Communicating expertise in system operation and fault diagnosis to non-experts

By:
William P. Staderman

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Approved:

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Brian M. Kleiner, Chair

______________________ ______________________
Tonya Smith-Jackson **Eva Hudlicka**

______________________ ______________________
Chistopher North **Robert C. Williges**

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Abstract

The use of systems that span many knowledge domains is becoming more common as technology advances, requiring expert-performance in a domain from users who are usually not experts in that domain. This study examined a means of communicating expertise (in system operation and fault diagnosis) to non-experts and furthering the understanding of expert mental models. It has been suggested that conceptions of abstract models of system-functions distinguish expert performance from non-expert performance (Hanisch, Kramer, and Hulin, 1991). This study examined the effects on performance of augmenting a simple control panel device with a model of the functions of the device, interacting with the model, and augmenting the device with graphically superimposed procedural indicators (directions). The five augmented display conditions studied were: Device Only, Device + Model, Device + Procedural Indicators, Interactive Model, and Interactive Model + Procedural Indicators. The device and displays were presented on a PC workstation. Performance measures (speed and accuracy) and subjective measures (questionnaires, NASA TLX, and structured interviews) were collected. It was expected that participants who interact with the device + procedural indicators would exhibit the shortest performance time and least errors; however, those who interacted with the simplest display (device only) were fastest and exhibited the least errors. Results of this study are discussed in terms of building a mental model and identifying situations that require a mental model.

Dedication

To my parents, grandparents, sisters and their families, and my friends who supported me and kept me going. This would not have been possible without their love and encouragement.

To my dear friend Judy Whitenack who helped me more than I can say. I owe so much to her constant support and personal sacrifices.

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Chapter 1: Introduction

Given the range, complexity, and capacity of technological systems in many work environments, operators need to be flexible with procedures for operating devices and systems. The term "device", as it is used here, is analogous to a system. Depending on one's perspective, a system may be comprised of independent devices or a device can be a system of smaller, independent elements. System or device operators are trained in a variety of anticipated situations, but simply following procedures is not effective for operations in unanticipated situations or specialized situations that require expert knowledge. Unanticipated situations such as system failures call for diagnosing faults and/or adopting novel procedures.

Kieras and Bovair (1984) and Kieras (1988; 1992) have developed a paradigm for exploring applications of diagrams and diagram displays to this kind of device, and how they support mental model reasoning. By "mental model" is meant some kind of understanding of how the device works in terms of its internal structure and processes (cf. Halasz and Moran, 1983; Norman, 1983). In the remainder of this dissertation, this type of mental model will be termed a *device model* to distinguish it from the many other senses of the term *mental model,* such as that used by Johnson-Laird (1981). A significant finding of Kieras and Bovair (1984) is that the provision of diagrams (i.e., mental models) improves both the operation of a device in malfunction situations and the efficiency of procedures.

1.1. Background

An operator's mental model of a device or system prescribes his or her interaction with that device or system (Endsley, 1995; Kieras and Bovair, 1984; Payne, 2002). Rouse and Morris (1986) defined mental models as "the mechanisms whereby humans are able to generate descriptions of system purpose and form, explanation of system functioning and observe system states, and predictions of future system states" (p. 351). Young (1983) described mental models as a representation or metaphor that users adopt to guide their actions and to help them interpret and understand their interactions with a system. The concept of mental models is intuitively appealing to human factors designers as a memory structure (or set of memory structures) hypothesized to be a key mechanism whereby users are able to efficiently process a complex "state of affairs" of a system and represent a user's understanding of that system. Endsley (1995) notes several benefits of a well-developed mental model: it provides (a) the knowledge for the elements of the system that can be used in directing attention and classifying information for the perception process; (b) a means of integrating the elements to form an understanding of their meaning; and, (c) a mechanism for projecting future state of the system based on its current state and an understanding of its dynamics.

While several different definitions of mental models have been proffered, studies of the effects of mental models on performance have been limited. An approach to investigating the effects of mental models embraced by Halasz and Moran (1983) and Kieras and Bovair (1984) emphasized a more basic, and slightly different aspect of system interaction: understanding how to operate an unfamiliar particular piece of equipment. As opposed to the notion of mental models as primarily representational structures emphasized in studies of complex system interactions, “mental model”, in this second approach, refers to some kind of device model that involves understanding of how the device works in terms of its internal structure and processes (Kieras and Bovair, 1984; Norman, 1983). A device model can be seen as a constrained type of mental model that represents the function and elements of a device, rather than those of a complex system.

Payne (2002) argued that this view of mental models identifies the problem space created through interaction with a device. “Mental models of machines can provide a problem space that allows more elaborate encoding of remembered methods, and in which novice or expert problem solvers can search for new methods to achieve tasks”. Stepping through a sequence of states in some mental model of a machine is often called “mental simulation” in the mental models literature, and the kind of model that allows simulation is often called a “surrogate” (Young, 1983). Payne argued that at an abstract level the mental activity in such a simulation is exactly the classical search in a problem space: operators are applied to problem states so the next problem state is generated. Consequently, a richer and more flexible behavior is enabled when a training method using a device model is used rather than merely a rote method.

Halasz and Moran (1983) provide a classic demonstration of how users’ (mis)understanding of how a device works influences their interactions. They examined user interactions with Reverse Polish Notation (RPN) calculators. RPN is a post-fix notation for arithmetic, so that to express 3+4 one would write 3 4 +. RPN does away with the need for parentheses to disambiguate composed operations. For example (1+2) * 3 can be expressed 1 2 + 3 * with no ambiguity. RPN calculators need a key to act as a separator between operands – this key is conventionally labeled ENTER, but they do not need an = key, as the current total can be computed and displayed whenever an operator is entered.

Halasz and Moran taught one group of students how to use an RPN calculator using instructions, like the introduction above, which merely described the appropriate syntax for arithmetic expressions. A second group of participants was instructed, using a diagram, about the stack model that underlies RPN calculation. Briefly, when a number is keyed in, it is "pushed" on top of a stack data structure (and the top slot is displayed). The ENTER key copies the contents of the top slot down to the next slot. Any binary arithmetic operation is always performed on the contents of the top two slots, and leads to the result being in the top slot, with the contents of slots 3 and below moving up the stack.

Halasz and Moran discovered that the stack model instructions made no difference to participant's ability to solve routine arithmetic tasks: the syntactic "method-based" instructions sufficed to allow participants to transform the tasks into RPN notation. However, for more creative problems (such as calculating (6+4) and (6+3) and (6+2) only keying the number 6 once) the stack group performed substantially better. Verbal protocols showed that these participants reasoned about such problems by mentally stepping through the transformations to the stack at each keystroke. This pointed to the non-intuitiveness of either the problem or the device and the critical role of a device model in the utility of the device.

In a similar study, Kieras and Bovair (1984) (Experiment 1) focused on the role of a mental model in learning how to operate an unfamiliar piece of equipment or device.

They investigated the effects of providing novice operators with a representation of a device model that described the underlying dynamics of a device. In this study, two groups of participants learned procedures for operating a simple control panel device consisting of switches, push buttons, and indicator lights. The goal of the procedures was to get a certain indicator light flash. The device model group received some how-it-works knowledge in the form of a description of the device based on the familiar television science-fiction series called Star Trek. They were also provided with a diagram illustrating a description of how the components of the device (a phaser-bank control panel) related to each other and how the controls controlled the flow of energy from one component to another. The rote group received no model training but only learned the procedures by rote without any description of the device components. The two groups received exactly the same procedure training. Results indicate that the model group performed faster, more efficiently, and remembered procedures one week after the initial training more accurately than the rote group. This experiment shows that having a device model improves performance on learning and retaining the operating procedures for a device.

Kieras and Bovair hypothesized that knowledge of how a system works helps by enabling the user to infer how to operate the device. It is also possible that providing a device model allowed model group participants to reconstruct by means of inference the operating procedures even if specific details of the direct memory of them have been forgotten. The model enables users to extract specific knowledge from generic and generalizable knowledge, which is presumably more easily encoded and related to existing knowledge. This provides a specific explanation for how making in device "meaningful" with the device model can allow the procedures to be learned and remembered better. Kieras and Bovair (1984) aimed to examine this hypothesis in Experiment 2. New participants were assigned to the same groups as in Experiment 1 and think-aloud protocols and changes in control settings were recorded as participants inferred the procedures to get the final indicator light to flash. Results showed that participants in the model group changed settings less and more efficiently (fewer wrong settings) than the rote group. While there was little comparison between protocols possible, since the model group used the terms of the model, it was clear from the patterns of changes that participants in the rote group relied on a trial and error method.

1.2. Problem Statement

Augmented reality refers to a technology wherein a real-world scene is augmented by computer-generated information. **Can AR communicate expertise to non-expert operators and support system interactions by displaying an explicit depiction of the device mental model?** The intent of nearly all applications of augmented reality is to aid task performance or system operation by providing a greater understanding of a real scene or system through information-aiding graphics. Current technologies may help illustrate features underlying a device so as to allow operators to interact with the device more flexibly and efficiently.

Augmented Reality (AR) offers a novel means of supporting interaction with a device (or system) by presenting a device model (or a broader sort of mental model) in order to improve an operator's performance by projecting the underlying components of a system over a real world scene. AR refers to a range of techniques that display segments of knowledge and information to an operator in response to the actual physical environment of the operator; thus, the perceived reality is *augmented* by the display of relevant information. The augmentation is usually in the form of computer graphics superimposed on video of a real world scene or projected onto a see-through display, with the real world scene beyond it. It is possible that an AR display of a mental model will reduce performance time due to its relation to the real world environment and use of a head-mounted display. In other terms, a computer-generated image of a device model superimposed on a real-world device may improve interactions with that device.

Alternative means of presenting augmenting a scene range from text and figures using external documentation (e.g., a paper manual next to a screen) to the design of instrument panels and advanced heads-up-displays that project computer-generated graphics on a see-through display. A theme that underlies these major methods of displaying augmenting information is reducing the cognitive distance between the augmenting information and the actual, relevant scene. "Cognitive distance" is used here to refer to the physical and conceptual separation between augmenting information and the relevant scene; the greater this distance, the more cognitive resources (such as working memory) are called upon for accurate application of the relevant information. The distance is less with AR approaches to providing augmentation than with approaches that rely on paper or external documentation (see Figure 1.1).

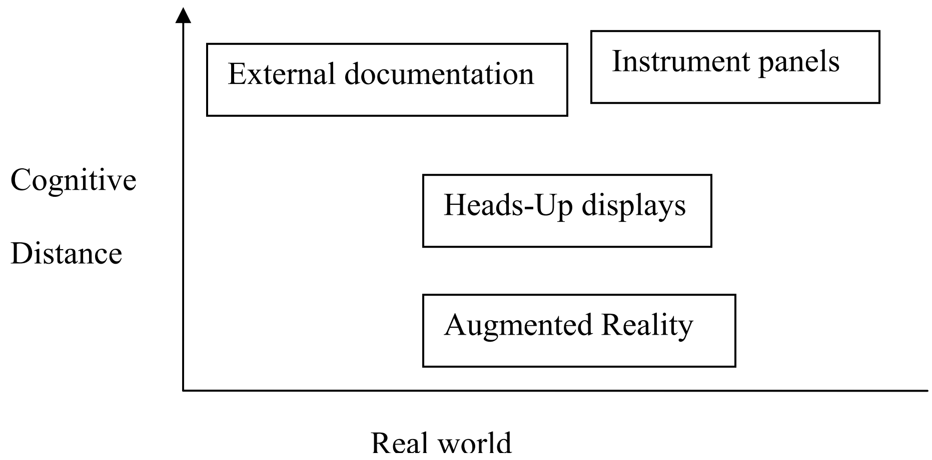

Figure 1.1: The cognitive distance of the augmenting information with the actual and relevant scene

Theoretically, a unified view of augmenting information and a real scene reduces the cognitive efforts (e.g., working memory, processing (spatial reasoning, updating, etc.)) required to interact with the system at hand. Furthermore, reduced cognitive effort, in most cases, means better performance[1]. Augmentation via external documentation maintains disunion of the information and the system at hand, and requires that the viewer make efforts to integrate them. A common theme in the design of instrument panels stresses the intuitive mapping of the display objects to the components and processes of the controlled device; thus, reducing cognitive demands on the operator/viewer. The use of heads-up displays is a further step in the unification of

[1] There are notable exceptions. For example, tasks that require little cognitive effort (e.g., making a shopping list) and other daydreaming episodes can reduce performance. There are many other examples of poor performance resulting if low cognitive effort is equated with low vigilance (e.g., Davies and Parasuraman, 1982; Wickens and Flach, 1988).

augmentation and a real scene. These displays can superimpose augmenting information onto a real scene, but they are not tolerant of changes in perspective. AR systems typically involve a display that superimposes the augmenting information, in the form of additional text or displays onto a real scene and a position-tracking device that updates the display to account for different perspectives. Augmenting information is *registered* to particular features of the real scene, thus assuring that when the operator moves his head, the augmenting information will still be there.

Communicating expertise to non-expert operators has important implications in many situations. For example, consider an astronaut on a long duration mission. He or she is required to interact efficiently with a large number of technical systems. In fact, there are likely to be too many systems and unanticipated situations for the individual astronaut to be an expert in all of them. In this case, it would be helpful if the expertise of others (e.g., support crew or ground crew) was communicated to the astronaut in order to operate efficiently in his or her environment. Analogous, but more terrestrial, examples involve communicating expertise to non-experts in remote environments. For example, communicating medical or surgical expertise to a doctor in an isolated community.

The superimposing of computer-generated information onto a real scene through some combining display technology can enhance an operator's understanding of a device by presenting features of the device (such as the relationships among components) that may be unknown to the operator. While the technology is still maturing, it is important to investigate potential applications and capabilities of augmented reality systems. **The primary aim of this dissertation is to examine the effects of displaying device models**

via augmented reality systems on system operation and fault diagnosis tasks. The general research objective of this dissertation is to investigate the implications of presenting mental models and procedural information via augmented reality systems so as to benefit the goal of improving non-expert operator performance and interaction with a device.

1.3. Research Model

Figure 1.2 illustrates the relationships among some of the important terms introduced above (i.e., device, control panel, device model, system, mental model) in order to clarify them.

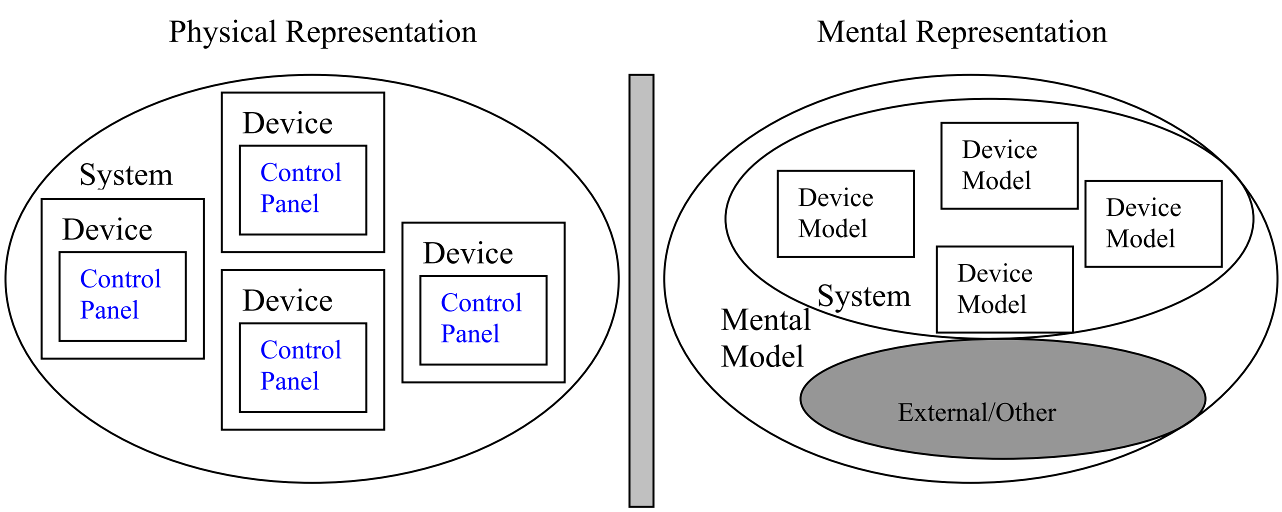

Figure 1.2: Conceptual model of the terms: system, device, mental model and device model.

The term "device" is a generic term that refers to the physical components of a technological system. A control panel was the kind of device used in this study. The term "device model" refers to a mental representation of a device's function as well as the relationships among the components of a device. The term "mental model," as used in this study, refers to a representation of the function(s) of a system and the relationships among the components of this system. More than representations of physical components constitute a complete mental model (e.g., external environment), but for research purposes, the domain of "mental model" as used here is limited to a representation of the physical components that constitute a system.

The research model (Figure 1.3) describes the effects of type of display presented to operators of a device (recall that the terms "device" and "control panel" are synonymous) on performance; e.g.., device operation times. The display types differ according to the augmentation they provide; they are: Device Only, Device + Model, Device + Procedural Indicators, Interactive Model, and Interactive Model + Procedural Indicators.

