line nurses because it is your issues we want to learn about! By understanding your needs we can hopefully create products that effectively support you and improve patient.”

Okay, so here is the lab that you will be working in this morning/afternoon. Why don’t we sit down right over there and get some paperwork out of the way.

Explanation of consent form and signing of the consent form

“OK – the first thing we should do is review the consent form. I believe Kyle sent it to you previously.

☐ Have you had a chance to read it? If not, ask if want some time to read it
☐ Paraphrase key pieces of info
  • Purpose: Today we will be looking at how we can improve the design and content of some eLearning modules. So to do this, we want to get your feedback and evaluate the effectiveness of the modules since you are the expert.
  • Study Background:
  • Procedure:
    o complete a written test
    o then watch the modules and get your feedback as you go on everything from how the information is present, how you navigate through the modules, graphics, and so on.
    o complete a second test and
    o the perform a few IV tasks in this simulated environment, while I observe behind this one-way mirror, which prevents me from distracting you when you are completing the tasks.
    o Then at then end, we will sit back down here and I will ask you a few questions to get your final thoughts about the modules
  • Confidentiality:
    o All information obtained will be held strictly confidential and we will only report on the data collected at an aggregate level. In fact, in all our notes, you are simply going to be a number so nothing will be tied to your name!
  • Voluntary: Your participation is voluntary and may withdraw at any time
  • Reimbursement: You will receive $125 to compensate you for you time in participating in this study
  • Video taped:
    o This session will be videotaped and audio taped just in case I miss anything after the session is completed.
    o If we share your video clips for educational purposed, for example in a presentation, your face will be blurred and audio altered. Can consent to this separately
Do you have any questions?

Participant and Coordinator signs two copies (one copy to participant and another for coordinator)

Put on microphones and lab coats (participant and you)

Background Questionnaire

“Okay, now that all the paper work is taken care of, I would like you to complete a short background questionnaire.”

Participant completes background questionnaire

Knowledge Test #1

“Okay, now here are 6 questions we would greatly appreciate you answering so we can evaluate what you know now compared to after watching the eLearning modules to see if they were effective. We will give you about 10 minutes to complete. Just let me know if you are done early.

So the first 2 questions are just for us....and then you will answer 6 questions, but since the numbering for you starts at 3, it will go to 8”

Please don’t navigate backwards as you do the test.

Please talk as you go if you are comfortable doing so as this can help me understand what you are thinking.

Participant completes Test #1

ITT Review

“Okay, so now let get to the modules. There are 2 separate modules, and each are about 15 min long, and they are still in draft form. And our approach is to get end user feedback as early as possible before we start to finalize the products. So some things are still missing or need refinement.

I am going to go behind the one-way mirror and talk to you over the speaker, which we will just test out before you start watching the modules.

Then, I will ask you to please watch the modules but as you go, if there is anything that isn’t clear to you, or may be an issue, or if you aren’t sure what to do next, please just let me know.

I will also ask you to stop at key points to get your feedback. And please remember, if you are having problems then please tell me because these are the sort of things we want to find out b/c if you are having them then so will others!

And sometimes if you ask me a question, I may redirect it back to you or not fully answer it, and this is not because I am trying to be difficult, but rather b/c I want to see what you would do if I wasn’t here”

Watch ITTs

Knowledge Test #2

“Okay, now please complete another set of 6 questions. As before, we will give you about 10 minutes to complete, but just let me know if you are done early.”
Participant completes Test #2

Performance - Introduction
So now let’s do a few IV-related tasks.

The study is structured so you will be delivering IV infusions to 2 patients. So there are a few things I want to highlight:
• First, we are not accessing your individual skills directly. Any problems that you may experienced are indicative of improvements that we need to make to the eLearning modules. The focus is on the modules and not you.
• I want to stress that the scenarios are meant to be as realistic as possible, and you should try to practice your nursing as you regularly would. For example, ensuring the eight-rights, flushing your lines, talking to the patients, infection control practices. If we ask you to do something, but you wouldn’t normally do it, just let us know.
• But there are a few areas where things will not be entirely realistic (show participant an example, if possible):
  - There will be an actor playing the role of the charge nurse. S/he is not a real nurses but rather will guide the scenarios.
  - Also, you will find that the charge nurse will micro manage your work more than normal to help guide the scenarios. In addition, when she is orienting you to a new patient, she will give you less information than you are used to since she will just focus on the information relevant to the study scenarios.
  - Also not all equipment is here, such as ventilators and other technology, because they are not required for the tasks today.
  - Today is Oct 1st, 2014

At Bedside:
  - There will be mannequins playing the role of patients.
  - There will be no real drugs used.
  - **All IV bags will be given to you pre-mixed and labelled so you are not responsible for mixing your meds.** We know that this is something you wouldn’t normally do and is part of your professional responsibility, but you can assume it is mixed properly according to the label
  - In the interest of time, IV lines will be pre-primed.
  - Also, you may find that we are condensing a lot of tasks in an unrealistic amount of time. So while we may “play” with time, we ask that you don’t. So, for example, for IV pushes please do it over the normal time you would administer it.

At foot of bed:
  - No paper chart
  - Please assume that the drug orders and instructions from charge nurse are correct.
    - Note: Also show contents of binder and various supplies here such as gloves, hand sanitizer, caps, which you can assume are clean
  - At the foot of each bed are supplies for flushing your lines, if needed.

At MOE/MAR Cart:
You are not responsible for any documentation. You don’t have to check off the items in Nursing inbox in MOE/MAR (show MOE/MAR). Your orders will be in a MOE/MAR that we have recreated but it is not the real system so has limited functionality so you can only see the orders in this view (show MOE/MAR) and scroll up and down using these buttons (show how to use mouse).

- Note: Also show other items on cart: paper and pen, formulary, calculator

Other:
- Don’t attach the iv tubing too tightly as we will need to disconnect it after the study!
- There is a clock on the wall if needed
- Please put on this lab coat and wireless microphone as they help with our recordings.
- As with the eLearning modules, please talk while you work. I am not a nurse so I want to understand why you are doing what you are! So for example, if please say things like “I am now going to the MOE/MAR to check the order. OK I see the order is…….. so now I am getting the IV bag”. I may remind you to do this as we progress.
- Also, ask before, please feel free to ask me or the charge nurse questions, but we may not directly answer them because we want to understand what you would do in this situation.

Any questions?”

Performance - Scenarios

Control Room
- Synch time on laptops with camera recording time
- Dim Lights in control room
- SimMan Controller ensures that the physiological monitor is on and working

SIMMAN CONTROL: Normal State (awaken the patient)

Nurse Actor
- Make sure all pumps are turned on and running
- All supplies ready for scenarios (e.g., flush syringes, drug syringes, new pumps and infusions, IV bags)
- Move other laptop to MOE/MAR cart. Pulls up patient’s MOE/MAR orders
Introduction – Ms Susan Chur

[Nurse Actor] “Hi ______________. It is so good to see you. We’ve just come off a crazy night shift and it is great to have you as our resource nurse today. Debbie, the nurse who was taking care of Ms. Susan Chur has just been called way, but she should be back momentarily. But if you could please cover this patient that would be great. Here’s a quick update on Ms. Susan Chur’s condition.

She is a vascular patient who had an open Abdominal Aortic Repair Aneurism done yesterday. She is 64 years old and her dry weight is 70 kg. We are about to take her to get an MRI because they are wondering about an endo leak, but things are really back-logged down there – not sure when she will go.

We are amining for a MAP of 65 so on the blue port she is getting:
  0.1 mcg/kg/min of norepinephrine
  1 unit/h of vasopressin; and
  a normal saline chaser

The CVP is on the brown port.
And her stat maintenance line for IV pushes and secondaries is on the white port.

Decrease fluids (IV push and Decrease Flow Rate) – Ms Susan Chur

[Nurse Actor] “The doctor was concerned because her weight was up and ankles swelling so he has ordered furosemide. The order is in the MOE/MAR. I prepared a furosemide syringe and it needs to be pushed in longer than one minute.

➢ Hand over IV syringe (lasix)

“The Doc also wanted the Normal Saline on the blue port dropped to 10 mL/h.”

I just got an urgent page so have to rush off but if you could please give the IV push and change the flow rate that would be great.

IV Push – Ms Susan Chur

<table>
<thead>
<tr>
<th>Furosemide (Bolus PUSH)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Order:</strong></td>
</tr>
<tr>
<td>Drug name: Furosemide</td>
</tr>
<tr>
<td>Dose: 40 mg</td>
</tr>
<tr>
<td>Vol: 4 cc in 5 cc syringe</td>
</tr>
</tbody>
</table>

Participant gives push and flush.

DY white port (3mL + 4mL + 0.39 mL) = **7.39 mL**

Note: if tries to push into CVP, say “thanks, we need to constantly monitor the CVP so please push it into the white port)
Note: if tries to disconnect the extension tubing (to push right at port), say “Thanks, but please push at the labeled stat port b/c we are trying to minimize tubing disconnections – it’s a new policy.

- Nurse Actor checks if participant is PUSHING into the med line (white port) and FLUSHING into the same port (white port), relay to control room.

Decrease Flow Rate – Ms Susan Chur

<table>
<thead>
<tr>
<th>Normal Saline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order: Change flow rate to 10 mL/h</td>
</tr>
</tbody>
</table>

SimMan Control: Drop BP (Call for help)

“The BP was alarming at the desk. What’s going on? What should we do?”

We will note what the participant says/does, but we will always then return to normal after a while

Normal State for Ms Chur (Awaken the patient)

Double Conc – Ms Susan Chur

“So I just ran into the Doc again and he would also like us to double strengthen the norepi. It is currently 8 mg in 250, but he wants her swapped to 16 mg, which is the standard here anyways. Can you please switch to the new IV concentration for her. The dose ordered hasn’t changed. The doctor said he has already put the changes into MOE/MAR. The bag has previously been spiked. But you can assume that it’s clean.