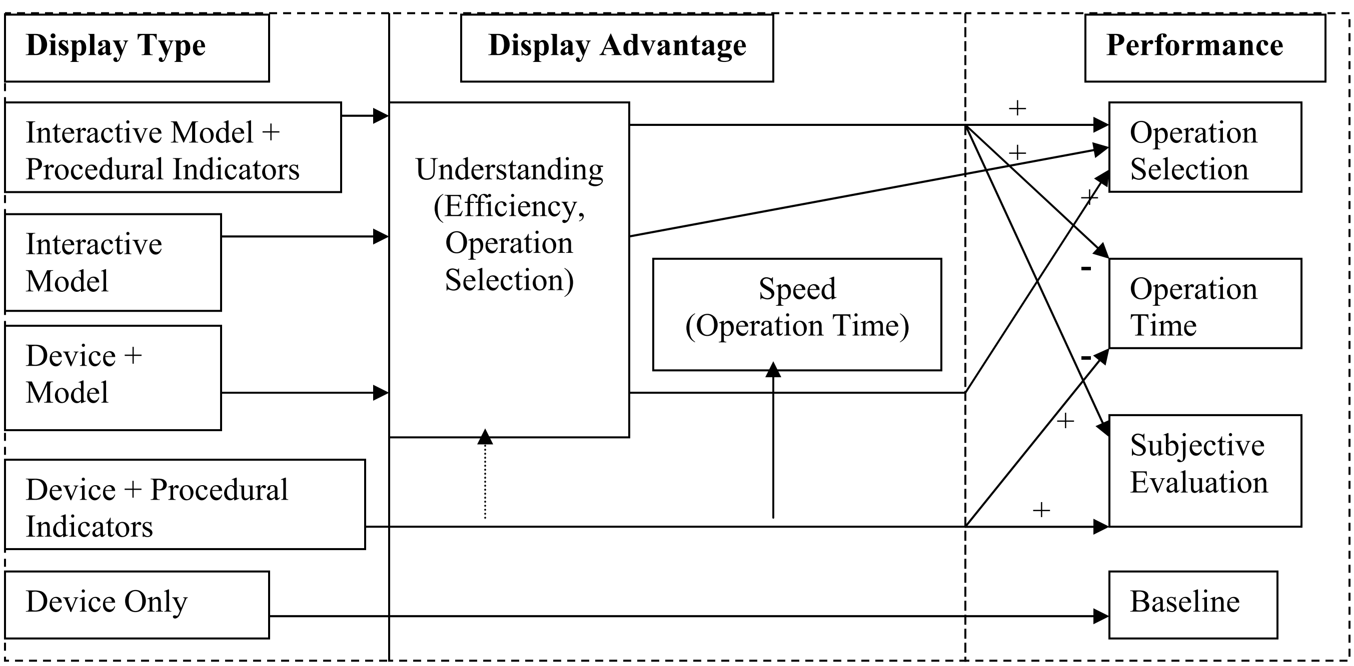

Figure 1.3: Research Model

The underlying hypothesis is that an operator's interactions with a device in abnormal conditions, and general understanding of device functioning, are likely to improve when an operator is provided with a an explicit visual representation (model) of the device. Augmenting the display with superimposed procedural indicators closely resembles standard augmented reality displays – aspects of which (such as physical and temporal relations to the real world) afford additional support mechanisms and are likely to improve performance beyond abstract presentations of the model. Therefore, an operator's understanding of the device and his performance with the device is most likely to be supported by the presentation of an interactive model with procedural indicators.

There is a broad range of potential research endeavors in the areas of mental models and augmented reality. The proposed study is limited to studying the effects of displaying a predefined mental model of a device on performance and interaction with that device. Among the issues that are worth studying in their own right, but are beyond the scope of this study are:

- The nature of mental models – i.e., How mental models are formed, where they reside, and so on.
- Representing mental models – i.e., In what form are mental models expressed? How are mental models represented internally? What types of memory structures are used to represent mental models?
- Human memory and retention
- Cognitive theories of learning
- Registration in AR

- Usability issues of AR
- Individual differences

1.4. Research questions

Does displaying a device model at the same time as the device itself increase the probability that an operator will select the appropriate procedure in malfunction situations relative to operators shown the device only? Kieras and Bovair (1984) suggested that displaying a model helps operators to remember procedures and interact with a device more efficiently than operators without a model.

Does a display of a model that is tied to the device lead to superior performance compared to an abstract device model? Displaying a type of model (augmentation) visually combined (superimposed) with the device itself should improve interactions beyond presenting an abstract model. Thus, a second research question presented itself: It is possible that a model constrained by the physical layout of the device will make the device more difficult to operate, but it is more likely that such a model will improve operators' understanding of the device.

Does the procedural information encoded in the superimposed augmentation influence operators' performance? A third question concerned encoding procedural information via the superimposed augmentation: Since this type of augmentation can indicate features of the device at each step in a procedure, it can be easily adapted to dynamically relate procedural information to operators. However, as noted above, the added graphics may hinder operations.

Chapter 2: Literature Review

2.1. Supporting expert performance

Equipping an individual operator with the knowledge necessary to perform a given task is an obvious necessity. However, an individual is likely to be asked to perform in a domain in which he or she is not expert. For example, an astronaut engaged in an extra-vehicular activity may encounter a situation such as a mechanical repair to a machine with which he or she is not an expert. The knowledge base pertaining to a given situation may be displayed via text or relayed via audio to the operator on demand, so as to expose him or her to the related information. Traditional displays of expert knowledge are generally cumbersome and difficult to adapt to the task at hand.

The use of text to convey knowledge is ubiquitous. Textual displays are found on paper, computer screens, and many other media. Instruction manuals and how-to guides are common reference materials that convey knowledge about devices and systems. However, using these reference materials while interacting with a device or system is usually difficult and occasionally impossible. Books, electronic display screens, and other textual media are usually cumbersome and require time-off-task (offline) for consultation. Extracting knowledge from a knowledge base contained in a textual medium and applying that knowledge in a given application environment imposes great memory demands on an operator (Wickens, 1992).

Verbal descriptions have a long history dating back to the beginnings of language and probably motivating its development. Verbal description of an environment, in real time, by an operator to an expert, is a step in establishing the link between the knowledge-base and the application environment of that knowledge. The descriptions provide a continuously updated context, which specifies relevant bits of the knowledge base. Hands-free verbalizations also benefit the operator who can access relevant knowledge while performing a task. The use of verbal descriptions of remote environments has benefited from technologies designed to speed and disperse communication devices (e.g., telegraph, telephone, wireless communications).

The prominence of textual and verbal descriptions has been augmented by visual descriptions (e.g., pictures, video). As the saying goes, "a picture is worth a thousand words." Pictures give a more vivid image of a scene in a much shorter time than verbal descriptions. Video or motion pictures go further in representing an environment (context) by illustrating the activity and dynamic features of that context. Videos also aid instruction by illustrating demonstrations of operations. One can easily see the difference in cognitive demands going from reading the daily newspaper to listening to a news-broadcast on the radio to watching the nightly news.

These methods of supporting performance build on each other. A video representation is usually accompanied by verbal representation, which represents textual information. It is obvious that a textual representation of a knowledge base (a type of declarative knowledge) is critical to future representations of knowledge. Expert systems are a popular class of systems intended to support performance that focus on the knowledge base.

2.1.1. Expert systems

The general intent of an expert system is to provide a user with access to knowledge of a domain and to apply this knowledge (Hopgood, 1993). A block diagram of the generic modules of an expert system is shown in figure 1. Unlike conventional programs, the knowledge base and the control module that applies this knowledge (i.e., the inference engine) are explicitly separated in expert systems. Knowledge acquisition is commonly an aspect of expert systems and it is required to supply the knowledge base.

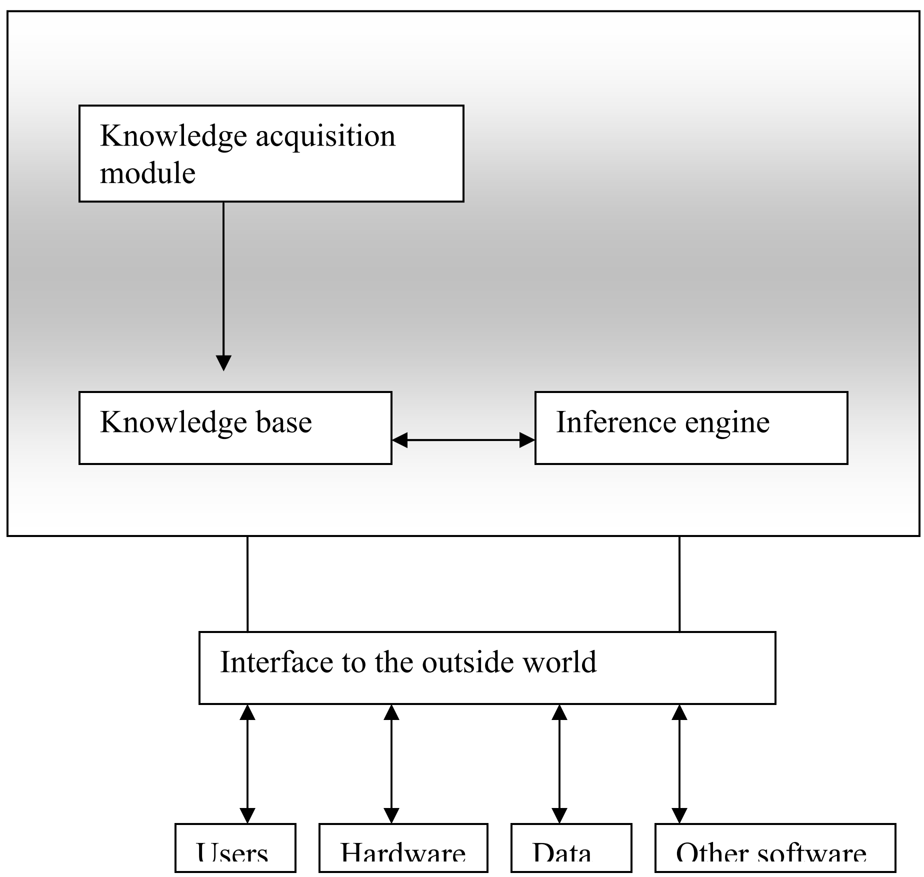

Figure 2.1: The main components of an expert system.

The knowledge base contains explicit facts and rules often represented as an associative or a semantic network that can be used to model a domain (Hopgood, 1993). Expertise is sometimes modeled by the knowledge structure (as well as inference procedures). The means by which the knowledge base pertaining to a given domain is gathered are varied (de Hoog, 1998; Liou, 1998). The knowledge can be gleaned from books on the subject, people familiar with the subject, or knowledge of a related subject. Computer systems intending to support individuals (operators or decision-makers) by presenting vast amounts of knowledge relevant to a given domain often gather the information in their databases from experts in that domain in addition to related declarative knowledge. These so-called "expert-systems" generally have the potential to present an individual with virtually every bit of knowledge relevant to a domain.

In order to complete a task of some sort, an operator must apply some sort of knowledge to the task at hand. For example, one must know a patient's history and current condition in order to diagnose an ailment (Pazos, 1998). As the complexity of the task increases, so does the amount of knowledge required. For example, a simple task such as pushing a button requires little knowledge, while a more complex task, such as repairing a machine requires much more knowledge. The amount of knowledge required can easily exceed the capacity of an individual (Chen and Rada, 1998). In addition to the amount of knowledge exceeding an individual's capacity, the domain or area of knowledge may go beyond an individual. An individual may be an expert in one domain and not another. For example, a machine repair task may demand knowledge of other machines; like the units of the International Space Station. It is clear that more than one individual is necessary for successful completion of complex tasks.

Inference engines vary among systems, but two important types can be distinguished: forward-chaining (data-driven) and backward-chaining (goal-driven). The general goal of the inference engine is to relate bits of knowledge and navigate either from a goal to relevant data or from data to a relevant goal (Hopgood, 1993). Navigating the knowledge base is a difficult task. Searching through the immense field of information in order to present an operator with only the bits of information needed at a particular moment is a daunting task for the non-expert. Automatic search methods are plagued by two problems: too much information results from a search or bits of important information are missed by a search. Neither outcome is characteristic of expert performance.

While expert systems have many advantages, they also have some weaknesses. Chen and Rada (1998) note that expert systems are not good at judgments that depend on meta-knowledge (i.e., knowledge about their own expertise) and they are not good at recognizing when no answer exists or when the problem is outside their domain of expertise. Researchers like Chen and Rada (1998) and De Greef and Neerincx (1995) suggest that expert systems can complement and support human decision-makers. Human experts, in addition to technical knowledge, have common sense. Human experts automatically adapt to changing environments; expert systems must be explicitly updated. Human experts can respond creatively to unusual situations, while expert systems cannot. It is not yet known how to give expert systems common sense.

2.1.2. Need for environment

Despite these advances in communication, interaction with the described or pictured environments is hampered by the need of an operator to consult expert sources. The verbally described environment needs to be visualized, then augmented, then acted upon. A pictured image skips the visualization step, but it still requires consultation with experts. The situation becomes much more complicated when the operator is not expert on matters of his environment and he needs to consult with experts. Now the visually described environment needs to be communicated by the operator to the experts, augmented by experts (not the operator), then returned to the operator who must follow-through with any augmentation, the revised environment is communicated to the experts, and so on.

Accurate interaction with an environment requires the physical abilities to interact with the environment, knowledge of the environment, and the knowledge to act appropriately within that environment (Suchman, 1987). Physical ability is often a limiting factor in accurate interaction with an environment. Physical disability can often prohibit knowledge from being expressed over a remote environment. The situation where knowledge is separated from its environment can exist for many reasons; the environment may be too distant for a knowledgeable person to get to; getting to the environment may require skills and abilities the expert lacks. Whatever the reason, experts are frequently away from their domain of expertise. An approach to improving operator performance, then, is to link the expert to the operator in the field. The link seems to be interactive knowledge of the environment.

2.2. Augmented reality

The widespread use of computers and computer-generated information has motivated the transition of computing from darkrooms behind closed doors to the actual site of application. Computer users often desire to augment their environments with computer-generated information. The availability of computing power (commonly tethered to a desktop computer or larger unit) within the application environment enables a user to quickly and continuously relate the benefits of computers (data recording and storage, referencing, precise measuring, data visualization, viewing normally unseen views) to their environments. Mobile computing refers, in general, to the unleashing of computer tools. The miniaturization of computers and the development of wireless technologies fuel the development of mobile computing. Computers that can be easily worn like clothing and accessories (i.e., wearable computers) are being developed with the general goal of making computer capabilities available to the user wherever and whenever she or he wants them.

Augmented reality (AR) refers to the addition of supplemental information to a real scene through the use of some combining methodology. The supplemental information is computer generated while the real scene is the real physical scene. An AR system displays segments of knowledge and information to an operator by overlaying computer graphics on a real world image; thus, the perceived reality is *augmented* by the display of relevant information. While AR is not restricted to visual information (information from other sensory modalities can be used to supplement the real world; see Table 2.1, adapted from Barfield et al., 1995), this discussion focuses on the visual modality.

Table 2.1: Augmentation available for the five main sensory systems.

Sense	**Type of Augmentation Possible**	**Examples**
Vision	Text, schematics, simple graphics, complex graphics, pictures, animation, video	Annotated text, wiring diagrams, navigation arrows, etc. The most common augmentation.
Hearing	Beeps, horns, signals, music spoken words	Alert signals, back-up alarms, directional signals
Touch	Friction, collision, virtual object boundaries	In HCI, a joystick can simulate the collision of the pointer with an object.
Smell	Additional smells	Some poisonous gases are mixed with identifying odors. The odor improves detection of a poisonous gas.
Taste	Sweet, sour, bitter, salty	Additional tastes can improve the taste of foods.

AR is reported to complement human understanding and information processing by reducing the cognitive load associated with an operator's task performance. Memory related to the task is a key loading factor (Wickens, 1992). The operator needs to remember the features (past, current, or projected) of the relevant domain. AR provides a means of presenting users with current features of the real world along with computer-generated images of past or projected (e.g., trajectories, maps, diagrams) states of the world. Current applications of AR typically take the form of simple graphics, schematic overlays, complex graphics, or text that annotates the real environment. The capability of AR to project synthetic objects, as well as unseen objects onto real objects has been exploited in the medical domain (Figure 2.2).

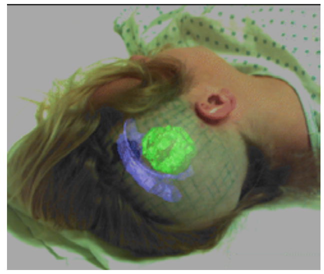

Figure 2.2: Example of AR application: Registration of computer graphics-display on a patient's head using optical scanning. [image courtesy MIT AI lab]

Most of the medical applications deal with image guided surgery. Augmented reality can be applied so that the surgical team can see the CT or MRI data correctly registered on the patient in the operating theater while the procedure is progressing. Being able to accurately register the images at this point will enhance the performance of the surgical team and eliminate the need for the painful and cumbersome stereotactic frames that are currently used for registration

AR has potential for instructing users of machines and systems. Figure 2.3 presents images from William Hoff at the Colorado School of Mining that illustrate how AR can be used to display machine maintenance and repair instructions. Figure 2.3a shows a user wearing a display device and looking down at a PC. Figure 2.3b shows the view that the person would see through the HMD. Visible in the picture is the outside frame of the eyepiece, and the overlays through the center of the eyepiece. The overlays in this particular example are a set of arrows, which show the person how to pull off the cover of the PC. AR can also provide navigational instruction by displaying maps and directional indicators.

(a) (b)

Figure 2.3: (a) A user wearing the AR system; (b) Augmented view of PC cover. (Hoff, 2000)

Baird (1999) examined an application of AR to machine assembly. Participants completed a machine assembly task while two aspects of the interface were manipulated: technologies for generating augmented reality displays (opaque head-mounted displays (HMDs) vs. see-through HMDs) and current types of assembly instructions (a traditional assembly instruction manual vs. computer aided instruction). Results suggested that using the augmented reality systems was preferred to using the manual and computer-aided instruction. Participants using the augmented reality interfaces also made fewer errors than with the alternatives.

Mizell (2001) discusses a pilot study of the Boeing wire bundle assembly project using AR conducted in 1997. The AR system projected the layout of wires that make up a bundle onto a blank form-board and unbundled wires. An intention of the system was to decrease bundling-time by eliminating a worker's need to look away from the wires in order to refer to a printout of the layout. This was not found to be the case. Mizell cites interface and usability issues for the equal time for bundling with or without AR. Other results of the study confirm the value of the technology despite the lack of change of process time. For example, the time to train a novice worker before the actual process was greatly decreased.

Mizell (1997) recorded worker reactions to using the AR system; feedback was bipolar. Some workers wore the system for an entire 8 hour shift and felt it was comfortable and it increased their productivity. Other workers removed the system after a minute and complained that it was hurting their neck/back. Interestingly, women unanimously refused to wear the system. Mizell attributes these reactions to social issues (e.g., a goofy looking device, "hat head" caused by the system, teasing from other workers). Following modifications to the system, the wire-bundling system became the norm. Informal sampling by Boeing has shown that the AR system has brought substantial benefits to the assembly line, finding 20-50% speed improvements in divisions that incorporated augmented reality into the assembly work process (Nash, 1997).

Some researchers are eager to show that a portable augmented reality system, a wearable computer, can be used at all times to help with everyday activities. Feiner, MacIntyre, Höllerer, and Webster (1997) present the touring machine as a prototype of an AR and wearable computer system that provides information related to sights on the Columbia University campus (see Figure 2.4). The user wears a backpack and an HMD, and holds a handheld display and its stylus. Wayn Pierkarski (2001) is working on a similar concept at the University of Southern Australia (see Figure 2.5).

(a) (b)

Figure 2.4: (a) User wearing the Touring Machine (b) An augmented view of the library at Columbia University (images courtesy of Columbia University Graphics and User Interface Lab)

Figure 2.5: The Tinmith mobile outdoor augmented reality system (images courtesy of W. Piekarski and B. H. Thomas - University of South Australia).

Mark Billinghurst at HIT lab at the University of Washington works at designing and evaluating AR interfaces that allow users to effectively interact with augmented virtual objects as well as share them with each other in a simple and efficient manner, just as we do it with everyday physical objects (see Figure 2.6).

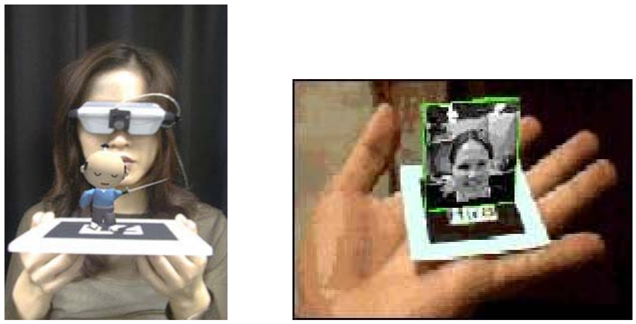

Figure 2.6: (a) Shared Space; (b) An AR display for meetings.

2.2.1. AR systems

Combining two visual scenes, one by a computer and one by the real world is the essence of augmented reality. In practice there are two methods to achieve the combined visual view that is employed in augmented reality. The first employs see-through head-mounted displays that are semi-transparent. Optics are used to relay a computer-generated scene to semi-transparent displays in front of the users eyes. The real world is simply viewed through semi transparent goggles, or some other display. This method yields computer-generated images that are slightly "ghosted" since the display lacks the ability to show opaque objects, and a real weld did this slightly darkened because the display is not totally transparent. The second method captures the real world with a video camera and then through some mixing process (either with the video equipment or computer software) transfers a combined view to a fully immersive head mounted display where the outside world is completely cut off visually. This method provides opaque images and brighter real scenes, but the user is more isolated and the "real" scene is now actually a video feed from the camera. While video quality has increased in recent years, it is still quite far from reality and typical display issues (image contrast, resolution, and field-of-view) arise with this method.

Despite the drawbacks to both augmented reality techniques, many successful systems have been developed. Applications are useful for any area where graphic-enhanced scenes help users have a greater understanding of their application environment (Azuma, 1997). Medicine, architecture design, maintenance and repair, manufacturing, annotation, data visual station, military, and entertainment are example where augmented reality has been use.

AR applications of either type typically uses head-mounted displays (HMDs) to display computer-generated graphics in addition to a real world scene. High precision head tracking provides the coordinates needed to accurately overlay graphics in the real world. A diagram of a generic AR system is presented in Figure 2.7. The integration of the real-world and computer-graphics coordinate system (i.e. graphics registration), as well as approaches to tracking are discussed below.

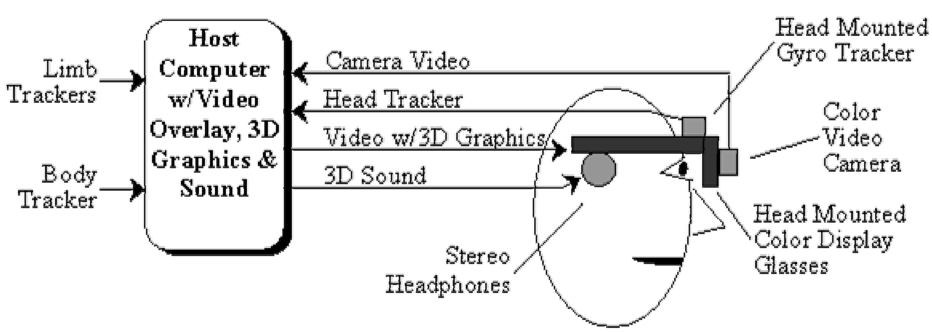

Figure 2.7: Schematic of generic AR system.

HMDs allow the user to view the world by turning his or her head to items of interest (as we normally do) rather than passively watching what is shown (as is common to most other displays). Furthermore, for augmented systems, the hands are free and visible along with the real world task (unlike with virtual reality systems where the entire environment – including the users hands is computer generated). Benefits of HMDs include:

- Sight and attention remain concentrated while data and images are displayed simultaneously
- Eliminates cumbersome manuals and external displays, freeing both hands of the operator
- Important information captures the attention of the user immediately. Traditional display systems must be noticed before the vital information can be conveyed

2.2.2. AR and the Registration Problem

A major difficulty in the application and acceptance of AR systems is the accuracy of the overlay of computer-generated graphics (Azuma, 2001). The generated information provided by an AR display is related meaningfully to real-world objects (e.g., the information represents an instruction related to an object, the information is information about an object, etc). It is a goal in AR, then, to maintain an accurate overlay of computer generated information onto a real world scene in order to maintain the illusion that the synthetic information and the real scene coexist.

Consider a medical application where computer-generated images are overlaid onto a patient (see Figure 2.2). Accurate registration of computer-generated imagery with the patient's anatomy is critical (Barfield and Caudell, 2001). If the virtual object is not where the real tumor is, the surgeon will miss the tumor and the biopsy will fail. The registration problem is a basic problem in AR that greatly hinders its acceptance.

There are many sources of potential registration error in AR systems. Azuma (2001) divides these errors into two categories: static errors and dynamic errors (Holloway, 2001 gives a thorough discussion of registration errors). Static errors of registration are those that occur when a viewer's viewpoint and objects in the world remain completely still. The four main sources of static error are: optical distortions, errors in the tracking system, mechanical misalignments and incorrect viewing parameters. Dynamic errors show when a viewpoint or objects begin to move. Dynamic errors are the result of system lags and they are the more common type of registration errors Methods used to reduce dynamic registration fall under four main categories: directly reducing system lag by manipulating software; reducing apparent lag by techniques such as image deflection (So and Griffin, 1992) and image warping (Mark, McMillan, and Bishop, 1997); matching temporal streams (with video-based systems); and, predicting future locations of objects (see Azuma and Bishop, 1994).

2.2.3. Sensing and tracking

Accurate registration of computer-generated imagery with a real world scene requires accurate tracking of the user's head and sensing of objects in the environment. A key requirement for creating the illusion of the coexistence of real images and computer-generated imagery is knowledge of the relationships among the object, world, and camera coordinate systems (Vallino and Kutulakos, 2001). These three coordinate systems are usually integrated into the same 3D Euclidean system. The following four steps are a simplification of the steps required to provide a prospective projection of computer-generated graphics in relation to real world objects:

1. Find the equation of the line segment connecting a general point P to the observer. Note the observer is the tracker, so this equation continuously changes as the tracker moves
2. Find the equation of the projection plane (i.e., screen).
3. Find the intersection of the line and the plane.
4. Convert the coordinates of the intersection point to screen coordinates.

Vallino (1997) has used an affine representation system that relates points on a real world object to a graphic generator using an affine reference system that does not require a common Euclidean frame for real world, camera, and graphics. In an affine reference frame, the projection of any point in the set can be computed as a linear combination of four points in the set. The affine representation allows the calculation of the projection of a point without having information about the camera position or its calibration parameters.

The coordinates produced by the tracking and scanning mechanisms indicate the location of imagery. The tracked viewing pose defines the virtual camera used to project 3D graphics onto the real world image, so tracking accuracy directly determines the visually perceived accuracy of augmented reality alignment and registration (You, Neumann, and Azuma, 1999). Rolland, Davis, and Baillot (2001) provide a thorough taxonomy of tracking technologies that emphasizes the underlying physical principles of operation and the types of measurements involved. The technologies discussed by Rolland et al. are summarized in Table 2.2.

Table 2.2: Summary of tracking technologies. Adapted from Rolland et al. (2001).

Technique	Physical phenomenon	Measured variable	Approach	Advantages	Limitations
Time Measurements:					
Ultrasonic Time-Of-Flight (TOF)	Acoustic pulse propagation	Time of flight	Active	Small, light, no distortion	Sensitive to temperature, pressure, humidity, occlusion, and ultrasonic noise from other electronic equipment
Phase-Difference	Phase difference (e.g., ultrasonic, optical)	Phase difference	Active	Less sensitive to noise than TOF systems, high data rate	Error increases in time since relative measurements. Sensitive to occlusion. Possible ambiguous measurements.
Global Positioning System (GPS)	Line-of-sight radio signal	Time of arrival arranging	Active	Worldwide availability, uniform accuracy	Sensitive to occlusion, currently suited to large scale tracking
Optical Gyroscope	Interference of light	Frequency of interference fringes	Active	Fast, accurate	Drift due to successive integrations, sensitive to vibration
Spatial Scanning:					
Outside-in Optical Scanning	Projection of an optical pattern	Shape of target features in an image acquired by a camera	Passive	Good update rate, self-contained	Sensitive to optical noise spurious light, ambiguity of surface, and occlusion.
Inside-out Optical Scanning	Spatial scan	Beam position or sweep detection	Passive	Better resolution than outside-in approach	Sensitive to occlusion

Technique	Physical principle	Measured variable	Approach	Advantages	Limitations
Inertial:					
Mechanical Gyroscope	Inertia	Orientation between the axis of the rotation of the wheel and the axis of the target	Passive	No reference needed	Drift of axis and measurements over time.
Accelerometer	Mass inertia	Depends on implementation	Passive	No reference needed, light.	Errors in position due to integration.
Magnetic Field Sensing	Magnetic coupling	Amplitude at the output of the receiving coil or sensor	Passive (when using Earth's magnetic field as reference)	No occlusion problem, small, inexpensive	Small working volume, accuracy degrades with distance. Sensitive to magnetic noise and metallic objects.
Mechanical Linkages	Mechanical linkages	Angle measured by rotating encoder(s)	Active	Good accuracy, precision. No environmental linked error.	Bulky, limitation of movement.

In attempts to confront the shortcomings of single-technology approaches to tracking, hybrid approaches that combine single-technology approaches have been proposed (table 2.3) with robust results. For example, You et el. (1999) exploited the complementary nature of natural feature trackers and inertial sensors to produce a hybrid orientation tracker that performs better than any of its components.

Table 2.3: Hybrid tracking technologies.

Approach	Examples
Active-Active	Magnetic-vision: State et al. (1996)
Active-Passive	Vision-inertial: Azuma and Bishop (1995) Acoustic-inertial: Foxlin et al. (1998)
Passive-Passive	Vision-inertial: You and Azuma (1999)

2.2.4. A Few Criticisms of Augmented Reality

In general, AR has the potential of improving our interactions with the world by providing access to databases that relate to objects in the world. This seems to be a noble goal that should be embraced and pursued by experts from a plethora of domains. Why, then, does AR research seem to be confined to Computer Science departments? The answer seems to be related to the technological difficulties of accurate registration and the automation of augmenting information.

Accurate registration is a difficult issue. The tracking methods listed above illustrate the complexities of this issue. Accurate registration is a difficult problem that is appropriately housed by computer science departments because of its technological requirements. Automatic and accurate registration of computer graphics is an appealing goal, but it is such a complex issue that issues related to usability and human factors easily become a secondary concern.

Many current efforts are aiming at automating the augmentation of the operator's environment. These efforts are also suited to computer science departments. Computers are certainly able to retain huge amounts of declarative knowledge. Entire libraries are stored on computers. Searching these huge databases to retrieve relevant knowledge on demand is another issue. Computers are not generally as adept as humans at retrieving knowledge on-demand. Whether this will change in the future is not at issue here. Recently, we have seen many advances in database management and intelligent searches that show an improvement in automated searches. For example, a search for the particular knowledge relevant to a particular machine repair will probably yield a huge amount of knowledge about the machine when performed automatically. The relevant knowledge that an operator really needs is likely to be buried.

Automation of expert augmentation is certainly a noble goal and a potentially fruitful pursuit, but how practical is automation in most potential application areas at present? Issues of function allocation and economics can help answer this question. The 'techno-centric' approach to providing augmentation leads to the same problem for the development of AR systems as registration, namely, it is a huge issue and a vast topic of research unto itself. The approach proposed below provides a method for studying usability, human factors, and psychological issues related to AR without serious involvement in issues of automation. The proposed system allows these issues to be studied while the issues of automation are concurrently pursued. It is assumed that issues related to automation will be addressed and meet up with issues related to users

2.3. Mental models

"Every person carries within his head a mental model of the world – a subjective representation of external reality" (Toffler, 1970). This simple definition captures the general idea of mental models; it has been developed somewhat differently in human factors literature and psychology literature. From the human factors position, Rouse and Morris (1986) defined mental models as "the mechanisms whereby humans are able to generate descriptions of system purpose and form, explanation of system functioning and observe do system states, and predictions of future system states." Young (1983) described mental models as a representation or metaphor that users adopt to guide their actions and to help them interpret and understand their interactions with a device or system.

From the cognitive psychology perspective Johnson-Laird (1981) provided a somewhat less functional description: "A [mental] model represents the state of affairs and accordingly its structure… plays direct representational or analogical role. Its structure mirrors the relevant aspects of the corresponding state of affairs in the world." In a later study he said that mental models "enable individuals to make inferences and predictions, to understand phenomena, to decide what action to take and to control its execution, and above all to experience events by proxy" (1983, p.397).

The concept of conceptual mental models is intuitively appealing to human factors designers as a memory structure (or set of memory structures) hypothesized to be a key mechanism whereby people are able to efficiently process a complex "state of affairs" of a system and represent a user's understanding of that system. Endsley (1995) notes several benefits of a well-developed mental model: (a) it provides the knowledge for the elements of the system that can be used in directing attention and classifying information the perception process; (b) a means of integrating the elements to form an understanding of their meaning; and, (c) a mechanism for projecting future state of the system based on its current state and an understanding of its dynamics.

2.3.1. Mental Model Development

Mental models are developed as a function of training and experience; experience (interaction with a system) leads to refinements of the model (Holland, Holyoak, Nisbett, and Thagard, 1986). It is desirable for novice's mental models to resemble those of experts since experts are assumed to have the most knowledge about a system (Hanisch, Kramer, and Hulin, 1991). Consequently, the structure of experts' mental models has implications for training and instructional aids. The framework provided by the expert's mental model provides structure for declarative knowledge of the system and the (presumably) analogical representation of the model allows for quick access to the benefits of a well-developed model. The development and refinement of this analogical representation is generally a function of experience and expertise is often lacking among particular users or operators of a system.

2.3.2. Formulations

Knowledge of the interrelationships between the concepts in a domain is a critical variable that influences initial learning, subsequent retention, and later knowledge transfer, and mental models can be viewed as a network of associations between domain concepts (Langan-Fox, Code, and Langfield-Smith, 2000). Various techniques have been used to elicit and represent individuals' (and, less frequently, teams') mental models (e.g., semantic nets, causal models, and propositions). Cognitive-interviewing techniques have been used by several researchers to elicit mental models (e.g., Calveri and Sterman, 1997; Lange and Burroughs-Lange, 1994; Hanisch, Kramer, and Hulin, 1991; Redding and Cannon, 1992). Among the advantages of cognitive-interviewing techniques are that it is straightforward and systematic, and consistent across interviewers and respondents (Langan-Fox et al., 2000). Representations of the clusters and cluster patterns of associated concepts are sometimes taken as representations of mental models.

2.3.3. Novice and Expert Mental Models

Mental models are of particular interest when considering complex systems. A well-developed mental model of a complex system is a representation of the system that can allow a user to interact with that system as if it were not so complex. A novice user, it is assumed, has at least some vague idea of system operation and important system components and sketchy rules or heuristics for determining the behavior he or she should employ with the system. The novice's model develops as recurrent associations and causal relationships are noticed as he or she becomes more experienced.

The expert's mental model is said to contain more information than that of the novice. Greeno and Simon (1984) note three aspects of a mental model that improve as experience increases: internal coherence, validity, and integration. Internal consistency refers to the extent to which knowledge of a system is organized in an integrated structure. Supposedly, this facilitates learning and improves the probability of recalling procedures and commands to operate the system. Validity refers to the correspondence of an operator's representation of a system and the output or performance of that system. Integration has to do with relations of the operator's mental model to knowledge in other areas. Experience strengthens each of these aspects and knowledge through experience fleshes them out.

Holland, Holyoak, Nisbett, and Thagard (1986) theorize that the development of a mental model involves learning a) categorization functions that allow people to map from objects in the real world to a representative category in their mental model, and b) model transition functions that describe how objects in the model will change over time. By comparing the predictions of internal models with the actual state of the system, the model is progressively refined. Refined models include more specific and numerous categorization functions, which allow for more accurate predictions based on detailed object characteristics and better transition functions for these specialized categorizations. For example, this process enables people to progressively refine their classification of a perceived object to an aircraft to fighter aircraft to F-18 to F-18c and gives them a more refined idea of the behavior and capabilities of the aircraft (Endsley, 1995).

Holland et al.'s (1986) explanation includes a "Q-morphism" in which default information for the system is provided in a higher layer of the model (i.e., a more general level of classification). This provision allows an individual to predict system performance when only limited information is available. For example, a pilot will make decisions based on general knowledge of how aircraft fighters maneuver if the specific model of aircraft is unknown. One of the ways expert mental models differ from those of novices is adequacy of *default information*. Expert mental models provide access to reasonable defaults that lead to more effective behavior than that of novices who simply have missing information (or poorer defaults).