- Hand participant 16mg/250mL norepi IV bag (do not give IV set with bag)

<table>
<thead>
<tr>
<th>Norepinephrine (Double the Concentration of the Norepinephrine)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order: Drug name: Norepinephrine</td>
</tr>
<tr>
<td>Concentration: 16mg/250mL</td>
</tr>
<tr>
<td>Order: 0.0-0.35mcg/kg/min, inj-IV-cont titrate to MAP 65</td>
</tr>
<tr>
<td>Programming: VTBI: 250mL</td>
</tr>
<tr>
<td>Dose: 0.1 mcg/kg/min</td>
</tr>
<tr>
<td>Rate: 6.5 mL/h</td>
</tr>
</tbody>
</table>

- Dead volume is: 29.5 mL

Possible Responses from participants

<table>
<thead>
<tr>
<th>Concentration Change</th>
<th>Possible Responses from participant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outcome 1: “Why do you need a new IV tubing set (and/or pump)....”</td>
<td></td>
</tr>
<tr>
<td>“Can I get a new IV line (and/or pump)....”</td>
<td></td>
</tr>
<tr>
<td>Participant responds:</td>
<td></td>
</tr>
</tbody>
</table>
Introduction – Thomas Sim

Can you please help me with another patient, Mr. Thomas Sim? His nurse, Jenny, had to admit her second patient. Just one of those days….

He is 72 years old and his dry weight is 80 kg. He was admitted yesterday from the Vascular Clinic because the ward had no room but he will be transferred there later today. He has infected leg wound, has a history of alcohol use, and is diabetic, nauseous and confused. And this morning he refused to be monitored.

His vitals are stable, and he just has a single central line running NS.

IV Push (Gravol) – Mr Thomas Sim

“Mr. Sim has been complaining that he is really nauseous. There is an order of gravol. I prepared it, but haven’t yet administered it. Could you?”
Line Change (Baseline) – Susan Chur

“OK – I just bumped into Chur’s doctor and he has cancelled Susan’s MRI b/c they are taking her to the Multi-purpose OR so they will give her a CT scan while she is there instead of an MRI.

And Debbie just called me and she had to rush home because of a family emergency with her daughter. She mentioned to me that the night agency nurse started the scheduled line change. She already did the brown and white ports, but deferred doing her blue port until her pressure stabilized. I think we are pretty good now. The night agency nurses did set up all the new pumps and primed the IV tubing for the blue port. And I just made all the other changes we make this morning, such as changing over the levo to the new conc and dropping the NS..... so could you please just swap her over to these new infusions?

- Show 3 new pumps
- If not attach new infusions b/c letting mix, then accelerate time
- If she removes extension tubing, ask why

POST- EXPERIMENT DEBREIFING

☐ Go over debrief questionnaire (fill out paper questionnaire)

Debriefing Questions:
- Nurse’s general study feedback
  - Was there anything you found challenging in managing the patient(s)?
- Explore observed nurse’s actions
  - Why did you/did you not perform a task a particular way?
  - What are the potential risks associated with an observed issue?

☐ Check all paperwork done
  o Consent form
  o Pre questionnaire
  o Debrief questionnaire
  o (2 tests, if paper)
Reimbursement paperwork

- Check they have contact info for Kyle if problem with reimbursement
- Remind participant
  - Thank you
  - to not discuss with colleagues
  - return to normal TGH practices when next work

Post-experiment – Closing Tasks

- Check that the collection bags are not full
- Make sure IV poles are aligned with markings on floor
- Charge batteries
- DVD tapes
- Turn off SimMan, ambient noise track, turn off walkie talkie and wireless microphones
Appendix G: Demographics Questionnaire for Cognitive Task Analysis

Pre-Session Demographic Questionnaire

1. Participant ID:
   ____________________

2. In what age range do you belong?
   • < 25 years
   • 25-35 years
   • 35-44 years
   • 45-54 years
   • 55-64 years
   • 65+ years

3. Are you:
   • Male
   • Female

4. What best describes your role in the hospital?
   • Staff nurse
   • Nurse manager
   • Clinical trials nurse
   • Physician – Anesthesiologist
   • Physician – Other

5. How long have you been working in your current role?
   • 5-10 years
   • 11-15 years
   • 16-20 years
   • 21+ years

6. What hospital organization have you been working in over the past 5 years?
   • UHN
   • Other

7. If you work in critical care, how often do you work in the critical care on average?
   • Less than once a week
   • 1 to 2 times a week
   • 3 to 5 times a week
   • More than 5 times a week
   • NA (I do not work in critical care)
Appendix H: Definition of Cognitive Elements

**Action**
Activity that is executed
Independent of time & person

*Example:* I delivered an IV push

**Action-Deliberation**
Discussion of reasons for and against the action
Careful consideration of the action
Refers to a specific action

*Example:* After delivering it, I realized the dose might have been too high

**Anticipation**
Something you expect to happen

*Example:* I assumed that the patient’s BP would stabilize

**Appraisal**
Personal opinion or judgment
Debatable

*Example:* To be honest, I don’t like giving IV pushes

**Contingency**
Debating over options (at least 2)

*Example:* The alternative option is to give a bolus, but I prefer…

**Cue**
Triggers a cognitive element
Involves some sort of sense

*Example:* I realized the BP was dropping…

**Cue-Deliberation**
Careful consideration of the cue
Refers to a specific cue

*Example:* that alarmed me…
Goal
Purpose or objective to be reached
Overarching

Example: Patient safety comes first

Knowledge
Prior Experience
Learned concepts
Neutral facts
Generally accepted comments

Example: Norepinephrine and insulin are incompatible
We are used to giving IV pushes

Metacognition
Awareness of own knowledge/thoughts

Example: I wasn’t sure if that was right decision…
Seeing the patient, made me think I forgot to deliver it…
Appendix I: Pre- and Post-Questionnaire for Validation Phase

Questionnaire A

Q1 Participant ID: __________________________

Q2 Circle: Pre or Post

Q3. A nurse administers an intermittent drug by piggybacking it to a primary infusion running tKVO (10 mL/h). The nurse programs the secondary infusion with a volume to be infused (VTBI) of 50 mL to match the stated bag volume of 50 mL (there is no overfill). The drug has been ordered to be administered over 60 minutes so the nurse programs the infusion to be administered over a duration of 60 minutes (50mL/h) and presses start. After 60 minutes, the pump reverts to the primary infusion rate and the secondary bag is empty. What best describes what has been administered to the patient?
   a) About half of the secondary infusion has been administered
   b) About half of the secondary infusion has been administered and some of the primary infusion
   c) All of the secondary infusion has been administered and some of the primary infusion
   d) All of the secondary infusion only
   e) None of the above

Q4. A nurse administers a rate sensitive intermittent drug by piggybacking it to a primary infusion running tKVO (10 mL/h). The nurse program the secondary infusion with a volume to be infused (VTBI) of 125 mL even though the stated bag volume is 100 mL, to account for the IV tubing priming volume (25 mL). The drug has been ordered to be administered over 30 minutes so the nurse programs the infusion to be administered over a duration of 30 minutes (250ml/h). Does the patient receive the dose as ordered (i.e. over 30 minutes)?
   a) Yes, all the dose will be administered over 30 minutes
   b) No, 25 mL of the dose will remain in the primary IV tubing
   c) No, the dose will be administered faster than specified in the order
   d) No, the dose will be administered slower than specified in the order
   e) None of the above
Q5. An IV syringe push of 5 mg of drug in 5 mL is ordered to be administered over 3 minutes to avoid side effects (i.e., speed shock). The nurse administers the syringe dose slowly over 3 minutes into an IV tube that is currently infusing sodium chloride 0.9% at a slow KVO rate (see Figure 1, below). The nurse then administers a prefilled 10 mL syringe of sodium chloride 0.9% slowly over 3 minutes to flush the line. What statement best describes what has just occurred?

- f) The patient did not receive all the medication
- g) The patient received all the medication as ordered
- h) The patient received all the medication slower than ordered
- i) The patient received all the medication faster than ordered
- j) None of the above

Q6. A patient is fluid restricted, so the physician orders the concentration of a continuous infusion of Drug A to be doubled from 8 mg (in 250 mL) to 16 mg (in 250 mL) but the dose rate be maintained. The nurse disconnects the single strength concentration and attaches the double strength concentration to the same primary IV tubing and then reprograms the pump to half the rate. What best describes this scenario immediately after this change?

- f) The patient received the medication as ordered
- g) The patient received half the dose rate ordered
- h) The patient received double the dose rate ordered
- i) The patient received a temporary interruption in therapy during the bag change
- j) None of the above
Q7. A patient is connected to a CVP line and is ordered a 50 mL intermittent drug that is rate sensitive, to be infused over 30 min. The only available port to administer this drug is through the CVP line, and it is urgent that the patient receives the medication. You adjust the stopcocks appropriately and piggyback the intermittent drug on a primary infusion that was running tKVO (10 mL/h via an infusion pump) sharing the CVP line. After 20 minutes, the physician asks for a CVP measurement in order to determine patient treatment. You notice that the CVP line needs to be recalibrated. As a nurse, what best describes what you should do next?

a) Flush the line (via the CVP transducer pull tab) before reading the CVP measurement on the monitor
b) Readjust the stopcocks, flush the line (via the CVP transducer), then read the CVP measurement on the monitor
c) Pause the secondary infusion, readjust the stopcocks, flush the line (via the CVP transducer), then read the CVP measurement on the monitor
d) Wait 10 minutes, readjust the stopcocks, flush the line (via the CVP transducer), then read the CVP measurement on the monitor
e) None of the above

Q8. In the scenario in Figure 2 (below), which of the following best describes the exact delivery of Drug A received by the patient immediately after the flow rate to Drug B is increased?

Old flow rates:
Drug A: 25 mL/h
Drug B: 5 mL/h

New flow rates:
Drug A: 25 mL/h
Drug B: 15 mL/h

f) Dose rate of drug A increases and then returns to the intended dose rate
g) Dose rate of drug A steadily increases and then stabilizes at a higher dose rate than intended
h) Dose rate of drug A decreases and then returns to the intended dose rate
i) Dose rate of drug A is unaffected by the change
j) None of the above
Q9. In the scenario described in the previous question (question 8 and Figure 3 below), which statement best describes the exact delivery of drug B after the change?