An expert operator can quickly recognize a situation and relate it to a mental model (Endsley, 1995). Upon recognition, the operator can identify system functions and decide behaviors. Klein (1989) argues that recognition and the identification of analogous cases are more central to expert decision-making than option comparison. This recognition-primed decision (RPD) model (see Figure 2.8), Klein argues, estimates proficient decision-making in natural settings. It involves four major steps: a) recognizing cases as typical; b) situational understanding; c) serial evaluation; d) mental simulation.

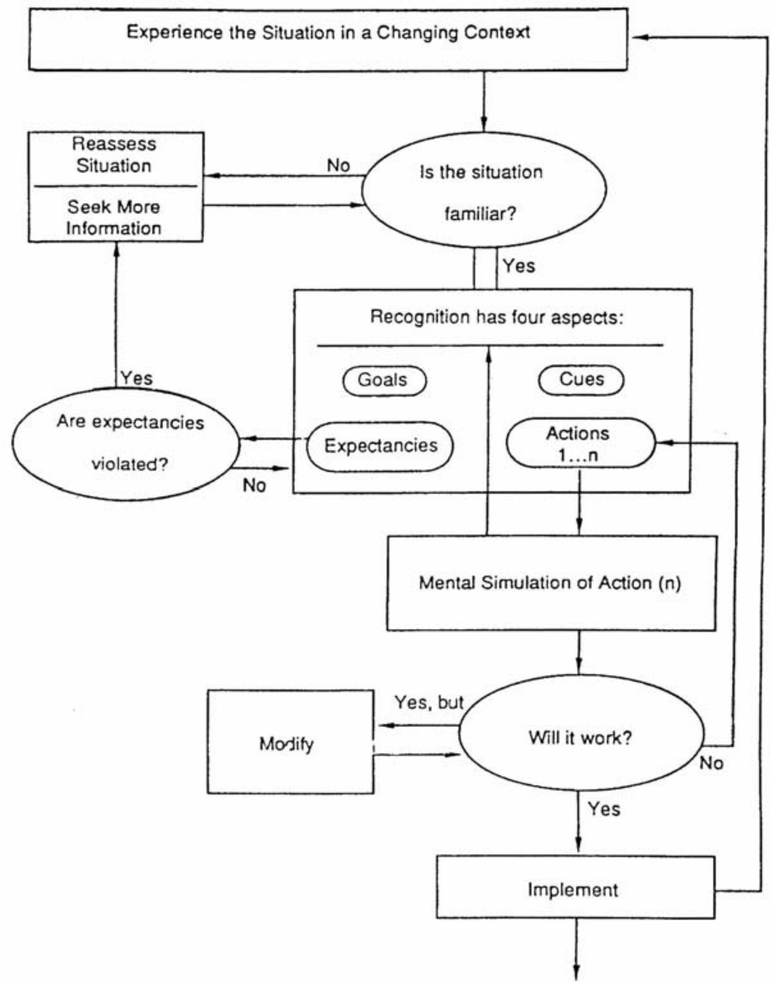

Figure 2.8: The Recognition-Primed Decision model [from Klein, 1989]

Although they are not identified explicitly in Klein's figure, mental models fit into different aspects of the RPD model. Mental models are surely involved in the recognition step of the model. Mental models are, in fact, the structures that will (or will not) be recognized. "Mental Simulation of Action" equates to running the mental model. As mentioned later, the computational function is a hallmark of mental models.

Option comparison (the decision-making process ascribed to novices) is a time-consuming process. The expert mental model allows for quick evaluations of hypotheses as well as a large base of recognizable situations. These features of an expert mental model allow the expert to perform automatically as situations are recognized and the appropriate model is activated.

Expert mental models seem to achieve the goal of simplifying the representation of a system to further extent than those of novices. Recognizing and remembering large amounts of system information, as well as recognition speed are implications of a well-defined mental model. Likewise, presuming future system states and understanding the capabilities and behaviors of comparable systems are benefits of mental models.

In sum, mental models of experts are expected to differ from those of novices in several ways. Following is a list of four differences between expert and novice mental models of an exemplary system (an automobile):

- The mental models of experts hold more information than those of novices. This great amount of information probably results from experiences yielding memories of variations of system functioning and the summation of declarative knowledge in procedural units. The expert mental model of an experienced automobile mechanic just retains more information that that of a novice. An experienced mechanic knows the functions and assembly of car parts, even sub-components of the components.
- Expert mental models lead to more refined ideas and projections of system behavior and capability. An experienced mechanic will be able to predict the

behavior of a car under certain circumstances. This is helpful in prediction as well as diagnosis since the mechanic can estimate the history of circumstances.

- The mental models of experts incorporate more reasonable defaults than those of novices. This allows operators to presume reasonable situations. The expert mechanic can presume reasonable values for certain components of a car (e.g., RPM, oil temperature, air-intake, gasoline level, etc.) so as to improve diagnoses or predictions.
- Expert mental models result in quick recognition of system states. In fact, this recognition can be accomplished in one step, rather than sequential steps as information is added. Automatic processing lessens the consumption of cognitive resources and allows an expert to project future states of the system and interactions with other systems since more resources are available for these types of cognitive processes. An expert mechanic can diagnose a car problem quickly by looking it over or even just listening to the car. Quick recognition of the problem allows the mechanic to spend cognitive resources on aspects of solving the problem (e.g., the actual labor, tracking down parts, scheduling, etc.).

Researchers have generally taken one of two positions when the concept of mental models has been applied to systems design. One is that the displays of a process or system must be compatible with operators' internal representations of the system; the other is that the displays themselves allow or determine that certain mental models be built up (Wilson and Rutherford, 1987). Wilson and Rutherford (1989) point out that the opinions that "information being presented about the system behavior must fit with the existing internal model of the system because that is the reference of change" (Kantowitz and Sorkin, 1983), "interface design can influence the formation of a user's mental model" (Bennett, Parasuraman, and Howard, 1984), and "the designer is obliged to ensure the users have or construct an appropriate user model" (Thimbley, 1984) are not wholly contradictory.

A primary difference between novice and expert mental models is the amount of detail within them. It follows that some systems capitalize on novice users' internal representations of a system and arrange displays and system components when extensive details of the system are not required. Details can be confusing for a novice. In order to operate a system to accomplish a particular goal, a thorough model of the system is not necessary.

In many situations, only the current state of a system and a goal state are known. The operation of the system to achieve the goal state is vague and the operation might not even be important. This is especially true for safety and emergency systems. Consider a fire extinguisher. Many buildings are required by law to be equipped with fire extinguishers based on the assumption that, in the event of fire, somebody will extinguish it - quickly.

Consideration of the novice's mental model of a fire extinguisher is key to its design. It is likely that the novice fire fighter will have at most minimal experience with a fire extinguisher, but it is probable that he or she will be familiar with things like aiming a nozzle and pulling a trigger. Therefore, a fire extinguisher's design should capitalize on the concepts and models that are common so it operates the way people expect it should.

Paying attention to novice mental models in systems design is not only important for improving the interactions of untrained individuals with systems, but trained individuals can benefit as well. It is likely that, in emergency situations, a trained individual may get lost in system details and forget a feature of the system that is obvious to the novice. For example, a trained individual may be thinking about the relationship between the chemicals in the extinguisher and those in the fire, and mis-aim the nozzle. Even experts sometimes revert to basic models of operations in emergency situations.

System designers should consider the structure of novice mental models when designing systems intended to be used by untrained users in addition to emergency systems. For example, a subway map (e.g., DC Metro) will be more effective for travelers if it omits some detail and illustrates only common landmarks and routes.

2.3.4. Benefits of exposure to an expert's mental model

Mental models are continually evolving representations of system operations (Endsley, 1995). Models evolve as new information is added and an updated model is required. With experience, novel information becomes less common and a model becomes more stable. A stable mental model is a result of numerous iterations of representations. Admittedly, a mental model is a theoretical memory structure that is likely to be meaningless to a novice operator; furthermore, the explicit display of experts' mental models is likely to be impossible. Aspects of the structure of an expert's mental model, however, may benefit an operator by identifying causal relationships and structuring information. A non-exhaustive list of plausible benefits follows

Exposure to an expert's mental model can accelerate the development of system knowledge by providing a type of scaffolding to *support learning*. The scaffolding can accelerate the novice's movement up the system learning curve by providing summations and hints at points along the curve.

Expert mental models retain a greater amount *of procedural rules and more extensive repertoire of procedures* than novices. While it is true that such procedural knowledge is mostly ineffable, the novice can develop these procedures, through observations of demonstrations by the expert and "going through the motions" as directed by the expert, in less time than the expert required to learn the procedures.

The expert mental model holds more information about the causal relationship of system components. Experts are adept at realizing the effects of component settings on overall system performance by running their models. Experts can identify the effects of component states on overall system performance better than novices. This feature of expert mental models (i.e., predicting system performance) is beneficial since it saves time and expense by allowing for the *mental simulation of system performance*. This is also a good feature for addressing safety issues. An expert can run through a simulation of a change to the system before sending an operator on a fool's errand.

Knowledge of the causal relations of system components is also valuable because it allows an expert to presume component states and settings. This is an important aspect of *trouble-shooting*. It allows for a type of fault-analysis that zeros in on a fault by presuming the usual states of components and noting the effects of a deviation in some component's actual state. Mental models of experts provide adequate default information that can be compared to actual information in order to identify major discrepancies.

Experts can *identify particularly important cues* that may not be especially salient. An expert can highlight a cue that he or she knows will have a big impact on system functioning. For example, an experienced meteorologist may see as very important a cue dismissed by a novice, such as an advancing cold front. By highlighting the front, the expert leads the novice to adjust his evaluation of the weather system accordingly.

Experts bring a store of previous experiences. They are able to *recognize a variety of situations* as similar to ones already experienced. Interactions with a system can be fast because system states and situations are recognized as a whole, rather than exhaustively researched. For example, my PC crashed recently due to a faltering power supply. The expert technician was able to make this diagnosis by knowing what happens when a power supply fails. Further, he had experience will several modes of PC failures. The list of failure modes was reduced as he systematically looked for symptoms of other plausible failure modes. The number of other plausible modes was small since the characteristics of the crashed system were recognized; also, knowledge of informative cues makes checking other cues (symptoms) fast in most cases. Klein (1989) argues that recognition is a key feature in decision-making.

An operator can benefit from these stores of knowledge. An expert can *refer the operator to a store of possibilities* an expert has compiled. For example, an inexperienced computer programmer may know only one way to write the code for a particular task. This may not be the most efficient way and it might not even fit the larger program. The expert is familiar with the entire program and several alternatives. By suggesting alternatives, the operator saves the time required to develop and test new code.

2.3.5. Transferring procedural knowledge

A key feature of an expert mental model is that it provides a structure and organizational framework for extensive knowledge and data derived from experience. This data, without an efficient organizational framework is overwhelming. A well-developed model slowly develops, as data is made available. Development of the model and the accumulation of data (via experience) run in parallel. As the model develops, the developing expert increases his or her understanding of operation of the system by following the expert's lead through system operations – not necessarily written words.

As mentioned above, the novice improves his or her mental model by "going through the motions" as directed by the expert. In this way, the novice saves the time required to learn the declarative knowledge and details underlying the procedures. The expert supposedly spent this time in developing his or her mental model. The means of sharing a mental model is akin to an apprenticeship model of learning. The novice benefits from observation of the expert.

The knowledge of procedures can result in very complex interactions with an environment. An environment usually invokes a series of procedures that could not be planned or declared before exposure to the environment. Suchman (1987) uses down-river canoeing as an analogy to illustrate how action and interpretation are tightly coupled with the context and timing of environmental (system) responses. Consider a canoe-operator who cannot specify his or her course before the trip, but the goal and environmental responses lay out the course as the trip goes on. The canoe-operator is not required to remember the particular river or course, but a goal and a repertoire of procedures insures a successful trip.

2.3.6. Representation and the importance of interaction and communication

The interaction of the expert/novice plays in important role in the interaction of experts and operators. The expert's mental model is already instantiated in the expert, so direct representation of the model is not necessary. While it is true that mental models cannot be represented *per se* and an effort to represent them is likely to fail, an operator can benefit from exposure to an expert's mental model.

The expert's mental model cannot be written or drawn, but it can be expressed through the interaction between operator and expert. This interaction allows the expert to guide the novice operator through the expert's mental model. By behaving according to the expert mental model, the novice operator has the opportunity to learn to perform like the expert or, at least, manifest the expert's performance. The operator acts as a tool by which the expert's performance is expressed.

2.4. Diagrammatic Displays

Kieras and Bovair (1984) and Kieras (1988; 1992) have developed a paradigm for exploring applications of diagrams and diagram displays, and how they support mental model reasoning. A significant finding of Kieras and Bovair (1984) is that the provision of diagrams (that, it is claimed, convey mental models) improves operation of a device in malfunction situations and efficiency of procedures.

Whether a diagram represents an actual mental model is debatable. A mental model is, by most definitions, unique to an individual (a personal construct) and tacit. It is also unknown whether a mental model is graphical in nature. The diagram is a standardized model that is presumed to be a good proxy for an expert's mental model, since it contains the necessary information. This work is based on the claim that *diagrams convey mental models.* As discussed by Kieras (1988), a mental model contains:

- *Knowledge of the system structure:* the components and their inerconnections (the system topology)
- *Knowledge of the principles* that govern the behavior of the system.
- *Strategic knowledge* about how to perform tasks using the structure and principles information.

Chapter 3: Proposed Methodology

The current study involved the experimental task and materials based on those used by Kieras and Bovair (1984). The Kieras and Bovair (1984) study examined the role of a mental model in participants' interactions with an unfamiliar piece of equipment/device. The type of device employed was a control panel simulated on a computer screen (see Figure 3.1). Participants pressed keys on an attached keyboard as a simulation of their interactions with the control panel. Following Kieras and Bovair, the term "device" refers to this control panel. "Device" is a more general term than "control panel".

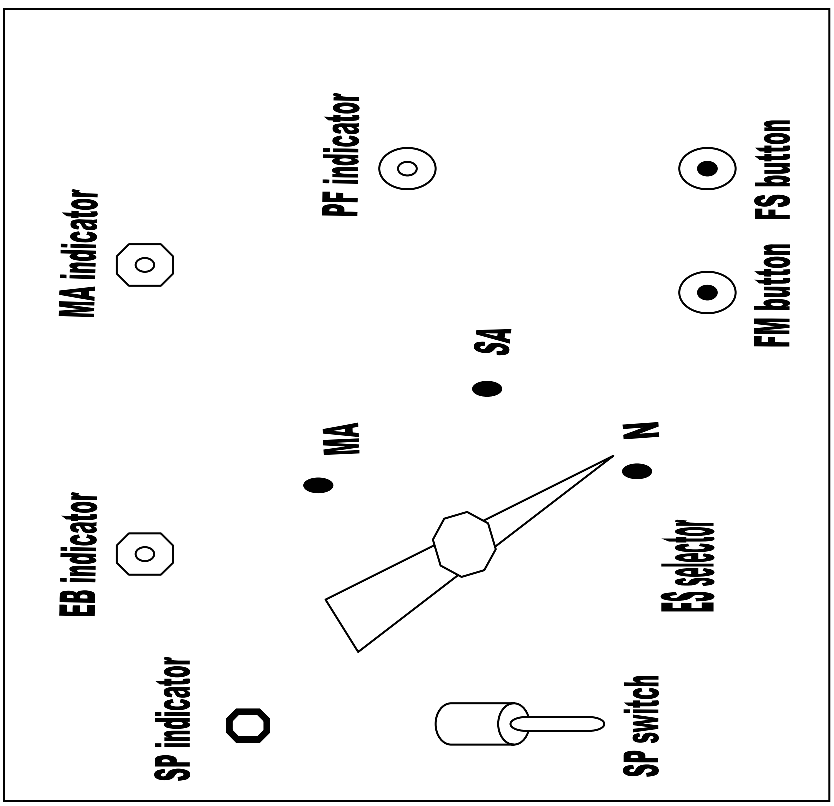

Figure 3.1: An illustration of the device.

The device represented a fictional device from the *Star Trek* TV series – a phaser firing control device. It was explained to the model groups that the device's main function was to route power to the phaser banks and fire them. The following explanation was given to participants:

"The energy booster takes in power from the ship and boosts it to the level necessary to fire the phasers. Power that has been boosted by the energy booster is fed into the two accumulators. Both accumulators store large amounts of power ready to be discharged to the phaser bank whenever the phasers are fired. Because the accumulators handle such large amounts of power, if they are used continuously they are liable to overload and burnout. To prevent continuous use of one accumulator, this system has two: the main accumulator (MA) and the secondary accumulator (SA).

The power coming in from the shipboard circuits is controlled by the ship's power switch (SP). When the switch is off, no power is being drawn from the ship. When the switch is turned on, power is drawn from the ship into the energy booster. To boosted power is then fed into the accumulators. The accumulator whose energy will be discharged to the phaser banks is selected by the energy source selector (ES). While the ES selector is set to neutral (N), no energy can be discharged from either accumulator to the phaser bank. If the ES selector is set to MA, then pressing the "fire main (FM)" button will use the main accumulator's power to fire the phasers. . If the ES selector is set to SA, then pressing the "fire secondary (FS)" button will use the secondary accumulator's power to fire the phasers."

Figure 3.2 presents a diagram of the device illustrated in Figure 3.1 that complemented the model explanation. Whether this model represents an actual mental model is debatable. A mental model is, by most definitions, unique to an individual (a personal construct) and tacit. It is also unknown whether a mental model is graphical in nature. This work is based on the claim that *diagrams convey mental models.* As discussed by Kieras (1988) a mental model contains:

- *Knowledge of the system structure:* the components and their inerconnections (the system topology)
- *Knowledge of the principles* that govern the behavior of the system.
- *Strategic knowledge* about how to perform tasks using the structure and principles information.

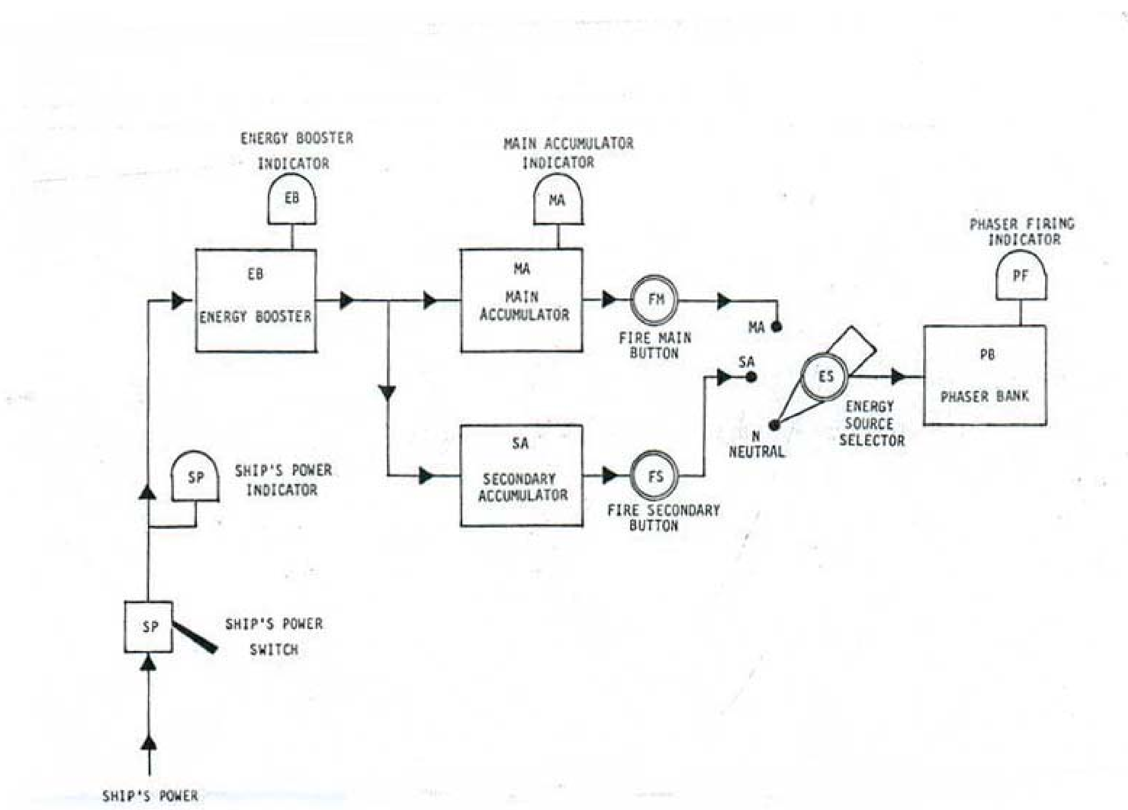

Figure 3.2: The block diagram model representation of the device model.

In the current study, all of the displays used were generated using Microsoft Visual Basic. Some modifications to Kieras and Bovair's device were introduced in this study in order to gain further insight into operators' interactions with the device. The device and model used here are shown in Figure 3.3.

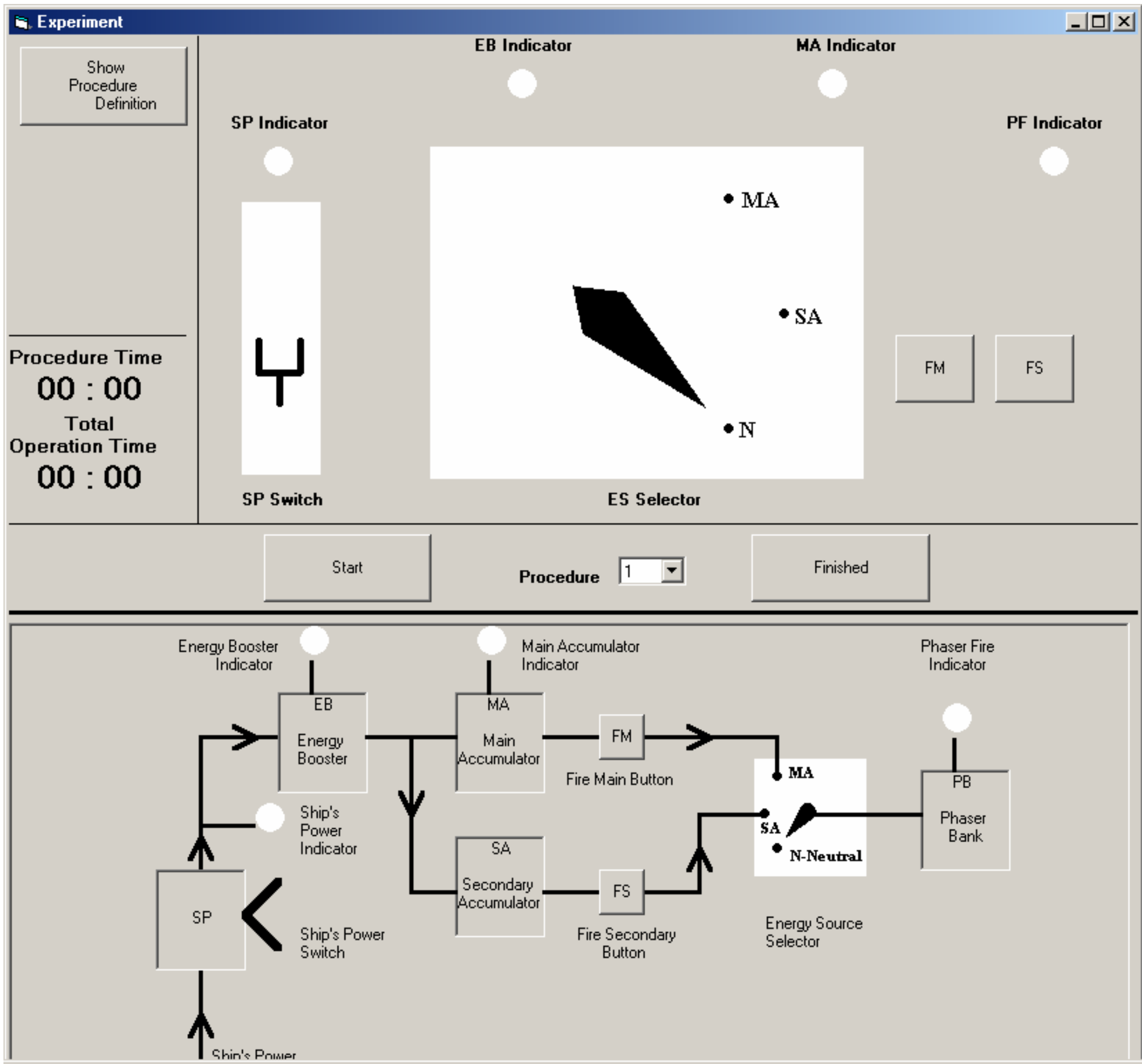

Figure 3.3: Device and Device Model.

Kieras and Bovair's task (operating a control panel) was justified as a common task that is generalizable to interactions with other systems that involve operations with similar controls. However, significant additions to the Kieras and Bovair model include the “Show procedure definition”, “Start”, and “Finish” buttons; and the procedure selection step. The “Show procedure definition” button allowed operators to review the steps involved in a procedure during operation of the device. All other buttons on the device were inactive while the procedure definition is shown. When the button was clicked again, the device was re-activated and the procedure definition disappeared. This allowed the experimenter to record the procedures used and how long an operator reviewed the procedures. The “Start” and “Finish” buttons took the place of the keystrokes used originally; the buttons were incorporated with the device.

In addition to the physical layout of the device, the indicators displayed serve as potential cues for operators. The states of the indicators had implications for the selection of procedures. Table 3.1 summarizes the indicators (operation cues) displayed. This table was not provided to participants.

Table 3.1: Indicator meanings and implications.

Indicator/Cue	**Meaning**	**Implications**
SP indicator	On indicates ship power is available; Off indicates ship power is not available	If on, then continue. If off, then go to procedure 7.
EB indicator	On indicates that energy is being routed from an energy source to the energy boosters. Off indicates no energy is being routed to the energy boosters.	If on, then MA or SA is active. If off, no energy source is active.
MA indicator	On indicates MA is active. Off indicates MA is not active.	If on, then procedures involving MA (1, 3, 5) may work.

		If off, then procedures NOT involving MA (2, 4, 6) may work.
PF indicator	Indicates a successful operation.	If on, then complete procedure. If off, then select a different procedure.

The current study is a laboratory study that examined the effects of five methods of augmenting the device illustrated in Figure 3.3 (Device Only, Device + Model, Device + Procedural Indicators, Interactive Model, and Interactive Model + Procedural Indicators) in order to improve performance in operating the device. An operator's interactions with a device in abnormal conditions and understanding of a device are likely to improve when an operator is given a model of the device. Presenting the device with superimposed procedural indicators closely resembles standard augmented reality displays – aspects of which (such as physical and temporal relations to the real world) afford additional support mechanisms and will improve performance beyond abstract presentations of the model. Therefore, an operator's understanding of the device and his or her performance with the device is most likely to be supported by the presentation of an interactive model with procedural indicators.

3.1. Experimental Design

Five groups of 10 participants were asked to successfully operate a simple control panel device consisting of switches, pushbuttons, and indicator lights. Getting a certain indicator light to flash (the goal of the device) marked a successful interaction. The types of augmentation provided for the interaction differentiate the groups. The independent variable in the experiment was augmentation type with five levels: Device Only, Device

+ Model, Device + Procedural Indicators, Interactive Model, and Interactive Model + Procedural Indicators. Performance during normal operating conditions and malfunction conditions was studied.

Participants in all groups were given a list of seven procedures for operating the device (see Table 3.2). Two of these procedures were designated as “normal” operating procedures, and these were successful (i.e., resulted in the flashing indicator) on the majority of trials. Participants were instructed that the system occasionally malfunctioned and the normal procedures were not effective, and one of five “malfunction” procedures would work instead. Operators could review the procedures during operations.

3.2. Research questions

The main focus of this study was to examine the effects of exposure to different types of visual augmentation of a device on operations of the device. These effects are presumably manifested in the selection of operating procedures during device malfunctions and increased performance speed. The independent variable of this study was augmentation display type. The five types of augmentation-display examined were: Device Only, Device + Model, Device + Procedural Indicators, Interactive Model, and Interactive Model + Procedural Indicators.

Data collected included performance measures and measures of operators’ assessment of workload and conceptual understanding of the device. Performance measures such as operation times, number of support references, reference times, incorrect procedures selected (errors), and questionnaire responses were collected. The following major research questions were addressed.

The first research question here was: how does displaying to operators a device model at the same time as the device itself influence performance relative to operators exposed to the device only? Kieras and Bovair (1984) suggested that displaying a model helps operators to remember procedures and they will interact with a device more efficiently than operators without a model.

Presumably, displaying a type of model (augmentation) visually combined (superimposed) with the device itself should improve interactions beyond presenting an abstract model. Thus, a second research question presented itself: how does a display of a model that is visually incorporated with the device concerned influence performance compared to an abstract device model? It is possible that a model constrained by the physical layout of the device will make the device more difficult to operate, but it is more likely that the model will lead to improved interactions.

A third question concerned encoding procedural information via the superimposed augmentation: how does the procedural information encoded in the superimposed augmentation influence operators' performance? Since this type of augmentation can indicate features of the device at each step in a procedure, it can be easily adapted to dynamically relate procedural information to operators. However, the added graphics may hinder operations.

3.3. Participants

The participants for this study were individual undergraduate students that agreed to participate in the study in exchange for $10. Since some familiarity with flow diagrams is assumed, CS and ISE students were be used.

3.4. Operating Procedures Given to Participants

The device either worked normally or malfunctioned. In malfunction situations, operators chose from five malfunction procedures. The operating procedures are shown in Table 3.2. This table was provided to participants.

Table 3.2: Operating procedures

Normal procedures

Procedure 1	Turn SP switch on; Set ES selector to MA; Press button FM; Wait until PF indicator finishes flashing; Set ES selector to N; Turn SP off; Press the “Finish” button
Procedure 2	Turn SP switch on; Set ES selector to SA; Press button FS; Wait until PF; indicator finishes flashing; Set ES selector to N; Turn SP off; Press the “Finish” button
Malfunction Procedures	
Procedure 3	Turn SP switch on; Set ES selector to MA; Press button FM; Wait until PF indicator finishes flashing; Set ES selector to N; Turn SP off; Press the “Finish” button
Procedure 4	Turn SP switch on; Set ES selector to SA; Press button FS; Wait until PF; indicator finishes flashing; Set ES selector to N; Turn SP off; Press the “Finish” button
Procedure 5	Turn SP switch on; Set ES selector to MA; Press button FS; Wait until PF; indicator finishes flashing; Set ES selector to N; Turn SP off; Press the “Finish” button.
Procedure 6	Turn SP switch on; Set ES selector to SA; Press button FM; Wait until PF; indicator finishes flashing; Set ES selector to N; Turn SP off; Press the “Finish” button.
Procedure 7	Turn SP switch on; Turn SP switch off; Press the “Finish” button.

3.5. Procedures

3.5.1. Levels of Independent Variable

Five methods of augmenting a device (Device Only, Device + Model, Device + Procedural Indicators, Interactive Model, and Interactive Model + Procedural Indicators) yielded five experimental groups (see Figure 3.4). Since exposure to more than one display could bias performance, display type was a between participants factor.

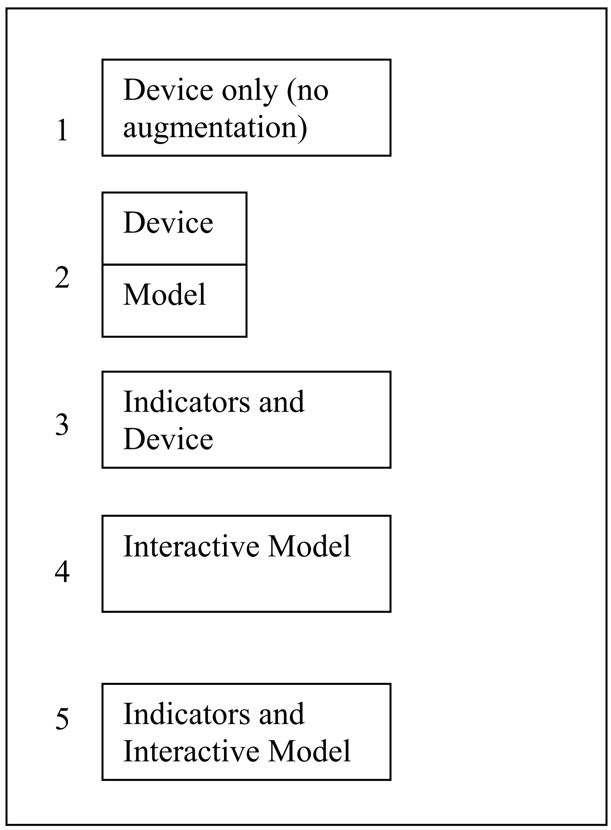

Figure 3.4: Experimental groups.

3.5.1.1. Device Only Group

All groups had *the same* brief list of procedures for operating the device available for review while they were actually presented with it. The procedure was displayed when a button labeled "Procedure definition" was pressed. Participants in the device only group relied on the displays of procedures and the device itself. The labels of features of the device that were used in the procedures matched the abbreviations of labels in the model, so identical procedures were used for all groups. Since all groups studied these procedures, this group served as a baseline of minimal performance support. The display for the Device Only condition is shown in Figure 3.5.

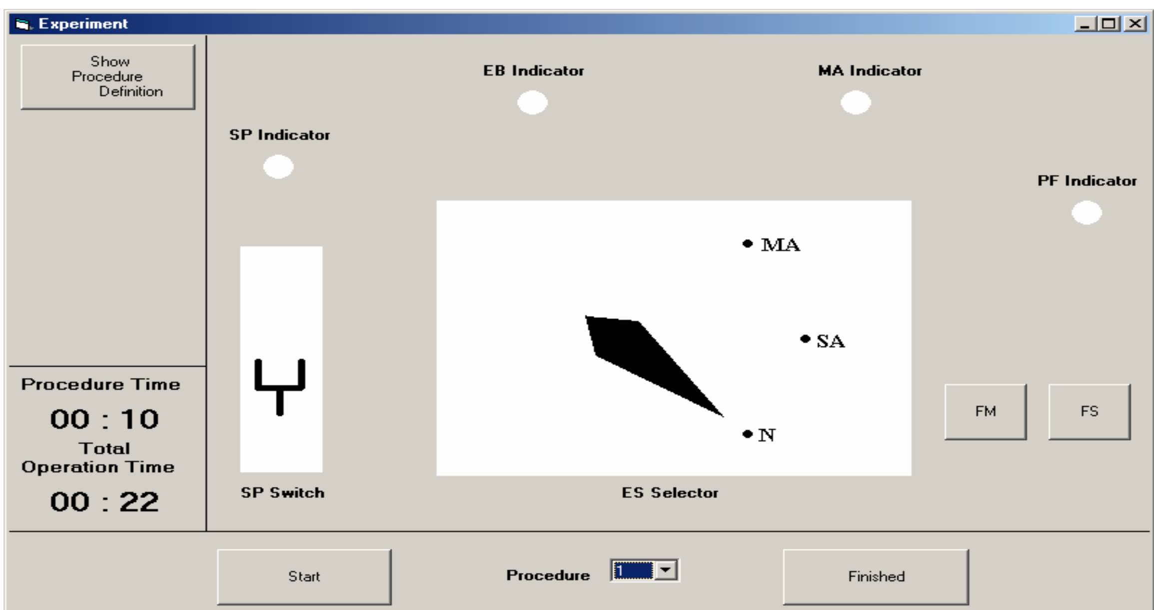

Figure 3.5: Condition 1: The Device Only display.