<table>
<thead>
<tr>
<th>Old flow rates</th>
<th>New flow rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drug A: 25 mL/h</td>
<td>Drug A: 25 mL/h</td>
</tr>
<tr>
<td>Drug B: 5 mL/h</td>
<td>Drug B: 15 mL/h</td>
</tr>
</tbody>
</table>

Figure 3

a) Dose rate of drug B steadily increases and then stabilizes at a higher dose rate than intended
b) Dose rate of drug B briefly decreases and then returns to the intended dose rate
c) Dose rate of drug B immediately increases to the intended rate
d) Dose rate of drug B is lower than intended for a few minutes and then stabilizes to the new dose rate
e) None of the above
Q10. A nurse has been asked to add another vasoactive drug (Drug E) to the setup in Figure 4 (below). Where should the nurse add Drug E?

Figure 4

f) At ① or ②; it doesn’t matter
g) At ①
h) At ②
i) Neither ① or ②
ej) Depends on when the IV tubings are next scheduled for change

Q11. A critically ill patient is connected to two life-sustaining drugs (with short half-lives) programmed at 4 mL/h and 6 mL/hr, and a normal saline line at 5mL/hr for a combined flow rate of 15mL/hr through a multi-port connector (priming volume = 1mL) into a central line. A nurse is asked to perform a line change in which all the IV tubing, multi-port connector, and bags need to be replaced. A nurse decides to setup the new infusions on a new bank of pumps to minimize interruptions in therapy and completes the following (in listed order):

–Primes each new IV tubing, inserts tubing into pumps and programs the pumps
–Primes a new multiport connector with a prefilled flush syringe and attaches the new IV tubing
–Starts the pumps and immediately swaps over the old connector (and tubing) for the new connector (and tubing) as quickly as possible.

What would occur immediately after the line change?

a) Patient is stable; the line change was completed as per best practice
b) Patient is unstable even though the line change was completed as per best practice
c) Patient is unstable because there is an interruption in therapy for a few seconds (i.e. time from disconnecting and then reconnecting the infusions)
d) Patient is unstable because there is about a 15 minute interruption in therapy
e) Pump is alarming because of an occlusion below the pump
**Questionnaire B**

**Q1 Participant ID: __________________________**

**Q2 Circle: Pre or Post**

**Q3.** A nurse administers an intermittent drug by piggybacking it to a primary infusion running tKVO (10 mL/h). The nurse programs the secondary infusion with a volume to be infused (VTBI) of 100 mL to match the stated bag volume of 100 mL (there is no overfill). The drug has been ordered to be administered over 30 minutes so the nurse programs the infusion to be administered over a duration of 30 minutes (200mL/h) and presses start. After 30 minutes, the pump reverts to the primary infusion rate and the secondary bag is empty. What best describes what has been administered to the patient?

   a) About half of the secondary infusion has been administered and some of the primary infusion  
   b) About a quarter of the secondary infusion has still not been administered  
   c) All of the secondary infusion has been administered and some of the primary infusion  
   d) All of the secondary infusion only  
   e) None of the above

**Q4.** A nurse administers a rate sensitive intermittent drug by piggybacking it to a primary infusion running tKVO (10 mL/h). The nurse program the secondary infusion with a volume to be infused (VTBI) of 75 mL even though the stated bag volume is 50 mL to account for the IV tubing priming volume (25 mL). The drug has been ordered to be administered over 15 minutes so the nurse programs the infusion to be administered over a duration of 15 minutes (300mL/h). Does the patient receive the dose as ordered (i.e. over 15 minutes)?

   a) Yes, all the dose will be administered over 60 minutes  
   b) No, 25 mL of the dose will remain in the primary IV tubing  
   c) No, the dose will be administered faster than specified in the order  
   d) No, the dose will be administered slower than specified in the order  
   e) None of the above
Q5. An IV syringe push of 3 mg of drug in 3 mL is ordered to be administered over 5 minutes to avoid side effects (i.e., speed shock). The nurse administers the dose slowly over 5 minutes into an IV tube that is currently infusing sodium chloride 0.9% at a slow KVO rate (see Figure 1, below). The nurse then titrates the infusion pump to 100 mL/h for 5 minute (8.3 mL) to flush the line. What statement best describes what has just occurred?

Figure 1

f) The patient received all the medication as ordered  
g) The patient did not receive all the medication  
h) The patient received all the medication slower than ordered  
i) The patient received all the medication faster than ordered  
j) None of the above

Q6. A patient is fluid restricted, so the physician orders the concentration of a continuous infusion of Drug A to be doubled from 4 mg (in 100 mL) to 8 mg (in 100 mL) but the dose rate be maintained. The nurse disconnects the single strength concentration and attaches the double strength concentration to the same primary IV tubing and then reprograms the pump to half the rate. What best describes this scenario immediately after this change?

f) The patient received a temporary interruption in therapy during the bag change  
g) The patient received half the dose rate ordered  
h) The patient received double the dose rate ordered  
i) The patient received the medication as ordered  
j) None of the above
Q7. A patient is connected to a CVP line and is ordered a 75 mL intermittent drug that is rate sensitive, to be infused over 1 hour. The only available port to administer this drug is through the CVP line, and it is urgent that the patient receives the medication. You adjust the stopcocks appropriately and piggyback the intermittent drug on a primary infusion that was running tKVO (10 mL/h via an infusion pump) sharing the CVP line. After 45 minutes, the physician asks for a CVP measurement in order to determine patient treatment. You notice that the CVP line needs to be recalibrated. As a nurse, what best describes what you should do next?
   a) Flush the line (via the CVP transducer pull tab) before reading the CVP measurement on the monitor  
   b) Readjust the stopcocks, flush the line (via the CVP transducer), then read the CVP measurement on the monitor  
   c) Pause the secondary infusion, readjust the stopcocks, flush the line (via the CVP transducer), then read the CVP measurement on the monitor  
   d) Wait 15 minutes, readjust the stopcocks, flush the line (via the CVP transducer), then read the CVP measurement on the monitor  
   e) None of the above

Q8. In the scenario in Figure 2 below, which of the following best describes the exact delivery of Drug A received by the patient immediately after the flow rate to Drug B is decreased?

<table>
<thead>
<tr>
<th>Old flow rates</th>
<th>New flow rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drug A: 25 mL/h</td>
<td>Drug A: 25 mL/h</td>
</tr>
<tr>
<td>Drug B: 15 mL/h</td>
<td>Drug B: 5 mL/h</td>
</tr>
</tbody>
</table>

Figure 2

a) Dose rate of drug A increases and then returns to the intended dose rate  
   b) Dose rate of drug A steadily increases and then stabilizes at a higher dose rate than intended  
   c) Dose rate of drug A decreases and then returns to the intended dose rate  
   d) Dose rate of drug A is unaffected by the change  
   e) None of the above
Q9. In the scenario described in the previous question (question 8 and Figure 3 below), which statement best describes the exact delivery of drug B after the change?

- **Old flow rates**
  - Drug A: 25 mL/h
  - Drug B: 15 mL/h

- **New flow rates**
  - Drug A: 25 mL/h
  - Drug B: 5 mL/h

**Figure 3**

- a) Dose rate of drug B steadily decreases and then stabilizes at a higher dose rate than intended
- b) Dose rate of drug B briefly increases and then returns to the intended dose rate
- c) Dose rate of drug B immediately decreases to the intended rate
- d) Dose rate of drug B is higher than intended for a few minutes and then stabilizes to the new dose rate
- e) None of the above
**Q10.** A nurse has been asked to add another sedative drug (Drug E) to the setup in Figure 4 (below). Where should the nurse add Drug E?

![Figure 4](image)

**Figure 4**

- f) At ① or ②; it doesn’t matter
- g) At ①
- h) At ②
- i) Neither ① or ②
- j) Depends on when the IV tubings are next scheduled for change

**Q11.** A critically ill patient is connected to two life-sustaining drugs (with short half-lives) programmed at 2 mL/h and 5 mL/hr, and a normal saline line at 5 mL/hr for a combined flow rate of 12 mL/hr through a multi-port connector (priming volume = 1mL) into a central line. A nurse is asked to perform a line change in which all the IV tubing, multi-port connector, and bags need to be replaced. A nurse decides to setup the new infusions on a new bank of pumps to minimize interruptions in therapy and completes the following (in listed order):
  - Primed each new IV tubing, inserts tubing into pumps and programs the pumps
  - Primed a new multiport connector with a prefilled flush syringe and attaches the new IV tubing
  - Starts the pumps and immediately swaps over the old connector (and tubing) for the new connector (and tubing) as quickly as possible.

What would occur immediately after the line change?