3.5.1.2. Device and Model Group

The Device and Model group was similar to the device model group in Kieras and Bovair (1984): "The device model group learned some how-it-works knowledge in the form of a description of the device based on the familiar television science fiction series *Star Trek*. Namely, they were taught that the device was a control panel for a "phaser bank" on the "Starship Enterprise," with the flashing light indicating a successful firing of the phaser bank. The internal components and processes of the device were explained in terms of this fictitious system." In addition to this explanation, participants reviewed a block diagram that illustrated internal processes while the device was displayed (see Figure 3.6).

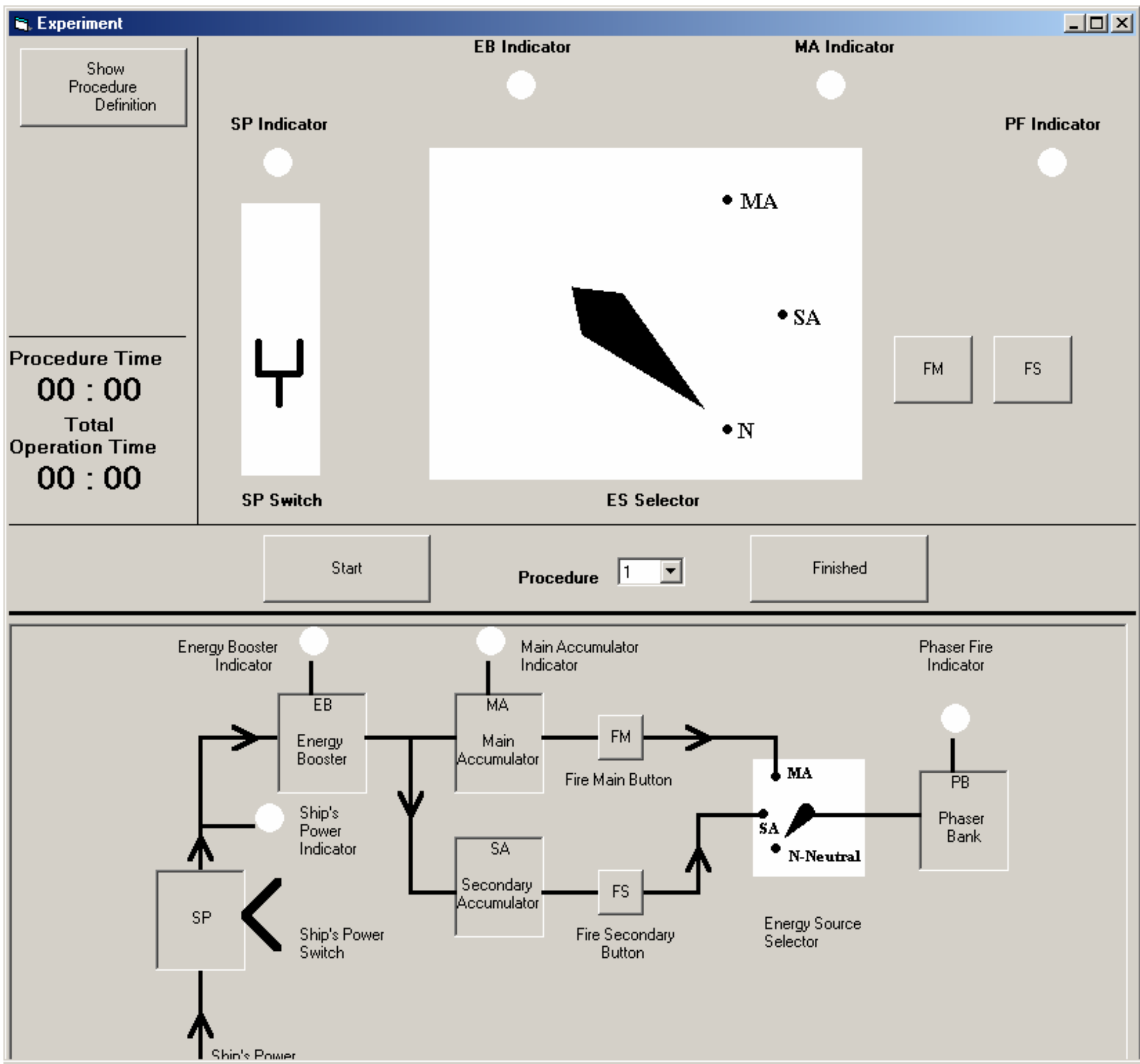

Figure 3.6: Condition 2: The Device and Model display.

3.5.1.3. Device and Procedural Indicators

The same textual description of procedures was available to all groups. In addition to this textual information, indicators (arrows) pointed to each step in a procedure in the Device and Indicators group; the arrows (augmentation) were superimposed on the device (see figure 3.7). Dark gray arrows pointed to all steps at all times in order to represent the entire procedure. The arrows were numbered and they were colored green when the step indicated was next in the procedure, in order to represent the procedural aspects of operating the device. The dashed lines showed the relation of a button or setting to an indicator (light) on the device. For example, setting the ES selector to MA caused the EB and MA indicators to light.

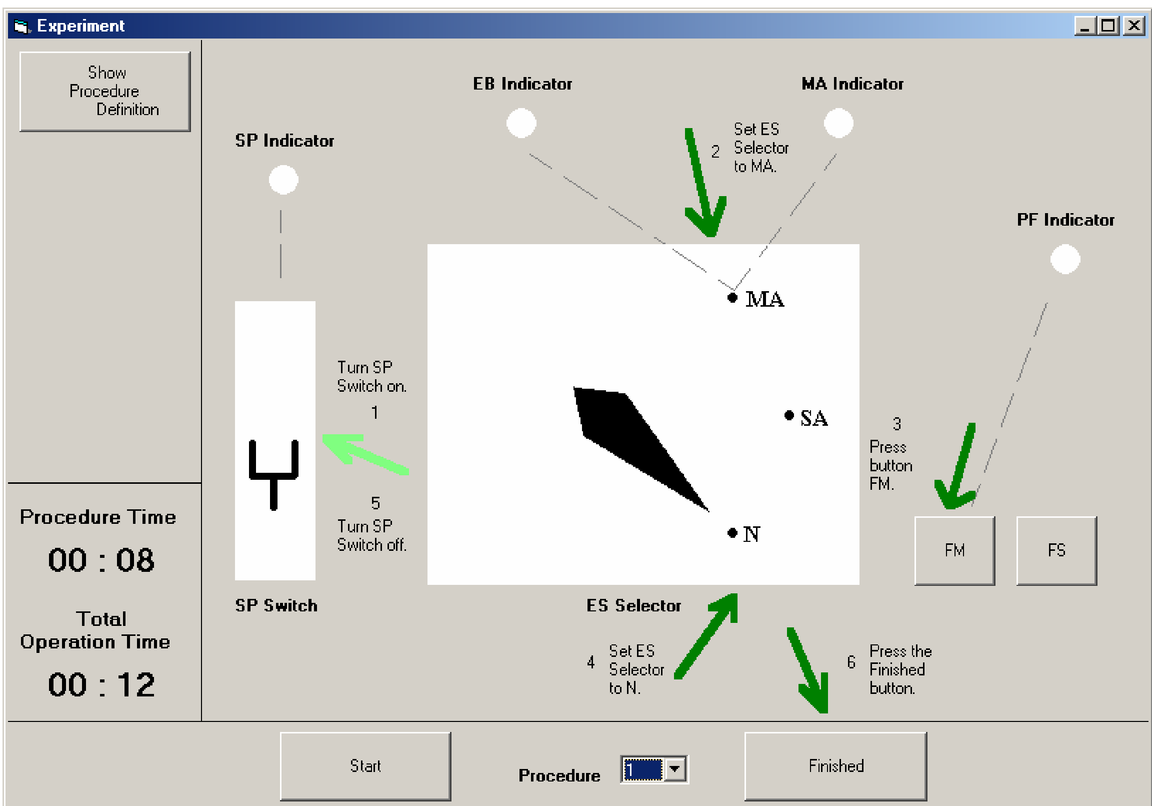

Figure 3.7: Condition 3: The Device and Indicators display.

This display most closely resembled a traditional augmented reality display. Since superimposing the model in the previous condition (lower section of Figure 3.6) onto the device (upper section of Figure 3.6) resulted in a confusing display, the indicators/arrows made up the augmenting display and they served as the model. The augmentation superimposed on the device provided further support for operators because they were constrained by the structure of the device and they did not require a redesign of the existing device.

It is arguable whether the inactive procedural indicators (dark-green arrows) along with the active ones (bright-green arrows) constitute a model. The procedural indicators fill the roles of a model discussed in Section 2.4. While it is true that a more substantial model could be designed, the model provided by the procedural indicators is sufficient for present purposes.

3.5.1.4. Interactive Model

A significant redesign of the device that successfully matched the model presented may help to convey a more accurate model of the device to operators. The device presented to the interactive model group was the model itself; the functions of the device were available to the model (see Figure 3.8).

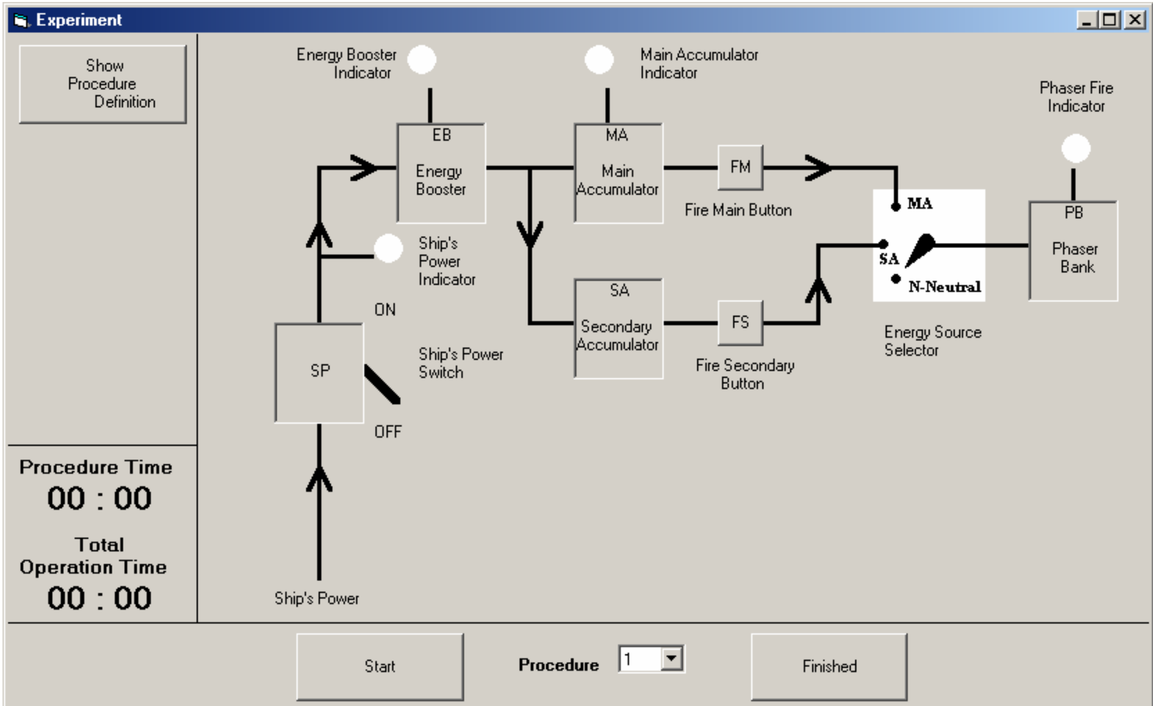

Figure 3.8: Condition 4: The Interactive Model display.

3.5.1.5. Interactive Model and Procedural Indicators

A fifth condition that intended to combine the procedural knowledge expressed by the indicators with the model, rather than the device is the Procedural Indicators and Interactive Model condition (see Figure 3.9).

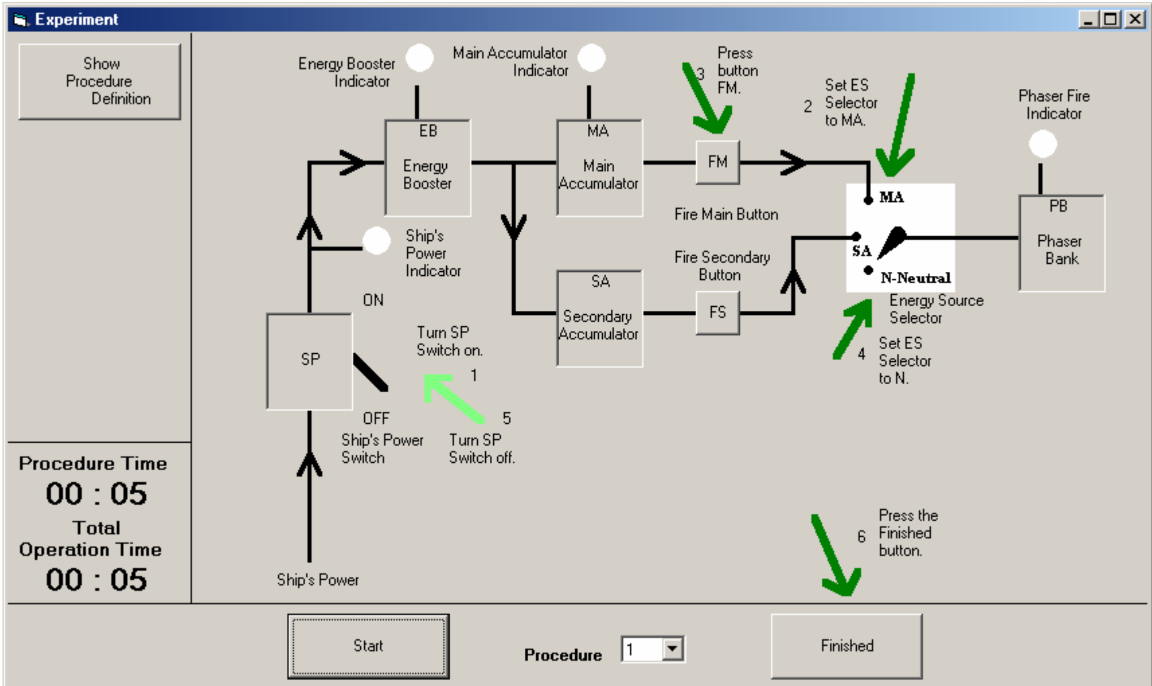

Figure 3.9: Condition 5: The Interactive Model and Procedural Indicators display.

3.5.2. Measures of Dependent Variables

Data collected included performance measures and subjective measures including questionnaires (see Appendix A), NASA – TLX (see Appendix B), and verbal responses.

3.5.2.1. Performance measures

Performance measures such as operation times, number of support references (how often "Define procedure" button was clicked), reference times (duration procedure was displayed), and incorrect procedures selected (errors) were recorded.

3.5.2.2. Subjective Measures

Subjective measures offered an insight into participants' interactions with the device that might not be provided by performance measures. Four types of subjective measures were gathered:

1. *General questionnaire items* were constant across subject groups and asked about participants' interactions with the device. The questionnaire (see Figure 3.10a) gave some insight into how operators interacted with the device. It is likely that some operators formed their own mental models independently of the given model. The questionnaire reflected subjective views on the tasks and model.
2. *Group-specific questionnaire items* focused on particular design features of the display presented to each group were presented (see Figure 3.10b-f).
3. *The NASA Taskload Index (TLX)* permitted the operator to rate the task on the following sub-scales: mental demand, physical demand, temporal demand, performance, effort, and frustration level. The TLX methodology calculated a weighted average for each operator and provided workload measures for each of the subscales. Wickens (1992) suggests that the TLX technique, which has a greater number of scales and better resolution per scale, allows more information to be conveyed. Completion of the TLX required participants to rate the task on one of six graphic sliders corresponding to the six subscales of the TLX and select from a pair of the subscales (presented on index cards) the one most important to participants during the task (see Appendix B).

4. *Open-ended questions* were asked of each participant, in order to get a rich insight into the participants' interactions. The verbal responses were recorded and transcribed. These questions are listed in Figure 3.11.

All questionnaire items used the same scale.

|_______________|_____________|___________|____________|

1	2	3	4	5
Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

General questionnaire items:

1. I believe the device displayed actually controlled the process.
2. I felt supported/able to operate the device.
3. I felt involved in the task.
4. The indicator lights on the device helped me determine the working procedures.
5. The route of energy flow to the phasers was clear.
6. The task was easy to do.
7. The task was easy to understand.
8. The layout of the device matched my model of it.

(a)

Questionnaire items for condition 1:

1. The simplicity of the device made it easy to operate.
2. The layout of the device matched the way I think energy is routed through the phaser-banks.
3. I found the display of the procedures onscreen as helpful as the paper.

(b)

Questionnaire items for condition 2:

1. The correspondence of the device (top) and the model diagram (bottom) was clear.
2. It was difficult to visually integrate the device (top) and the model (bottom)
3. I scanned the model (bottom) frequently.
4. The model (bottom) made it easier to understand the procedures for operating the device (top).
5. The presence of the model/diagram (bottom) made it easier to operate the device (top).

(c)

Questionnaire items for condition 3:

1. The colored arrows helped me follow procedures.
2. The colored arrows got in the way.
3. The colored arrows helped me follow the routing of energy to the phaser-banks.

(d)

Questionnaire items for condition 4:

1. The device/diagram matched my own model of the energy flow through the phaser-banks.
2. I found the display of the procedures onscreen as helpful as the paper.

(e)

Questionnaire items for condition 5:

1. The colored arrows helped me follow the routing of energy to the phaser-banks.
2. The device/diagram matched my own model of the energy flow through the phaser-banks
3. The colored arrows helped me follow procedures.
4. The colored arrows were confusing.
5. The colored arrows helped me determine which procedure would lead to a successful operation of the device.

(f)

Figure 3.10: (a) General questionnaire; (b)-(f) Group 1-5 questionnaires.

- Was operating the device easy/difficult?
- What was easy/difficult?
- What additional info would have made your task easier here?
- Was it apparent what the different buttons and switches did? If not, what additional info would have helped clarify their function?
- Did you understand the role / function of all buttons? If not, which ones were confusing? How did this affect your performance?
- Did you find yourself using any procedure for selecting procedures?

Figure 3.11.: Open-ended questions

3.5.3. Experimental Procedure

Participants in each condition operated the respective device individually. The device display corresponding to each participant's group was displayed on a CRT when he or she entered. After reading and signing an Informed Consent form (Appendix C), each participant was given a brief document introducing them to the device (Appendix D) and he or she was told that their knowledge of Star Trek was not critical to understanding the task. The experimenter read through the document aloud, emphasizing certain instructions (e.g., “Participants are encouraged to use the most efficient procedures”; “Consider the indicators as you go through an operation”). Participants then ran through 30 operations. Following 30 completed operations, participants completed the general questionnaire and the group-specific questionnaire (Figure 3.10). Participants then completed the NASA TLX. Finally, the open-ended questions were asked of each participant.

In summary:

1. Display condition
2. Sign informed consent
3. Distribute and read through instruction document
4. Perform operations
5. Complete questionnaires
6. NASA TLX
7. Respond to open-ended items

3.6. Data Analysis

3.6.1. Response Biases

It is likely that recorded data were biased by different response strategies employed by participants. One strategy that needs to be considered when interpreting results involved some participants rushing through operations and disregarding errors. The converse situation is also likely to have occurred: some participants may mull over support materials in order to perform accurately. In both cases, the time values and accuracy values were not representative of those of all participants, and these values probably cancelled each other out when0 combined with others. The validity of these measures was threatened; however, invalid responses should not differ across experimental groups. General differences among groups (i.e., levels of the independent variable) represented meaningful differences.

In order to minimize these events, it was stressed in the instructions given to participants that their speed and accuracy were equally important. A Pearson product-moment correlation of total time by error score was used to check the validity of recorded time values. Internal validity is threatened if participants place more value on their speed than their accuracy, and vice versa (speed/accuracy trade-off). Participants may commit more errors for the sake of shorter performance times. A very high positive correlation between performance time and errors suggests that this threat is likely, and it was considered when interpreting the results. Differences in speed/accuracy tradeoffs across levels were not expected. Such differences suggest features of the displays seen by different subject groups that made tradeoffs more or less likely.

Analyses of Variance (ANOVAs) were used to analyze the data collected in this study. The ANOVA examines differences among population means. In the present case, differences in the means of performance measures differed according to the augmentation-display types that define groups. The data matrix for each of the one-way ANOVAs was structured the same way, but the factor concerned differed. The general structure is pictured in Figure 3.12.

The remainder of this section is divided according to specific research questions. Note that, in addition to the general research questions discussed previously, questions that arose from the experimental set-up are discussed below.

Factor A (Augmentation Type)				
AS_{11}= X	AS_{21}= X	AS_{31}=X	A_{41}= X	AS_{51}=X
AS_{12}= X	AS_{22}= X	AS_{32}=X	A_{42}= X	AS_{52}=X
AS_{13}= X	AS_{23}= X	AS_{33}=X	A_{43}= X	AS_{53}=X
AS_{14}= X	AS_{24}= X	AS_{34}=X	A_{44}= X	AS_{54}=X
AS_{15}= X	AS_{25}= X	AS_{35}=X	A_{45}= X	AS_{55}=X
AS_{16}= X	AS_{26}= X	AS_{36}=X	A_{46}= X	AS_{56}=X
AS_{17}= X	AS_{27}= X	AS_{37}=X	A_{47}= X	AS_{57}=X
AS_{18}= X	AS_{28}= X	AS_{38}=X	A_{48}= X	AS_{58}=X
AS_{19}=X	AS_{29}=X	AS_{39}=X	AS_{49}=X	AS_{59} =X
AS_{110}=X	AS_{210}=X	AS_{310}=X	AS_{410}=X	AS_{510}=X

Figure 3.12: ANOVA data matrix

3.6.2. Hypothesis 1: Model Effects

The first research question discussed previously was: Does displaying a device model at the same time as the device itself increase the probability that an operator will select the appropriate procedure in malfunction situations relative to operators exposed to the device only? In order to investigate this question, the numbers of incorrect procedures selected by operators in conditions exposed to the model and not exposed to the model were compared. These data were analyzed with a one-way ANOVA using the device only and device + model groups. It was hypothesized that an ANOVA of incorrect procedures indicated that operators in the device + model group selected significantly fewer incorrect procedures than the device only group. The hypothesis tested was:

H_0: There was no difference among groups in number of incorrect procedures.

H_1: There was a difference among groups in number of incorrect procedures

3.6.3. Hypothesis 2: Superimposed Augmentation

The second research question discussed earlier concerned superimposing augmenting information: Does a display of a model that is fit to the device concerned lead to superior performance compared to an abstract device model? A one-way ANOVA of operation times, using augmentation types as five levels of the factor identified significant differences. Recall that operation time was effectively the sum of correct procedure time, incorrect procedure times, and reviews of procedures. Superimposing augmentation was hypothesized to increase procedure time (see Research Question 3) and reduce selection of incorrect procedures (see Research Question 1). Therefore, it was hypothesized that groups with the superimposition of indicators will have significantly shorter operation times than other groups. The hypothesis tested was:

H_0: There was no difference among groups in operation times.

H_1: There was a difference among groups in operation times.

3.6.4. Hypothesis 3: Procedural Information

The third research question involved the encoding of procedural information into the superimposed augmentation: Does the procedural information encoded in the superimposed augmentation influence operators' performance? It was assumed that the procedural information encoded in the superimposed augmentation would reduce procedure-review times. Operators in the superimposed augmentation groups were less likely to review textual descriptions of procedures because the procedural information was available via the display. A one-way ANOVA of correct procedure review times was used to investigate this question. It was hypothesized that operators in superimposed augmentation groups would have significantly shorter operation times than the other groups. The hypothesis tested is:

$H_{0:}$ There was no difference among groups in procedure-review times

$H_{1:}$ There was a difference among groups in procedure review times.

3.6.5. Hypothesis 4: Interactive Model

The interactive model conditions were expected to provide participants with the most thorough understanding of all the conditions. The complete "energy flow" information was available to participants in the Interactive Model condition. This information was augmented with the procedural indicators in the "Procedural Indicators + Interactive Model" condition. It was likely that both groups would exhibit fewer wrong procedure selections than other groups; further, the group with indicators would have shorter procedure times than the group without indicators.

3.6.6. Subjective Experience

The fifth question (or set of questions) had to do with the subjective experience of participants. The first set of questions concerned participants' responses to the questionnaire items. Each questionnaire item was associated with a five-point scale. A series of one-way ANOVAs with the five display conditions as levels of the independent variable was used to analyze responses to the general questionnaire. Responses to the condition-specific questionnaires were analyzed across individuals exposed to a particular condition.

The next set of questions concerned the workload data. The TLX methodology resulted in an Overall Workload Score ranging from 1-100 and a score for each of the six subscales.

The final set of analyses concerned the verbal responses gathered. Transcriptions of verbal responses were analyzed using the HyperRESEARCH (Scolari, CA) software. HyperRESEARCH allows the coding and retrieval of data, the development of theories, and data analyses within an integrated data environment. This software package has been successfully used in the past by many researchers in the social sciences and other fields for similar purposes. The software transforms the interview data into frequency of comments for each of the codes of interest. These frequency data were grouped into the conditions in which they occurred. These data can possibly be used in Chi-square tests and ANOVAs. While it seems unorthodox to employ ratio data analysis techniques (e.g. ANOVA, regression) on frequency data from the transcripts, these techniques have been suggested in the literature as valid data analysis methods for similar data (Ericsson and

Simon, 1984; Gibson, Fiedler, and Barrett, 1993; Kleiner and Drury, 1998; Sims, Jr. and Manz, 1984).

Chapter 4: Results and Discussion

Recall that the main focus of this study was to examine the effects of exposure to different types of visual augmentation of a device on operations of the device. It was hypothesized that these effects would result in the selection of operating procedures during system malfunctions and increased performance speed. The following measures were collected:

- operation times
- incorrect procedures selected (errors)
- number of support references required – how often did participants review support material?
- reference times – how much time was spent processing additional reference information?
- questionnaire responses
- NASA-TLX score

The following major research questions were addressed.

- How does displaying to operators a device model at the same time as the device itself influence performance relative to operators exposed to the device only? Kieras and Bovair (1984) suggested that displaying a model helps operators to remember procedures and promote more efficient interaction with a device more efficiently than operators without a model. This study attempted to confirm their general findings in an AR context.
- Is there a difference in performance between conditions using abstract, generic device models and models tailored to the specific device being controlled? It is

possible that a model constrained by the physical layout of the device will make the device more difficult to operate, but it is more likely that additional information benefited operators.

- How does the procedural information encoded in the superimposed augmentation influence operators' performance? Since this type of augmentation indicated features of the device at each step in a procedure, it was easily adapted to dynamically relate procedural information to operators.
- Does the given model provide an adequate mental model? The given model accurately represented the functional relationships of elements in the device, but this abstract relationship might not suffice to provide the benefits of a well-formed, internal mental model.
- The subjective data collected offered insight into subjective experiences and support to the evaluation of the research questions above. How do individual participants perform the task? Do individuals pay more attention to some features of the display more or less than other features? Do individuals understand the device?

The remainder of this chapter is organized by the types of data collected and the relevance of these data to the specific research questions. Quantitative performance measures are discussed, followed by subjective measures (i.e., general questionnaires, condition-specific questionnaires, workload data, and verbal data). The subjective data added insights and support to the performance data – especially clearing conditions when the performance data do not provide unambiguous answers. The subjective data also exposed subjective experience and processes that the performance measures do not capture.

Table 4.1: Data sets and analytic procedures discussed throughout this chapter.

Analysis	**Data sets used**
Pearson's product moment correlation	Overall time Wrong trials General questionnaires
ANOVA	Overall time Wrong trials Verbal data
Kruskal-Wallis	General questionnaires Workload scores

4.1. Quantitative Performance Measures

The data of most interest were measures of task performance related to speeds and errors. Specifically, the values of the variable "wrong trials" and the variable "overall time" were of interest. Wrong trials contained the number of non-working procedures selected by a participant for each trial. Overall time was the time in seconds that it took an operator to complete each trial. Each participant completed 30 trials. The first five trials were considered as participants' familiarization with the task and interface; these trials were not taken into account in the following analyses. In other words, each participant completed 30 trials, of which the latter 25 went into the following analyses. Fifty individuals participated in one of five conditions, resulting in 1250 trials overall and 250 per condition.

The means and standard deviations of the variables overall time and wrong trial are summarized in Table 4.2. In the table, the mean, N, and standard deviation for each Condition is listed, and the total (across Conditions) mean, N, and standard deviation are listed. While there was some variability among values within conditions, mean values for conditions were within one standard deviation of the total means[2]. In other words, despite some individual differences, mean values of Conditions were comparable.

Table 4.2: Descriptive statistics for performance data.

Condition		overall time	wrong trials
1	**Mean**	25.59	2.55
	N	250	250
	Std. Deviation	20.748	2.662
2	**Mean**	34.23	3.28
	N	250	250
	Std. Deviation	29.720	3.228
3	**Mean**	31.87	3.64
	N	250	250
	Std. Deviation	48.994	6.313
4	**Mean**	30.26	2.67
	N	250	250
	Std. Deviation	32.823	3.518
5	**Mean**	26.25	2.75
	N	250	250
	Std. Deviation	20.992	2.840
Total	**Mean**	29.64	2.98
	N	1250	1250
	Std. Deviation	32.465	3.960

A boxplot (Figure 4.1) indicated three obvious outliers in terms of overall time. Overall-time values for participants 8, 44, and 38 on one trial were outliers. Values were considered outliers if they were more than 10 standard deviations above the total mean of overall time.[3] However, these outliers were included in the following analyses because (1) interpretation of the results of the analyses were not different when the outliers were removed, and (2) major individual differences were a common characteristic of performance and the outliers bring attention to common individual variations.

[2] For example, given the total mean for overall time is 29.64sec and the standard deviation of the total is 32.465, the range above or below the total mean +/- the standard deviation (-3.005sec - 62.105sec) is within 1 standard deviation from the mean.

[3] For example, the value of overall time for participant 8 is 470sec, 470-29.64 (mean overall time) divided by 32.47 (standard deviation) = 13.6 standard deviations.

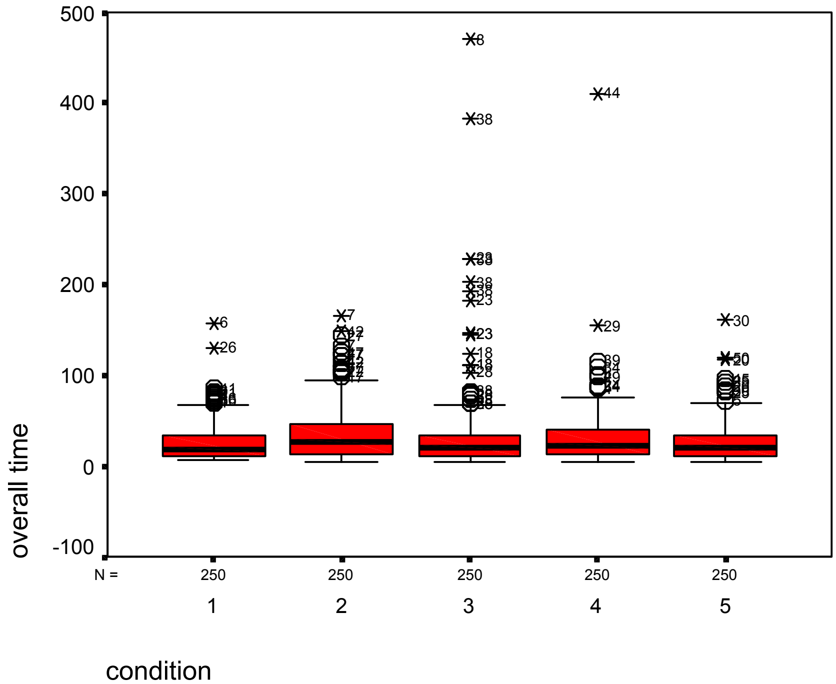

Figure 4.1: A box-plot of “overall time”.

4.1.1. General Response Biases

A Pearson product-moment correlation of total time by wrong trial was performed. Naturally, more wrong trials should be positively correlated with longer overall time; lack of this correlation would have suggested that wrong trials were not being considered in calculations of overall time values. Table 4.3 summarizes the correlations observed.

Table 4.3: Correlation between wrong trial and overall time

Pearson Correlation Coefficients
Prob > |r| under H0: Rho = 0

	Overall time	**Wrong trials**
Overall time		.89*
Wrong trials	.89*	

*p < .001

As expected, overall time is highly correlated with wrong trials. Overall time necessarily increases as time is spent on wrong trials. The correlation is high, but not perfect, probably because the amount of time spent on wrong trials differed among participants or because they spent more or less time on the correct trials.

A one-way analysis of variance was used to evaluate differences among Conditions in the number of wrong trials chosen by operators. As can be seen in Table 4.4, the amount of wrong trials selected by operators did not vary much as a function of display type group (Condition). However, participants in Condition 3 (Device + Procedural Indicators) chose the greatest number of wrong trials among all Conditions. The overall ANOVA indicated that there was an overall significant difference in wrong trials by Condition (F = 3.46, p,.05, see Table 4.5). A graph of the "wrong trial" data by all conditions is presented in Figure 4.2.

Table 4.4: Least Squares means of wrong trials by Condition (Adjustment for Multiple Comparisons: Tukey-Kramer).

Condition	Wrong trials LSMEAN	LSMEAN Number
1	2.55	1
2	3.27	2
3	3.64	3
4	2.67	4
5	2.75	5

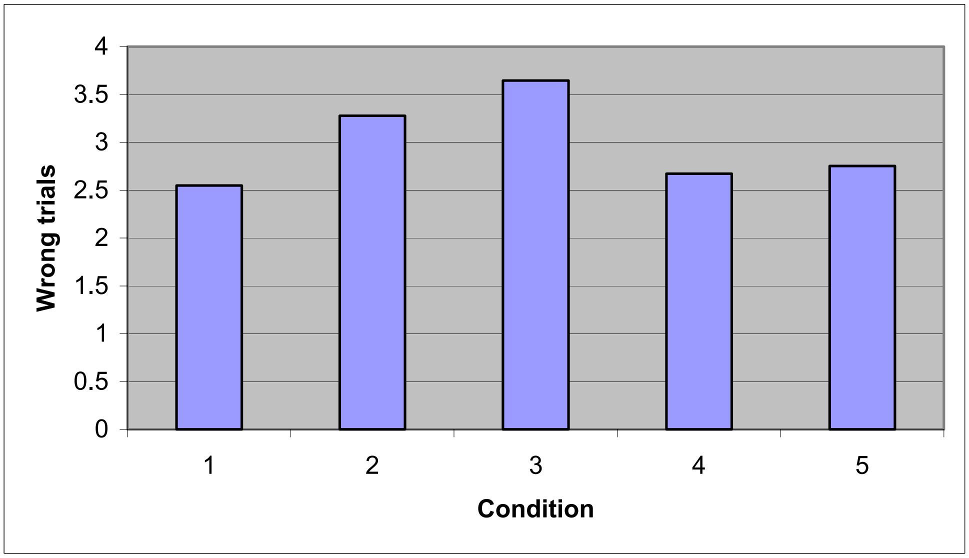

Figure 4.2: Mean "wrong trial" values by Condition.

Table 4.5: ANOVA summary Table: wrong trials by Condition

Source	DF	SS	MS	F Value	Pr > F
Model	4	215	53	3.46	0.0080*
Error	1245	19370	15		
Total	1249	19586			

*p < .05

Post hoc tests (Tukey's Honestly Significant Difference) indicated that the largest source of the difference was due to the difference between Condition 1 (least wrong trials) and Condition 3 (most wrong trials). In addition to the significant difference between groups 1 and 3, there was a significant difference between groups 3 and 4. Table 4.6 presents a summary of these comparisons.