- a) Patient is stable; the line change was completed as per best practice
- b) Patient is unstable even though the line change was completed as per best practice
- c) Patient is unstable because there is an interruption in therapy for a few seconds (i.e. time from disconnecting and then reconnecting the infusions)
- d) Patient is unstable because there is about a 30 minute interruption in therapy
- e) Pump is alarming because of an occlusion below the pump
Appendix J: Experimental Protocol and Script for Validation Phase

General Roles

Person 1

- Meet and greet participant, introduce participant to study and lab
- Facilitation
- Note taking in observation room

Person 2

- Cameras
- Sim Man Control
- Note taking?
- Set-up of labs between protocols

Person 3

- Nurse Actor
PRE-EQUIPMENT SET-UP

Scenario Setup

Lab
- Bring up orders on MOE/MAR computer
- Adjust MOE/MAR cart height for participant
- Paper, pen, pencil, calculator on MOE/MAR cart
- Bring out bins with meds
- Check flush supplies at the bedside
- Check IV collection bags
- Laptop and extension cord (plug in laptop)
- Make sure tubing is primed and IV bags are full
- Garbage can at each bedside
- Start pumps
- Small poster in a visible area to (a) ensure the participant that they are in the correct location for the study and (b) extension to contact study coordinator when they reach the center.
- Check that the drip chambers for all IV sets are not full

Control Room
- Easel pad (write participant name, ID for each experiment, condition number)
- Laptops
- Synch time on laptops with camera recording time
- Put do not disturb signs on lab and control room doors
- Telephone
- SIM Man Controller on
- Replace batteries (Walkie-Talkie, Pager)

Nurse Actor
- Wireless microphone
- Walkie Talkie
- Scrubs and ID badge

Consent Table Set-up
- Have paper questionnaires? (pretest, posttest, debrief)
- Consent forms x2
- Chequebook and/or cheque req
- Receipts (Participant and HTSRT)
- Sign on to computer and bring up demographic questionnaire (and pre/post education test?)
- Lab coat for participant
- Drinks/snacks and water
- Wireless microphone (on Table)
- Laptop
Patient Setup

Pre-experiment Set-up: Ms. Susan Chur

PATIENT
- IV access points:
  - Triple Lumen Catheter - Right Internal Jugular Vein (IJ)
    - Brown port:
      - Central Venous Pressure (CVP) Transducer (ICU) or locked (Floor RN)
      - Blue port (with extension set and Bridge):
        - Normal Saline
        - Vasopressin
        - Norepinephrine (Levo)
      - Proximal Line (with extension set): Med Line
        - Normal Saline

- Wig
- Armband
- 10 cc IV flush syringe
- New multiport bridge

EQUIPMENT SET-UP
- Physiological monitor

Bags:

<table>
<thead>
<tr>
<th>Infusion</th>
<th>Bag volume and type</th>
<th>Number</th>
<th>Label</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVP – brown port</td>
<td>1000 mL NS</td>
<td>1</td>
<td>NA</td>
</tr>
<tr>
<td>Normal Saline – blue port</td>
<td>1000 mL NS</td>
<td>2</td>
<td>NA</td>
</tr>
<tr>
<td>Vasopressin – blue port</td>
<td>100 mL NS</td>
<td>2</td>
<td>RN Med Added: 40 units in 100 mL</td>
</tr>
<tr>
<td>Norepi – blue port</td>
<td>250 mL D5W</td>
<td>4 (1 initial, 2 conc change, 1 line change)</td>
<td>Rx label: 8 mg in 250 mL</td>
</tr>
<tr>
<td>Normal Saline – white port</td>
<td>1000 mL NS</td>
<td>1</td>
<td>NA</td>
</tr>
</tbody>
</table>

Bin:
- Furosemide/Lasix: 5 mL syringe (w 4mL) + med added label
- 16 mg in 250 D5W norepi
- primed primary Iv tubing
- extension set

Initial Pump programming

On patient:

<table>
<thead>
<tr>
<th>Infusion</th>
<th>VTBI</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Saline – blue port</td>
<td>1000</td>
<td>25 ml/h</td>
</tr>
<tr>
<td>Vasopressin – blue port</td>
<td>100</td>
<td>2.5 mL/h (1 unit/h)</td>
</tr>
<tr>
<td>Norepi (8mg) – blue port</td>
<td>250</td>
<td>13 mL/h (0.1 mcg/kg/min)</td>
</tr>
<tr>
<td>Normal Saline – white port</td>
<td>1000</td>
<td>10 mL/h</td>
</tr>
</tbody>
</table>

Off to side:

Pole #1

<table>
<thead>
<tr>
<th>Infusion</th>
<th>VTBI</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Saline – blue port</td>
<td>1000</td>
<td>10 ml/h</td>
</tr>
<tr>
<td>Vasopressin – blue port</td>
<td>100</td>
<td>2.5 mL/h (1 unit/h)</td>
</tr>
</tbody>
</table>
Norepi (16 mg) – blue port | 250 | 6.5 mL/h (0.1 mcg/kg/min)

Pole #2

<table>
<thead>
<tr>
<th>Infusion</th>
<th>VTBI</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norepi (16 mg)</td>
<td>0</td>
<td>999 mL/h</td>
</tr>
</tbody>
</table>

Pre-experiment Set-up: Ms. Carrie Woods

**PATIENT**

- IV access points:
  - Triple Lumen Catheter - Right Internal Jugular Vein (IJ)
    - Brown port:
      - Central Venous Pressure (CVP) Transducer (ICU) or locked (Floor RN)
      - Blue port (with extension set and Bridge):
        - Normal Saline
        - Vasopressin
        - Norepinephrine (Levo)
    - Proximal Line (with extension set): Med Line
      - Normal Saline
      - Cefazolin (Ancef)

- Wig
- Airband
- 10 cc IV flush syringe
- New multiport bridge

**EQUIPMENT SET-UP**

**Bags:**

<table>
<thead>
<tr>
<th>Infusion</th>
<th>Bag volume and type</th>
<th>Number</th>
<th>Label</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVP – brown port</td>
<td>1000 mL NS</td>
<td>1</td>
<td>NA</td>
</tr>
<tr>
<td>Normal Saline – blue port</td>
<td>1000 mL NS</td>
<td>2</td>
<td>NA</td>
</tr>
<tr>
<td>Vasopressin – blue port</td>
<td>100 mL NS</td>
<td>2</td>
<td>RN Med Added: 40 units in 100 mL</td>
</tr>
<tr>
<td>Norepi – blue port</td>
<td>250 mL D5W</td>
<td>4</td>
<td>Rx label: 8 mg in 250 mL</td>
</tr>
<tr>
<td>Normal Saline – white port</td>
<td>1000 mL NS</td>
<td>1</td>
<td>NA</td>
</tr>
<tr>
<td>Ancef – white port</td>
<td>50 mL NS (empty)</td>
<td>1</td>
<td>Ancef label</td>
</tr>
</tbody>
</table>

**Bin:**

- Diazepam: IV Push Syringe (Rate Sensitive) – 10mg in 5cc

**Initial Pump programming**

**On patient:**

<table>
<thead>
<tr>
<th>Infusion</th>
<th>VTBI</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Saline – blue port</td>
<td>1000</td>
<td>25 mL/h</td>
</tr>
<tr>
<td>Vasopressin – blue port</td>
<td>100</td>
<td>2.5 mL/h (1 unit/h)</td>
</tr>
<tr>
<td>Norepi (8mg) – blue port</td>
<td>250</td>
<td>13 mL/h (0.1 mcg/kg/min)</td>
</tr>
<tr>
<td>Normal Saline – white port</td>
<td>1000</td>
<td>10 mL/h</td>
</tr>
<tr>
<td>Ancef – white port</td>
<td>50mL</td>
<td>200 mL/h (1g/50mL)</td>
</tr>
</tbody>
</table>

**Off to side:**

Pole #1
<table>
<thead>
<tr>
<th>Infusion</th>
<th>VTBI</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Saline – blue port</td>
<td>1000</td>
<td>10 ml/h</td>
</tr>
<tr>
<td>Vasopressin – blue port</td>
<td>100</td>
<td>2.5 mL/h (1 unit/h)</td>
</tr>
<tr>
<td>Norepi (8 mg) – blue port</td>
<td>250</td>
<td>13 mL/h (0.1 mcg/kg/min)</td>
</tr>
</tbody>
</table>

Pre-experiment Set-up: Mr. Andrew Wigg

**PATIENT**

- IV access points:
  - Cordis - Right Internal Jugular Ven (IJ)
    - Port A:
      - Capped
    - Port B (connected to bridge):
      - Propofol
      - Normal saline
      - Norepi (Levo)

- Wig
- Armband

**EQUIPMENT SET-UP**

- Physiological monitor

**Bags:**

<table>
<thead>
<tr>
<th>Infusion</th>
<th>Bag volume and type</th>
<th>Number</th>
<th>Label</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fentanyl</td>
<td>100 mL NS</td>
<td>1</td>
<td>2000mcg in 100cc</td>
</tr>
<tr>
<td>Versed</td>
<td>50 mL NS</td>
<td>1</td>
<td>50mg in 50cc</td>
</tr>
<tr>
<td>Normal Saline</td>
<td>1000 mL NS</td>
<td>1</td>
<td>NA</td>
</tr>
<tr>
<td>Norepinephrine</td>
<td>250 mL D5W</td>
<td>1</td>
<td>Rx label: 8 mg in 250 mL</td>
</tr>
<tr>
<td>Propofol</td>
<td>100 mL bottle</td>
<td>1</td>
<td>1000mg / 100 mL</td>
</tr>
</tbody>
</table>

**Bin:**

- Fentanyl Bag (2000mcg/100cc) – 10mL/h (200mcg/h)
- Midazolam (Versed) 50mg/50cc – 4 mL/h (0.05 mg/kg/hr → 4 mg/h)

**Initial Pump programming**

**On patient:**

<table>
<thead>
<tr>
<th>Infusion</th>
<th>VTBI</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Saline</td>
<td>1000</td>
<td>25 ml/h</td>
</tr>
<tr>
<td>Propofol (1000mg)</td>
<td>100</td>
<td>2.5 mL/h (5.1 mcg/kg/min) (25mg/h)</td>
</tr>
<tr>
<td>Norepi (?mg)</td>
<td>250</td>
<td>15 mL/h (0.1 mcg/kg/min)</td>
</tr>
</tbody>
</table>

- IV access points:
- Armbands
Orientation

Meet and greet participant

**Location:** Main office area and innovation lab hallway

“Hi _____________________, welcome to the centre! My name is ________________ and I’m one of the study coordinators for the multiple IV infusion study. How are you? [Small talk ... i.e. did you have any problems finding the center etc?] We are really happy that you’re able to participate in this study. Have you ever been to center before? No? All right, let me give you a quick summary of what goes on here.”

Introduction to the study and the lab

**Lead participant into innovation lab hallway toward lab**

[While walking to lab give quick summary of the center]

“So, [Name of Participant] this center was created to improve healthcare for people through safe, usable and effective technologies and processes. A key component of our work is to conduct usability simulation studies on new products so we can understand potential safety and usability issues prior to roll-out. We often require the help of front-line nurses because it is your issues we want to learn about! By understanding your needs we can hopefully can create products that effectively support you and improve patient.”

Okay, so here is the lab that you will be working in this morning/afternoon. Why don’t we sit down right over there and get some paperwork out of the way.

Explanation of consent form and signing of the consent form

“OK – the first thing we should do is review the consent form. I believe Kyle sent it to you previously.

☐ Have you had a chance to read it? If not, ask if want some time to read it
☐ Paraphrase key pieces of info

• Purpose: Today we will be looking at how we can improve the design and content of some eLearning modules. So to do this, we want to get your feedback and evaluate the effectiveness of the modules since you are the expert.
• Study Background:
• Procedure:
  o Perform a few IV tasks in this simulated environment while I observe behind the one-way mirror, which prevents me from distracting you when you are completing the tasks
  o Complete a written test
  o Watch the modules and get your feedback as you go on everything from how the information is present, how you navigate through the modules, graphics, and so on.
- A second test and
- Perform another few IV tasks in this simulated environment
- Then at then end, we will sit back down here and I will ask you a few questions to get your final thoughts about the modules

**Confidentiality:**
- All information obtained will be held strictly confidential and we will only report on the data collected at an aggregate level. In fact, in all our notes, you are simply going to be a number so nothing will be tied to your name!

**Voluntary:** Your participation is voluntary and may withdraw at any time

**Reimbursement:** You will receive $165 to compensate you for you time in participating in this study

**Video taped:**
- This session will be videotaped and audio taped just in case I miss anything after the session is completed.
- If we share your video clips for educational purposes, for example in a presentation, your face will be blurred and audio altered. Can consent to this separately

- Do you have any questions?
- Participant and Coordinator signs two copies (one copy to participant and another for coordinator)
- Put on microphones and lab coats (participant and you)

### Background Questionnaire

“Okay, now that all the paper work is taken care of, I would like you to complete a short background questionnaire.”

- Participant completes background questionnaire

### Performance - Introduction

So now let’s do a few IV-related tasks.

The study is structured so you will be delivering IV infusions to 2 patients. So there are a few things I want to highlight:

- **First**, we are not accessing your individual skills directly. Any problems that you may experienced are indicative of improvements that we need to make to the eLearning modules. The focus is on the modules and not you.
- **I want to stress that** the scenarios are meant to be as realistic as possible, and you should try to practice your nursing as you regularly would. For example, ensuring the eight-rights, flushing your lines, talking to the patients, infection control practices. If we ask you to do something, but you wouldn’t normally do it, just let us know.
- **But there are a few areas where** things will not be entirely realistic (show participant an example, if possible):
  - There will be an actor playing the role of the charge nurse. S/he is not a real nurse but rather will guide the scenarios.

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Also, you will find that the charge nurse will micro manage your work more than normal to help guide the scenarios. In addition, when she is orienting you to a new patient, she will give you less information than you are used to since she will just focus on the information relevant to the study scenarios.

Also not all equipment is here, such as ventilators and other technology, even though some patients described in the scenarios would normally have them.

Today is Oct 1st, 2014

At Bedside:
- There will be mannequins playing the role of patients.
- There will be no real drugs used.
- All IV bags will be given to you pre-mixed and labelled so you are not responsible for mixing your meds. We know that this is something you wouldn’t normally do and is part of your professional responsibility, but you can assume it is mixed properly according to the label.
- In the interest of time, IV lines will be pre-primed.
- Also, you may find that we are condensing a lot of tasks in an unrealistic amount of time. So while we may “play” with time, we ask that you don’t. So, for example, for IV pushes please do it over the normal time you would administer it.

At foot of bed:
- No paper chart
- Please assume that the drug orders and instructions from charge nurse are correct.
  - Note: Also show contents of binder and various supplies here such as gloves, hand sanitizer, caps, which you can assume are clean
- At the foot of each bed are supplies for flushing your lines, if needed.

At MOE/MAR Cart:
- You are not responsible for any documentation. You don’t have to check off the items in Nursing inbox in MOE/MAR (show MOE/MAR). Your orders will be in a MOE/MAR that we have recreated but it is not the real system so has limited functionality so you can only see the orders in this view (show MOE/MAR) and scroll up and down using these buttons (show how to use mouse).
  - Note: Also show other items on cart: paper and pen, formulary, calculator

Other:
- Don’t attach the iv tubing too tightly as we will need to disconnect it after the study!
- There is a clock on the wall if needed
- Please put on this lab coat and wireless microphone as they help with our recordings.
- As with the eLearning modules, please talk while you work. I am not a nurse so I want to understand why you are doing what you are! So for example, if please say things like “I am now going to the MOE/MAR to check the order. OK I see the order is……... so now I am getting the IV bag”. I may remind you to do this as we progress.
- Also, ask before, please feel free to ask me or the charge nurse questions, but we may not directly answer them because we want to understand what you would do in this situation.

Any questions?”
Pre-Performance - Scenarios

**Control Room**
- Synch time on laptops with camera recording time
- Dim Lights in control room
- SimMan Controller ensures that the physiological monitor is on and working

**SIMMAN CONTROL: Normal State (awaken the patient)**

**Nurse Actor**
- Make sure all pumps are turned on and running
- All supplies ready for scenarios (e.g., flush syringes, drug syringes, new pumps and infusions, IV bags)
- Move other laptop to MOE/MAR cart. Pulls up patient’s MOE/MAR orders
Task Set-Up Required

- Get Norepi 16mg/250mL from Andrew Wigg into Susan Chur’s bin
- Get Vaso 40mg/250mL from Susan Chur’s bucket and hang onto the vaso line
- Blue Port
  - Vaso – Rate: 2.5mL/h; VTBI: 50mL
  - Norepi – Rate: 13mL/h; VTBI: 250mL
    - Use 8mg in 250mL bag
  - Normal Saline – Rate: 30mL/h; VTBI: 500mL
- Rip off label from pump in the back
- On the single pump, use norepi bag that says 16mg/250mL bag

Introduction – Ms Susan Chur

[Nurse Actor] “Hi _______________. It is so good to see you. We’ve just come off a crazy night shift and it is great to have you as our resource nurse today. Debbie, the nurse who was taking care of Ms. Susan Chur has just been called away, but she should be back momentarily. But if you could please cover this patient that would be great. Here’s a quick update on Ms. Susan Chur’s condition.

She is a vascular patient who had an open Abdominal Aortic Repair Aneurism done yesterday. She is 64 years old and her dry weight is 70 kg. We are about to take her to get an MRI because they are wondering about an endo leak, but things are really back-logged down there – not sure when she will go.

We are aiming for a MAP of 65 so on the blue port she is getting:
  - 0.1 mcg/kg/min of norepinephrine
  - 1 unit/h of vasopressin; and
  - a normal saline chaser

The CVP is on the brown port.
And her stat and medication is on the white port.

Before we give you any of the tasks, is there anything in particular about the current set-up that may affect your decision-making?

Decrease fluids (IV push and Decrease Flow Rate) – Ms Susan Chur

[Nurse Actor] “The doctor was concerned because her weight was up and ankles swelling so he has ordered furosemide. The order is in the MOE/MAR. I prepared a furosemide syringe and it needs to be pushed in longer than one minute.

➢ Hand over IV syringe (lasix)

“The Doc also wanted the Normal Saline on the blue port dropped to 10 mL/h.”
I just got an urgent page so I have to rush off but if you could please give the IV push and change the flow rate that would be great.

1.1.1.1 IV Push – Ms Susan Chur

<table>
<thead>
<tr>
<th>Furosemide (Bolus PUSH)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Order:</strong></td>
</tr>
<tr>
<td>Drug name: Furosemide</td>
</tr>
<tr>
<td>Dose: 40 mg</td>
</tr>
<tr>
<td>Vol: 4 cc in 5 cc syringe</td>
</tr>
</tbody>
</table>

**Participant gives push and flush.**

**DV white port (3mL + 4mL +0.39 mL) = 7.39 mL**

*Note: if tries to push into CVP (brown port line), say “thanks, we need to constantly monitor the CVP so please push it into the white port)*

*Note: if tries to disconnect the extension tubing (to push right at port), say “thanks, but please push at the labeled stat port because we are trying to minimize tubing disconnections to reduce risk of infection.*

- Nurse Actor checks if participant is PUSHING into the med line (white port) and FLUSHING into the same port (white port), relay to control room.

[While she is delivering the push] Is there anything you are thinking about while you are delivering the push?

1.1.1.2 Decrease Flow Rate – Ms Susan Chur

<table>
<thead>
<tr>
<th>Normal Saline</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Order:</strong></td>
</tr>
<tr>
<td>Change flow rate to 10 mL/h</td>
</tr>
</tbody>
</table>

**SimMan Control: Drop BP (Call for help)**

“The BP was alarming at the desk. What’s going on? What should we do?”

*We will note what the participant says/does, but we will always then return to normal after a while*

**Normal State for Ms Chur (Awaken the patient)**

1.1.1.3 Double Conc – Ms Susan Chur

“So I just ran into the Doc again and he would also like us to double the concentration of norepinephrine. It is currently 8 mg in 250, but he wants her swapped to 16 mg, which is the standard here anyway. Can you please switch to the new concentration for her? The dose ordered hasn’t changed. The doctor said he has already put the
changes into MOE/MAR. The bag has previously been spiked. But you can assume that it’s clean.

- Hand participant 16mg/250mL norepi IV bag (do not give IV set with bag)

<table>
<thead>
<tr>
<th>Norepinephrine (Double the Concentration of the Norepinephrine)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Order:</strong> Drug name: Norepinephrine</td>
</tr>
<tr>
<td>Concentration: 16mg/250mL</td>
</tr>
<tr>
<td>Order: 0.0-0.35mcg/kg/min, IV-cont titrate to MAP 65</td>
</tr>
<tr>
<td><strong>Programming:</strong> VTBI: 250mL</td>
</tr>
<tr>
<td>Dose: 0.1 mcg/kg/min</td>
</tr>
<tr>
<td>Rate: 6.5 mL/h</td>
</tr>
</tbody>
</table>

- dead volume is: 29.5 mL

Possible Responses from participants

<table>
<thead>
<tr>
<th>Concentration Change</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Outcome 1:</strong></td>
<td>“Why do you need a new IV tubing set (and/or pump)....”</td>
</tr>
<tr>
<td>“Can I get a new IV line (and/or pump)&quot;</td>
<td>Participant responds:</td>
</tr>
<tr>
<td>Note: provide only what asked (i.e., tubing vs pump)</td>
<td>“Oh yeah, of course – I forgot that I had already started to do this. Here is a new pump and IV tubing and bag, primed with the new conc”</td>
</tr>
<tr>
<td>After change flow rate and connect to pt:</td>
<td>SimMan Control: Drop BP (Call for help)</td>
</tr>
<tr>
<td>“What’s going on? What should we do?”</td>
<td>We will note what the participant says/does, but we will always then return to normal after a while</td>
</tr>
<tr>
<td>Normal State for Ms Chur (Awaken the patient)</td>
<td></td>
</tr>
<tr>
<td><strong>Outcome 2:</strong></td>
<td>After the participant finish programming and start the norepinephrine infusion:</td>
</tr>
<tr>
<td>Swap bags (reuses tubing) and decreases the original flow rate to half (6.5mL/h)</td>
<td>SimMan Control: Drop BP (Call for help)</td>
</tr>
<tr>
<td>“What’s going on? What should we do?”</td>
<td>We will note what the participant says/does, but we will always then return to normal after a while</td>
</tr>
<tr>
<td>Normal State for Ms Chur (Awaken the patient)</td>
<td></td>
</tr>
<tr>
<td><strong>Outcome 3:</strong></td>
<td>After the participant swaps the bags:</td>
</tr>
<tr>
<td>Swaps bags (reuses IV tubing) and keep the original flow rate</td>
<td>Are you all done, it looks like the rate is the same (or it looks like the rate is a little lower than before)?”</td>
</tr>
<tr>
<td>See if she Understands DV with conc change</td>
<td></td>
</tr>
</tbody>
</table>
Line Change (Baseline) – Susan Chur

“OK – I just bumped into Chur’s doctor and he has cancelled Susan’s MRI because they are taking her to the Multi-purpose OR so they will give her a CT scan while she is there instead of an MRI.

And Debbie just called me and she had to rush home because of a family emergency with her daughter. She mentioned to me that the night agency nurse started the scheduled line change. She already did the brown and white ports, but deferred doing her blue port until her pressure stabilized. I think we are pretty good now. The night agency nurses did set up all the new pumps and primed the IV tubing for the blue port. And I just made all the other changes we make this morning, such as changing over the norepinephrine to the new conc and dropping the NS... so could you please just swap her over to these new infusions?

- Show 3 new pumps
- If not attach new infusions b/c letting mix, then accelerate time
- If she removes extension tubing, ask why

[While she is changing the lines, if she mixes the drugs] Why are you mixing the drugs in the bridge? How do you determine how long you need to mix the drugs? What is this based on?

Knowledge Test #1

“Okay, now here are 11 questions we would greatly appreciate you answering so we can evaluate what you know now compared to after watching the eLearning modules to see if they were effective. We will give you about 10 minutes to complete. Just let me know if you are done early.
So the first 2 questions are just for us....and then you will answer 9 questions, but since the numbering for you starts at 3, it will go to 11”
Please don’t navigate backwards as you do the test.
Please talk as you go if you are comfortable doing so as this can help me understand what you are thinking.

☐ Participant completes Test #1

ITT Review

“Okay, so now let get to the modules. There are 2 separate modules, and each are about 15 min long, and they are still in draft form. And our approach is to get end user feedback as early as possible before we start to finalize the products. So some things are still missing or need refinement. I am going to go behind the one-way mirror and talk to you over the speaker, which we will just test out before you start watching the modules.
Then, I will ask you to please watch the modules but as you go, if there is anything that isn’t clear to you, or may be an issue, or if you aren’t sure what to do next, please just let me know. 
I will also ask you to stop at key points to get your feedback. And please remember, if you are having problems then please tell me because these are the sort of things we want to find out b/c if you are having them then so will others! 
And sometimes if you ask me a question, I may redirect it back to you or not fully answer it, and this is not because I am trying to be difficult, but rather b/c I want to see what you would do if I wasn’t here”

- Watch ITTs

Knowledge Test #2

“Okay, now please complete another set of 9 questions. As before, we will give you about 10 minutes to complete, but just let me know if you are done early.”

- Participant completes Test #2

Post-performance - Scenarios

Task Set Up for Andrew Wigg

- Propofol attached to bridge
- Propofol rate = 2.5mL/h; VTBI = 35mL
- Normal saline rate = 10 mL/h; VTBI = 900 mL.
- Norepinephrine (levo) = 7.6 mL/h; VTBI = 240 mL

Not connected (hiding in the back)

- Fentanyl = 999mL/h; VTBI = 999mL
- Versed = 999mL/h; VTBI = 999mL

Task Set Up for Carrie Woods

- Flush Syringe, and bridge on table
- Blue Port – Three Pumps
  - 20 units in 100mL of Vasopressin; Rate: 5mL/h; VTBI: 45mL
  - 16mg in 250ml of Norepi; Rate: 6.5mL/h; VTBI: 240mL
  - Normal Saline; Rate: 10mL/h; VTBI: 500mL
- White Port – One Pump
  - Normal Saline; Rate: 10mL/h; VTBI: 500mL

Not connected (hiding in the back)

- Vasopressin - Rate: 2.5mL, VTBI: 50
- Norepi - Rate: 6.5mL, VTBI: 250
- Normal Saline – Rate: 10mL, VTBI: 500

- Alone pump – Rate: 999mL, VTBI: 999mL
Introduction – Ms Carrie Woods – Line Change

[Nurse Actor] “Hi _____________. It is so good to see you. We’ve just come off a crazy night shift and it is great to have you as our resource nurse today.

Here’s a quick update on Ms. Carrie Woods’ condition.

Overview of Carrie Woods

She is a patient who came in with renal failure and developed aspiration pneumonia. She is 68 years old and her dry weight is 70 kg.

We are aiming for a MAP of 65 so on the blue port she is getting:
- 0.1 mcg/kg/min of norepinephrine
- 1 unit/h of vasopressin; and
- a normal saline chaser

The CVP is on the brown port.

Her stat maintenance line for IV pushes is on the white port. She is also receiving an infusion of Ancef as a secondary medication.

Shelby, the nurse who was taking care of Ms. Carrie Woods has just left, but she forgot to perform Carrie’s tubing change on the blue port. She already did the brown and white ports, but deferred doing her blue port until her pressure stabilized. I think we are pretty good now. She has found all the new pumps and primed the IV tubings for the infusions connected to the blue port. Could you please just swap her over to these new infusions?

Shot of 3 pumps
Shot of bridge connector

[While she is changing the lines, if she mixes the drugs] Why are you mixing the drugs in the bridge? How do you determine how long you need to mix the drugs? What is this based on?

- Show 3 new pumps
- If not attach new infusions b/c letting mix, then accelerate time
- Ask why they need to mix the infusions

Introduction – Mr. Andrew Wigg

Can you please help me with another patient, Mr. Andrew Wigg? His nurse, Carly, had to admit her second patient.

He is 54 years old and his dry weight is 81 kg. He recently had a pulmonary thoracic embolus removed from his pulmonary artery. He’s currently in the ICU for recovery following the surgery.
His vitals are stable, and the drugs he’s currently on are running through a bridge connector, which include:

- A normal saline chaser
- 0.1 mcg/kg/min of norepinephrine
- 5.1 mcg/kg/min of propofol

The doctor has ordered Andrew to switch the patient off propofol and start the patient on Fentanyl and Versed. I’ve already set up new pumps with these two drugs and the IV tubings have also been primed. I need to answer an urgent page, could you help me set up these infusions for me?

**Shot of 4 pumps**

- Hand participant 50mcg/50cc pumps of Versed
- Hand participant 5mg/250cc pumps of Fentanyl

### Order:

**Drug name:** Norepinephrine  
**Concentration:** 8mg/250mL  
**Order:** 0.0-0.35mcg/kg/min, inj-IV-cont titrate to MAP 65

**Drug name:** Midazolam (Versed)  
**Concentration:** 50mg/50mL  
**Order:** 4mg/h

**Drug name:** Fentanyl  
**Concentration:** 2mg/100cc  
**Order:** 200mcg/h

### Programming:

**VTBI:** 250mL  
**Dose:** 0.0 - 0.35 mcg/kg/min  
**Rate:** 6.5 mL/h

**VTBI:** 50mL  
**Dose:** 0.08mg/kg/hr  
**Rate:** 4 mL/hr

**VTBI:** 250mL  
**Dose:** 400mcg/h  
**Rate:** 10 mL/hr

### Possible Responses from participants

<table>
<thead>
<tr>
<th>Outcome 1:</th>
<th>Concentration Change</th>
</tr>
</thead>
</table>
| Obtains new IV tubing and pumps for Fentanyl and Versed | During flow rate change:  
  “You seem to be weening the patient off Propofol while slowly increasing the rates of fent/versed. Why is that?” |
| Weens patient off Propofol and | Look for reasoning regarding shared infusion volume containing Propofol. |

**After change flow rate and connect to pt:**  
SimMan Control: Increase BP (Call for help)
slowly increases Fentanyl/Versed to reduce sudden change in flow rates

“The BP was alarming at the desk.”
“What’s going on? What should we do?”

We will note what the participant says/does, but we will always then return to normal after a while

Normal State for Ms Chur (Awaken the patient)

<table>
<thead>
<tr>
<th>Outcome 2: Obtains new IV tubing and pumps for Fentanyl and Versed</th>
<th>After change flow rate and connect to pt: SimMan Control: Increase BP (Call for help)</th>
</tr>
</thead>
</table>
| Pauses propofol and starts Fentanyl/Versed at ordered rates      | “The BP was alarming at the desk.”
“What’s going on? What should we do?”

We will note what the participant says/does, but we will always then return to normal after a while

---

**IV Push – Ms. Carrie Woods**

- *Ancef beeps*
- “Looks like Ms. Woods order of Ancef has just finished. The doctor has ordered an IV push for Ms. Woods as she takes it at home for anxiety. There is an order of Diazepam, 10 mg over 2 minutes. I prepared it, but haven’t yet administered it. Could you?”

Shot of STAT line

---

### 1.1.1.4 IV Push – Ms Carrie Woods

**Diazepam (Bolus PUSH)**

- **Order:**
- **Dose:** 10 mg over 2 minutes
- **Vol:** 2mL in 3 cc syringe

*Participant gives push and flush.*

*DV white port (3mL + 4mL +0.39 mL) = 7.39 mL*

*Note: if tries to push into CVP, say “thanks, we need to constantly monitor the CVP so please push it into the white port)*

*Note: if tries to disconnect the extension tubing (to push right at port), say “thanks, but please push at the labeled stat port b/c we are trying to minimize tubing disconnections – it’s a new policy.*

- **Nurse Actor checks if participant is PUSHING into the med line (white port) and FLUSHING into the same port (white port), relay to control room.**
Check the flush rate, requires 20 cc NS flush

[While she is delivering the push] Is there anything you are thinking about while you are delivering the push?

POST-EXPERIMENT DEBRIEFING

☐ Go over debrief questionnaire (fill out paper questionnaire)

Debriefing Questions:
- Nurse’s general study feedback
  ▪ Was there anything you found challenging in managing the patient(s)?
- Explore observed nurse’s actions
  ▪ Why did you/did you not perform a task a particular way?
  ▪ What are the potential risks associated with an observed issue?

☐ Check all paperwork done
  o Consent form
  o Pre questionnaire
  o Debrief questionnaire
  o (2 tests, if paper)
  o Reimbursement paperwork

☐ Check they have contact info for Kyle if problem with reimbursement

☐ Remind participant
  o Thank you
  o to not discuss with colleagues
  o return to normal TGH practices when next work

Post-experiment – Closing Tasks

LOCK up CHEQUES

☐ Check that the collection bags are not full
☐ Make sure IV poles are aligned with markings on floor
☐ Charge batteries
☐ DVD tapes
☐ Turn off SimMan, ambient noise track, turn off walkie talkie and wireless microphones
Appendix K: Consent Form for Validation Phase

Error! Not a valid link.CONSENT FORM TO PARTICIPATE IN A RESEARCH STUDY

Study Title: Mitigation Risk Associate with Multiple IV Infusions: Phase 3b eLearning Modules – Formative Usability Tests

Principal Investigator: Dr. Patricia Trbovich

Contact Information: 416-340-4800 x7180

Funder: Health Quality Ontario

Introduction:
You are being asked to take part in a research study. Please read the information about the study presented in this form. The form includes details on study’s risks and benefits that you should know before you decide if you would like to take part. You should take as much time as you need to make your decision. You should ask the study staff to explain anything that you do not understand and make sure that all of your questions have been answered before signing this consent form. Before you make your decision, feel free to talk about this study with anyone you wish. Participation in this study is voluntary.

Background/Purpose:
Past research has identified that administering multiple IV infusions to a single patient is a high-risk activity. One contributing factor to these errors is that Ontario nurses are not consistently taught fundamental principles associated with administering secondary intravenous (IV) infusions and managing shared infusion volume (the common volume shared by 2 or more infusions).

Researchers at the University Health Network (UHN) are investigating the effectiveness of eLearning modules on improving the safety of administering multiple IV infusions to a single patient. Past research showed that watching a computer-based training module about multiple IV infusions improves safety, but areas for improvement were also identified.

Your participation will help us to determine content and design improvements to the newly developed eLearning modules. The primary audience for the eLearning modules is practicing critical care nurses. However, we are also interested in evaluating the appropriateness of the eLearning modules for use by critical care nursing students and non-critical care nurses that administer multiple IV infusions.
**Study Procedures and Visits:**
Five critical care nurses will be included in this study. Each nurse will participate separately and each session will last no more than 2.5 hours.

If you agree to participate in the study, you will be asked to come to the Centre for Global eHealth Innovation at UHN to do the following:

7. Complete a background (demographic) questionnaire (e.g., age, sex, years nursing experience)
8. Complete clinical tasks in a simulated clinical environment (i.e., laboratory facility) to a simulated patient (mannequin and/or actor*). You will be asked to complete common IV-related tasks such as: setting up secondary IV infusions, administering an IV manual push dose, and changing a parameter to a continuous infusion (e.g., increase the flow rate). No actual drugs will be used; instead, water will be used. You will be asked to “think aloud” (i.e., verbalize your thoughts) as you complete the tasks to help us understand what you are doing and why.
9. Complete a written test
10. View the eLearning modules and provide your feedback as you navigate through them. The eLearning modules review the fundamental principles associated with administering secondary IV infusions and managing shared infusion volume.
11. Complete a second written test
12. Complete a second round of clinical tasks in a simulated clinical environment (i.e., laboratory facility) to a simulated patient (mannequin and/or actor*) similar to step 2.
13. Complete a semi-structured debrief interview with the study coordinator to clarify and summarize your feedback about the eLearning modules so we can improve its content and design.

*Note: All actors are part of the research team; they are not direct colleagues or management. Your performance/competency is NOT being evaluated in a way that will impact your employment. Any issues or errors observed during the simulation tasks will be noted as related to the evaluation of the eLearning modules to better understand how we can improve it.

Human factors experts (i.e., not direct nursing colleagues or management) will record your feedback and other observations made from behind a one-way mirror. The entire session will be video and audio taped using ceiling-mounted cameras in the simulation laboratory to aid in subsequent analysis.

**Risks:**
There are no anticipated or known medical risks associated with this study. You may experience discomfort in sharing your opinions with the researchers. You only have to share as much about your opinions as you wish. Your participation will have NO impact on your employment at UHN (or your student evaluation, if applicable).

**Benefits:**
You may or may not receive direct benefit from participating in this study. Information from this study may help to increase your knowledge about managing multiple IV infusions.

**Confidentiality:**
If you agree to join this study, you will be asked to provide the following personal information that could identify you:
- name
- address
- phone number
- email

All information obtained during the study, including your personal information, will be kept confidential and will not be shared with anyone outside the study unless required by law. You will not be named in any reports, publications, or presentations that may come from this study. You will be identified with a subject number only. A list linking your study number with your name will be kept by the study Principal Investigator (PI) in a secure place, separate from your study data file. The study PI will keep any personal information about you in a secure and confidential location for at least 5 years and a maximum of 10 years. Any personal identifiable information will be stored and protected on secured servers or kept in a locked filing cabinet and then destroyed by shredding of paper or erasing of digital information.

No information identifying you will be transferred outside the investigators of this study. All results shared outside the study team will be de-identified and aggregated such that no results will be directly associated with you. If the video/audio tapes from the research are shown outside the research team, your face will be blurred, audio modified, and all identifying information will be made anonymous. However, despite best efforts, there is a very small possibility that you may still be identified.

Representatives of the University Health Network (UHN) including the UHN Research Ethics Board may come to the hospital to look at the study records and at your personal information to check that the information collected for the study is correct and to make sure the study is following proper laws and guidelines.

**Voluntary Participation:**
Your participation in this study is voluntary. You may decide not to be in this study, or to be in the study now, and then change your mind while completing the simulation study. You may also refuse to answer any questions you do not want to answer during the study. Whether you choose to participate or not has no impact on your employment at UHN (or your student evaluation, if applicable).

**Costs and Reimbursement:**
You will receive monetary compensation in the amount of $165 for your participation in this study.

**Rights as a Participant:**
If you are harmed as a direct result of taking part in this study, all necessary medical treatment will be made available to you at no cost.
By signing this form you do not give up any of your legal rights against the investigators, sponsor or involved institutions for compensation, nor does this form relieve the investigators, sponsor or involved institutions of their legal and professional responsibilities.

**Conflict of Interest:**
Health Quality Ontario, the funder of this study, will reimburse the hospital and Principal Investigator for the costs of doing this study. All of these people have an interest in completing this study. Their interests should not influence your decision to participate in this study.

**Commercialization:**
The project sponsor and study team intend to claim sole ownership of any results that would come from this study. You will not receive any financial benefit that might come from the results of this study.

**Questions about the Study:**
If you have any questions, concerns or would like to speak to the study team for any reason, please call the Principal Investigator Patricia Trbovich at (416) 340-4800 x 7180 or the Study Lead, Kyle Tsang, at (416)-340-4800 x 4766.

If you have any questions about your rights as a research participant or have concerns about this study, call the Chair of the University Health Network Research Ethics Board (REB) or the Research Ethics office number at 416-581-7849. The REB is a group of people who oversee the ethical conduct of research studies. The REB is not part of the study team. Everything that you discuss will be kept confidential.

You will be given a signed copy of this consent form.

**Consent:**
This study has been explained to me and any questions I had have been answered. I know that I may leave the study at any time. I agree to the use of my information as described in this form. I agree to take part in this study.

I allow video clips in which my face is obscured (i.e., blurred) and audio modified to be shown for educational purposes (e.g., illustrate eLearning module issues):

☐ Yes, video clips may be shared
☐ No, video clips may NOT be shared

__________________________  __________________________  _________________
Print Study Participant’s Name    Signature     Date

My signature means that I have explained the study to the participant named above. I have answered all questions.

__________________________  __________________________  _________________
Print Name of Person Obtaining Consent    Signature     Date
## Appendix L: Ideal Answer Spreadsheet

<table>
<thead>
<tr>
<th>SIV Scenario</th>
<th>Incorrect Answer</th>
<th>Correct Answer</th>
<th>Task Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>IV Push for Rate-Sensitive Drug over 2 minutes</td>
<td>Takes IV push syringe and attaches it any available port</td>
<td>Takes IV push syringe and attaches it to the closest available port</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>Administers contents of syringe over the wrong time</td>
<td>Administers contents of syringe over 2 minutes as specified in order</td>
<td>R</td>
</tr>
<tr>
<td></td>
<td>Does not flush the IV push</td>
<td>Chooses to flush the medication using an appropriate method (syringe or pump)</td>
<td>R</td>
</tr>
<tr>
<td></td>
<td>Flushes IV push too quickly</td>
<td>Delivers flush at the same rate as the original IV push</td>
<td>K</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SIV Scenario</th>
<th>Incorrect Answer</th>
<th>Correct Answer</th>
<th>Task Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doubling concentration of norepinephrine IV bag while maintaining overall dose rate</td>
<td>Switches the bag over immediately without accounting for the SIV</td>
<td>Obtains a new infusion pump</td>
<td>S/R</td>
</tr>
<tr>
<td></td>
<td>Program new pump with same VTBI and the same flow rate</td>
<td>Gets new primary IV tubing and attach it to the new infusion bag</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Program new pump with same VTBI and half the flow rate to maintain dose rate</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pauses the old infusion and de-attach the old norepinephrine</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Attach the new pump to the same port and start the new norepinephrine bag</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R</td>
</tr>
<tr>
<td>SIV Scenario</td>
<td>Incorrect Answer</td>
<td>Correct Answer</td>
<td>Task Type</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>---------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>Tubing change with three infusions</td>
<td>Attach the three new infusions using piggybacking technique</td>
<td>Attach the three new infusions to a new bridge connector</td>
<td>R</td>
</tr>
<tr>
<td></td>
<td>Does not allow drugs to mix in the bridge</td>
<td>Allow the drugs to mix over at least 15 minutes to ensure the slowest infusion has cleared the SIV OR allow the drugs to mix in the bridge by increasing the rate to ensure the entire bridge is primed with some medication</td>
<td>K</td>
</tr>
<tr>
<td></td>
<td>Detach then pause the original 3 infusions</td>
<td>Pause and detach the original 3 infusions</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>Attach the three new infusions without a bridge to a different port</td>
<td>Attach the three new infusions with the bridge to the same port</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SIV Scenario</th>
<th>Incorrect Answer</th>
<th>Correct Answer</th>
<th>Task Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changing infusion flow rate for a patient connected to multiple IV infusions</td>
<td>Changes infusion rate to the incorrect flow rate</td>
<td>Changes infusions rate to the correct flow rate</td>
<td>S</td>
</tr>
</tbody>
</table>

**Table 21:** Incorrect versus correct answers for the practical performance of the validation phase
Appendix M: Breakdown of Results from Validation Phase

Table 21a Task Description: Delivering a rate-sensitive IV Push medication

<table>
<thead>
<tr>
<th></th>
<th>Theoretical Knowledge Results</th>
<th>Practical Performance Score for Skill/Rule-based Tasks</th>
<th>Practical Performance Score for Knowledge-based Tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
</tr>
<tr>
<td>P1</td>
<td>Pass</td>
<td>Fail</td>
<td>N/A</td>
</tr>
<tr>
<td>P2</td>
<td>Fail</td>
<td>Pass</td>
<td>100%</td>
</tr>
<tr>
<td>P3</td>
<td>Fail</td>
<td>Fail</td>
<td>100%</td>
</tr>
<tr>
<td>P4</td>
<td>Fail</td>
<td>Pass</td>
<td>50%</td>
</tr>
<tr>
<td>P5</td>
<td>Fail</td>
<td>Pass</td>
<td>100%</td>
</tr>
<tr>
<td>P6</td>
<td>Fail</td>
<td>Pass</td>
<td>75%</td>
</tr>
<tr>
<td>P7</td>
<td>Fail</td>
<td>Pass</td>
<td>100%</td>
</tr>
<tr>
<td>P8</td>
<td>Fail</td>
<td>Pass</td>
<td>75%</td>
</tr>
</tbody>
</table>

Table 21b Task Description: Doubling the concentration of a previously connected infusion

<table>
<thead>
<tr>
<th></th>
<th>Theoretical Knowledge Results</th>
<th>Practical Performance Score for Skill/Rule-based Tasks</th>
<th>Practical Performance Score for Knowledge-based Tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
</tr>
<tr>
<td>P1</td>
<td>Pass</td>
<td>Pass</td>
<td>N/A</td>
</tr>
<tr>
<td>P2</td>
<td>Pass</td>
<td>Pass</td>
<td>50%</td>
</tr>
<tr>
<td>P3</td>
<td>Fail</td>
<td>Pass</td>
<td>50%</td>
</tr>
<tr>
<td>P4</td>
<td>Fail</td>
<td>Pass</td>
<td>50%</td>
</tr>
<tr>
<td>P5</td>
<td>Pass</td>
<td>Pass</td>
<td>100%</td>
</tr>
<tr>
<td>P6</td>
<td>Fail</td>
<td>Pass</td>
<td>25%</td>
</tr>
<tr>
<td>P7</td>
<td>Fail</td>
<td>Pass</td>
<td>50%</td>
</tr>
<tr>
<td>P8</td>
<td>Fail</td>
<td>Pass</td>
<td>100%</td>
</tr>
</tbody>
</table>
Table 21c  Task Description: Performing a proper tubing change

<table>
<thead>
<tr>
<th>Subject</th>
<th>Theoretical Knowledge Results</th>
<th>Practical Performance Score for Skill/Rule-based Tasks</th>
<th>Practical Performance Score for Knowledge-based Tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
</tr>
<tr>
<td>P1</td>
<td>Fail</td>
<td>Fail</td>
<td>N/A</td>
</tr>
<tr>
<td>P2</td>
<td>Fail</td>
<td>Fail</td>
<td>100%</td>
</tr>
<tr>
<td>P3</td>
<td>Fail</td>
<td>Fail</td>
<td>50%</td>
</tr>
<tr>
<td>P4</td>
<td>Fail</td>
<td>Pass</td>
<td>75%</td>
</tr>
<tr>
<td>P5</td>
<td>Fail</td>
<td>Fail</td>
<td>100%</td>
</tr>
<tr>
<td>P6</td>
<td>Fail</td>
<td>Fail</td>
<td>50%</td>
</tr>
<tr>
<td>P7</td>
<td>Fail</td>
<td>Fail</td>
<td>75%</td>
</tr>
<tr>
<td>P8</td>
<td>Fail</td>
<td>Pass</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 21d  Task Description: Changing the rate of a connected infusion in a multiple intravenous infusion system (Note: There were two questions testing a participant’s theoretical knowledge)

<table>
<thead>
<tr>
<th>Subject</th>
<th>Theoretical Knowledge Results</th>
<th>Practical Performance Score for Skill/Rule-based Tasks</th>
<th>Practical Performance Score for Knowledge-based Tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
</tr>
<tr>
<td>P1</td>
<td>1/2</td>
<td>1/2</td>
<td>N/A</td>
</tr>
<tr>
<td>P2</td>
<td>1/2</td>
<td>2/2</td>
<td>100%</td>
</tr>
<tr>
<td>P3</td>
<td>1/2</td>
<td>1/2</td>
<td>100%</td>
</tr>
<tr>
<td>P4</td>
<td>1/2</td>
<td>2/2</td>
<td>100%</td>
</tr>
<tr>
<td>P5</td>
<td>1/2</td>
<td>1/2</td>
<td>100%</td>
</tr>
<tr>
<td>P6</td>
<td>1/2</td>
<td>1/2</td>
<td>100%</td>
</tr>
<tr>
<td>P7</td>
<td>2/2</td>
<td>2/2</td>
<td>100%</td>
</tr>
<tr>
<td>P8</td>
<td>1/2</td>
<td>2/2</td>
<td>50%</td>
</tr>
</tbody>
</table>

Table 22: Breakdown of theoretical knowledge and practical performance results for each SIV scenario
Appendix N: Probing Questions for Cognitive Walkthrough

<table>
<thead>
<tr>
<th>Probing Questions</th>
<th>Incorrect Answer</th>
<th>Correct Answer</th>
<th>Task Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Why do you need to deliver a flush?</td>
<td>1. I have delivered a flush because that is my general practice. [No specific reason]</td>
<td>1. I need to deliver a flush because there is medication remaining in the SIV</td>
<td>R</td>
</tr>
<tr>
<td>2. How do you determine how much to flush</td>
<td>2. [Arbitrary value]</td>
<td>2. The flush volume must be equal or greater to the SIV</td>
<td>K</td>
</tr>
<tr>
<td>3. How long do you need to flush for and why?</td>
<td>3. Not sure</td>
<td>3. I need to make sure the flush syringe is at the same rate as the specified order to ensure all the medication is received by the patient at the specified rate</td>
<td>K</td>
</tr>
<tr>
<td>4. Why do you need new IV tubing/pump?</td>
<td>4. This is just my practice. I’m not entirely sure why I would need to switch the new IV tubing</td>
<td>4. I need IV tubing because of the concentration change. Since the dose order has not changed, I will be programming the pump at half the original rate to account for the double concentrating bag. If I were to use the same IV tubing, the patient would receive a significant delay in therapy resulting in low blood pressure until the SIV has cleared</td>
<td>K</td>
</tr>
<tr>
<td>5. Why are you mixing the drugs in the bridge?</td>
<td>5. This is just my practice. I’m not entirely sure why I am mixing the drugs.</td>
<td>5. I mix the drugs in the bridge to ensure the correct concentrations of drugs are being delivered to the patient</td>
<td>R</td>
</tr>
<tr>
<td>6. Why are you flushing the bridge with normal saline or drug X?</td>
<td>6. I always prime the bridge with the most important drug (norepi/vaso) because the patient is heavily reliant on (norepi/vaso)</td>
<td>6. I always prime the bridge with normal saline first, and then allow the other drugs to mix afterwards. Any extra fluid is dumped into a sterile bag.</td>
<td>K</td>
</tr>
<tr>
<td>Question</td>
<td>Response</td>
<td>K</td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>7. How long do you need to mix the drugs for?</td>
<td>7. I generally use 30 minutes to mix the drugs, there is no particular reason</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Why is the blood pressure dropping after you made a change to the infusion flow rate?</td>
<td>8. That's strange. The patient is probably extremely labile. I will increase the (norepi/vaso) slightly to account for this dip/raise in blood pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8. That's expected because the total flow rate has decreased/increased, which means the patient is receiving lower/higher amounts of other connected infusions temporarily. This effect is most likely temporary and I just need to wait a few minutes for the patient's blood pressure to stabilize. I will monitor the patient's BP and wait for her BP to return to normal once the SIV has cleared.</td>
<td>K</td>
<td></td>
</tr>
</tbody>
</table>

**Table 23**: Probing questions asked in the cognitive walkthrough after each SIV scenario