Table 4.6: Comparisons Least Squares Means with Tukey adjustment for effect Condition: Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: wrong trials

Condition	1	2	3	4	5
1		0.24	0.01*	0.99	0.97
2			0.83	0.42	0.57
3				0.04*	0.08
4					0.99
5					

* p<.05

A second one-way ANOVA was performed in order to evaluate differences in overall time by Condition (display group). As can be seen in Table 4.7, overall time was least for Condition 1, followed closely by that for Condition 5, while groups 2, 3, and 4 achieved times above 30 seconds. A graph of the "overall time" data is presented in Figure 4.3.

Table 4. 7: Least Squares Means (Adjustment for Multiple Comparisons: Tukey-Kramer)

Condition	Overall time (sec) LSMEAN	LSMEAN Number
1	25.59	1
2	34.23	2
3	31.87	3
4	30.257	4
5	26.250	5

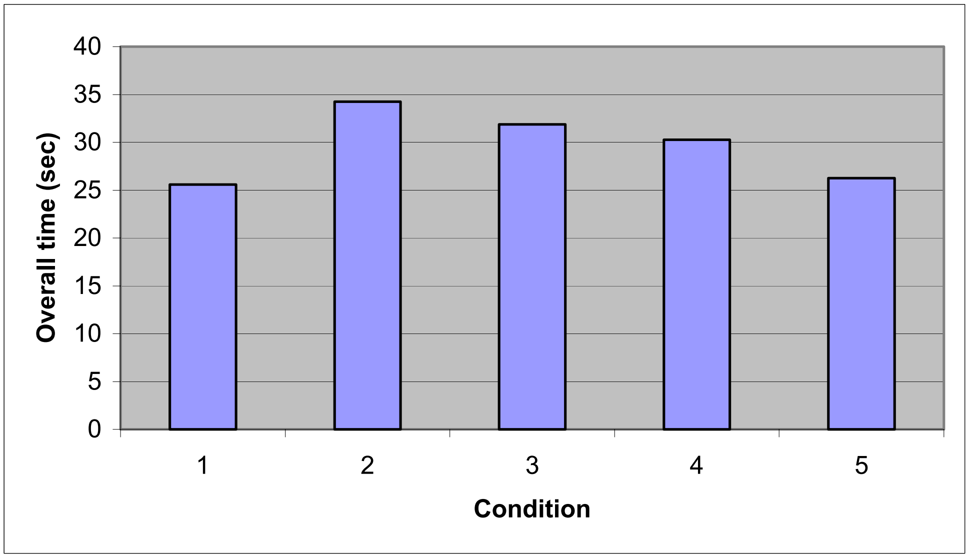

Figure 4.3: Mean "overall time" results by Condition.

The overall ANOVA indicated that there is a significant difference as a function of Condition in overall time. Table 4.8 presents a summary of this ANOVA.

Table 4.8: ANOVA summary Table: overall time by Condition

Source	DF	SS	MS	F Value	Pr > F
Model	4	13585	3396	3.25	0.0116*
Error	1245	1302833	1046		
Total	1249	1316418			
*p < .05					

Post hoc tests (Tukey's HSD) indicated that the largest source of the difference is due to the difference between Condition 1 (least wrong trials) and Condition 2 (most wrong trials). Table 4.9 presents a summary of these results.

Table 4.9: Comparisons Least Squares Means with Tukey adjustment for effect Condition: Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: overall time (sec)

Condition:	1	2	3	4	5
1		0.02*	0.19	0.49	0.99
2			0.92	0.64	0.04*
3				0.98	0.29
4					0.64
5					

*p<.05

4.1.2. Hypothesis 1: Model Effects

Recall the first research question was: How does displaying to operators a device model at the same time as the device itself influence performance relative to operators exposed to the device only? It was expected that fewer selections of nonworking procedures (wrong trials) would be made by participants in Condition 2 (device + model) than Condition 1 (device only). In other words, these Conditions were expected to differ, with fewer wrong trials in Condition 2 than Condition 1. Following the results of Kieras and Bovair (1984), participants in Condition 2 should select fewer wrong trials than Condition 1 because operators with a model of the device should have a better understanding of its functions and the relation of its parts to one another. The understanding of the device by participants with a model should lead them to select more correct operating procedures than participants without a model. However, the present data indicated the opposite: significantly more wrong trials were selected in Condition 2 (3.27) than in Condition 1 (2.55; see Table 4.10).

Table 4.10: Contrast of Conditions 1 and 2 using variable: wrong trials.

		Contrast	Value of Contrast	Std. Error	t	df	Sig. (2-tailed)
Wrong trials	Assume equal variances	1	-.73	.353	-2.063	1245	.039
	Does not assume equal variances	1	-.73	.265	-2.751	480.566	.006

Why did participants in Condition 1 outperform those in Condition 2? One possibility is a matter of the layout of the device in Condition 1: the display was "clean"; there were no distracting display-elements, and interaction went smoothly from left to right. The display in Condition 2 was "messy" – the presence of both the device and the model resulted in a cluttered display, and the presence of both allowed for comparisons of the layouts of each (they were not isomorphic). Therefore, participants in Condition 2 could have been more confused in their understanding of the device than those in Condition 1 (see Figures 3.5 and 3.6).

Another possibility for this result stems from the fact that participants in Condition 2 had essentially two displays requiring the maintenance of two mental models (As will be discussed later, many participants did not unite the device and model.), while those in Condition 1 required only one. The layout of the device and the fact that it was all that was displayed may have made it more likely for participants in Condition 1 to form their own mental model of the device. Further, one's own mental model is bound to have more of an effect on behavior than a given model because it is an internal, self-made construct.

Although the performance data and analyses discussed were considered valid, it could be argued that the actual difference in numerical terms is misleading. The actual mean number of wrong trials recorded was significantly different, with Condition 2 (3.27) being higher than Condition 1 (2.55), but the variable "wrong trial" referred to a count of non-working procedures selected; it was necessarily a whole number (1, 2, 3, etc.). Therefore, what sense do the values 3.27 and 2.55 make? Perhaps these numbers should be rounded. Rounding values with a fraction higher than .5 up, and values with a fraction below .5 down we end up with 3 wrong trials for both Conditions. An equal outcome is not predicted, but it is more understandable than an opposite outcome. Consider the range of values displayed in Figure 4.2; the means of wrong trials for every Condition are very low – the meaning of variation within this range is difficult to establish.

Perhaps the "wrong trial" measured reflects a ceiling-effect. The experimental task might have been so easy that every participant did either very well, or hit the limit (ceiling) on how well one could do. Recall the methodology of this study: Participants selected and performed a working procedure from seven alternatives 30 times. One procedure worked on every trial, so a subject who did not repeat procedures, would choose, at most six wrong trials. Also recall that procedure 1 was the correct choice 30 percent of the time (about 9 of 30) and procedure 2 was the correct choice 20 percent (about 6 of 30), so a participant who chose procedures sequentially beginning with procedure 1 (the default procedure was 1 or 2) the number of wrong trials was substantially constrained. Procedures 3 – 7 were each correct 10 percent of the time (3 of 30). Since the correct procedure was chosen at random (constrained by the probabilities mentioned), the low number and little variation of wrong trials was understandable. The "sequential strategy" mentioned was common, and it is revisited in the section on verbal data. The ramification of this methodological issue was that "wrong trial" may not be an accurate measure of participants' understanding of the device.

This study cannot adequately establish whether the measure actually did incur a ceiling effect, although it seems likely. Future studies of this type would benefit by an extensive consideration of the ease and sensitivity of the experimental task; specifically, is it easy enough for participants to do, yet complex enough to allow differences in performance? Future studies should also consider the adequacy of a measure such as wrong trial as a measure of understanding. Given a sufficiently complex experimental task, thorough verbal protocols or conceptual mappings may appropriately reflect participants' understanding and would thus be more appropriate.

The original research question was whether a model display in addition to a device display improved operators' performance. In this study, performance did not improve, but performance of participants with a model was better than that of participants without a model in Kieras and Bovair's (1984) study. The biggest difference between these studies is the displays used: the model was on paper and the device was onscreen in the 1984 study, while both were simultaneously onscreen in the present study. Perhaps the ostensible benefits of the model display appeared when it was physically separate from the device, and not when the displays are presented together in a bigger display.

Presenting separate displays can certainly reduce visual clutter and confusion. The separate displays used by Kieras and Bovair may have also enhanced the development of mental models by individuals. As opposed to participants in the present study, participants given separate displays were unable to physically relate the device and model, but had to conceptually relate them; so, physical discrepancies between the device and model had little effect on participants with separate displays. Further, participants with separate displays were led to adopt the given model by conceptually relating it to the device.

4.1.3. Hypothesis 2: Superimposed Augmentation

The second research question was: Is there a difference in performance between conditions using abstract, generic device models and models tailored to the specific device being controlled? The expectation was that operation time (overall time) differed among display conditions. Because superimposed augmentation (i.e., procedural indicator arrows) was expected to decrease operation time, Conditions with superimposed augmentation (Conditions 3 and 5) were expected to lead to the lower operation times. However, the results show that the overall time recorded was lowest for Condition 1 (Device Only, mean = 25.59sec), followed closely by those for Condition 5 (Interactive Model + Procedural Indicators, mean = 26.25sec). Mean overall times for the other Conditions (Condition 2 = 34.23sec; Condition 3 = 31.87sec; Condition 4 = 30.26sec) were obviously greater. A contrast of the means of Conditions 1 and 5 versus the remaining Conditions indicated that they together were significantly different (see Table 4.11).

Table 4.11: Contrasts of Conditions using variable: overall time. Contrast 1 is Conditions 3 and 5 versus the rest; Contrast 2 is Conditions 1 and 5 versus the rest.

		Contrast	Value of Contrast	Std. Error	t	df	Sig. (2-tailed)
overall time	Assume equal variances	1	-2.90	5.603	-.518	1245	.605
		2	-18.60	5.603	-3.320	1245	.001
	Does not assume equal variances	1	-2.90	5.927	-.489	595.136	.625
		2	-18.60	5.028	-3.699	1033.787	.000

The difference of times among Conditions is large enough to suggest that it is not due to random fluctuations. Similar to the situation of Hypothesis 1, the results are constrained by the methodology used; namely, the time required to go through all procedures, thereby guaranteeing success, was a significant time limit. However, differences in time among Conditions resulted.

Overall time was highest for Condition 2 (Table 4.7). This result did not actually contradict the present hypothesis. The confusion that resulted from visual clutter and the non-isomorphic relationship between the model and the device was a potential cause of increased time. Several participants verbalized that they did not relate the model to the device, or even consider the model much during trials (as noted in participants' verbal responses); therefore, visual clutter and distraction appeared to be a more likely reason for the increased time than the relationship between the model and the device. It is noteworthy that Kieras and Bovair (1984) used a model on paper and device onscreen, and they found participants with a model and device had shorter times than those with the device only.

Mean times for Condition 3 were second highest; this was not predicted. It should be noted that of the three outliers in the data mentioned above, two belonged to Condition 3 and one to Condition 4. An ANOVA with these three outliers removed was performed, and a significant difference ($p<.001$) was found among Conditions in overall time, with Condition 1 being the lowest. A graphic representation of the means is presented in Figure 4.4.

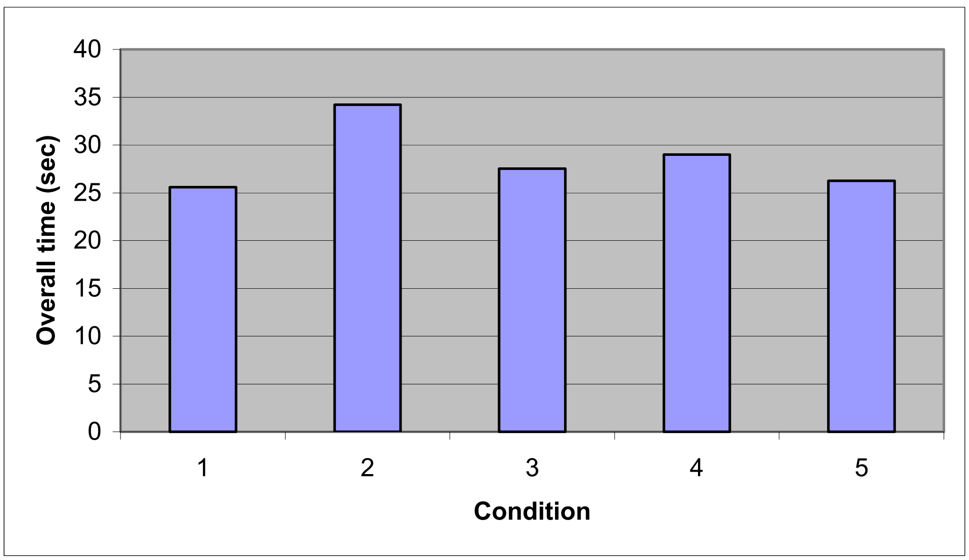

Figure 4.4: Mean "overall time" results by Condition with outliers removed.

The fact that times for Condition 1 were lower than those for Condition 3 remained. The only manipulated difference between these Conditions was the presence of superimposed procedural indicators in Condition 3. Perhaps unaccountable contextual effects helped produce this result that is the opposite of the prediction. One should first consider the small difference in times when the outliers are removed (25.59sec vs.

27.51sec); it is plausible that subtle individual time differences among participants resulted in such a small difference. Second, consider the effects of individual differences in this study; some participants quickly understood the indicators and faithfully followed them, other participants did not readily understand the indicators and were reluctant to follow them without double-checking.

It was no surprise that overall times for Condition 4 were lower than those for Condition 2, due to the visual clutter and dual display issues discussed above; and, they were slightly higher than those for Condition 5 which benefited from the addition of procedural indicators. It was reasonable to expect an interactive model to lead to a good understanding of the device and consequently lower overall times than a device-display and a non-interactive model. It was also reasonable to expect a further reduction in overall time when procedural indicators are added to the interactive model, as in Condition 5.

An unexpected result was that the shortest overall time was associated with Condition 1. Why did participants in Condition 1 outperform their peers in other Conditions? Let's consider three possibilities. *First,* the physical layout of the buttons and dials of the device was very sensible to most participants. Like English writing, the procedures flowed from left (ship power) to right (PF indicator); this was common to every procedure. This common direction might have helped to induce an individual's mental model of the device that was preferred over the model provided in the later conditions. It is possible that the given model conflicted with the individual's model that arose naturally from the layout of the device. The flow of procedures with the device was unidirectional; the presented model involved a back step. Execution of the procedures given the device involved actions left-to-right: ship power, energy selector, fire, check the PF indicator. Execution of procedures following the model involved switching ship power then the energy selector, then going back to the left to fire and back to the right to check the PF indicator. The flow of the process paralleled the layout of the device and individuals' models. Therefore, it is reasonable that operation times were faster with the device only than with the presented model that contained a back step.

The model used in this study seemed inappropriate for the above reasons. It is reasonable to wonder why such a model was used here. The main motivation for using this model was that Kieras and Bovair had used it with promising results. Similar results were expected. However, despite the plausible inappropriateness of the model within the context of this study, insights into the role of individual mental models and the role of mental models as memory structures were made.

A *second* explanation for this difference involves the ostensible advantage of Condition 3 over 1: the presentation of instructions superimposed on the device. This advantage might have been overshadowed by the presentation of the instructions on paper available during operations; most operators preferred the paper presentation (this preference is discussed in the Verbal Responses section).

A *third* possible explanation for the superior performance of Condition 1 is the visual clutter resulting from the superimposed instructions in Condition 3.

4.1.4. Hypothesis 3: Procedural Information

The third hypothesis proposed was that Conditions differ in operation times due to the decrease in procedure review times in Conditions with procedural indicators.

However, because the overwhelming majority of operators (48 of 50) never used the procedure review function on the display, there were no relevant data to analyze. Almost every participant preferred to review the descriptions of the procedures on paper.

Many participants verbalized why they preferred to review the paper. A frequent theme among these 21 verbal responses was the ease and readiness with which participants could review the paper while minimizing the time away from the task. Consider the following excerpts:

- "I thought it was easier just to look at this and then look on the screen because if you hit the on-line definitions, the whole program kind of paused, so it was kind of easier just to look between this and that." (Participant 8, Condition 3)
- "I guess 'cause clicking, more clicking would take more time than just looking at the paper and using the mouse at the same time to click." (Participant 14, Condition 4)
- "…it was a time-demand task and the time would have continued flowing had I done that plus I still had the procedures in front of me had I wanted to look at them." (Participant 15, Condition 5)

Several participants noted that they did not need to review procedures either onscreen or paper much. Consider the following excerpts:

- "I didn't look at the on-line thing. Maybe if I had looked at it before, then I would have seen what it looked like; then I would have used it more. But I guess you didn't really have to use the paper that much; that's why I didn't click on the on-line." (Participant 4, Condition 4)

- "I don't know. I just think sometimes it's quicker for me. I was trying to get an idea in my head so I could eventually after a couple trials have a pretty good idea in my head of which one was which." (Participant 7, Condition 2)
- "Initially I had to, but then I could not get a grasp of the task but once I got in there and never looked back." (Participant 20, Condition 5)
- "I looked at them on the paper and I felt like, okay, I thought that the online one was going to be similar if not exactly the same and I figured I've them here on paper in front of me, I'll keep the screen free for the controls." (Participant 31, Condition 1)

Other participants noted that it was not routine to refer to onscreen information when the information is available on paper. Consider the following excerpts:

- "Oh, it never crossed my mind. I was just so used to flipping through the pages, it didn't occur to me just to click the procedure on the screen." (Participant 9, Condition 4)
- "I just don't like reading off a computer screen, so a lot of times even with schoolwork, I print things off and then read them, cause I just don't like reading off of a monitor." (Participant 6, Condition 1)

The efforts to save time and remember procedures benefited from the green procedural indicators displayed in Conditions 3 and 5. Consider the following excerpts:

- "I read through these and then I just started following the arrows." (Participant 10, Condition 5)
- "…after the first two or three I came to know the bright green arrows actually indicative of what I had to do, so I followed that out pretty easily." (Participant 18, Condition 3)
- "Because it was quicker to look at the arrows and go to where they were pointing rather than to keep referring back to the paper." (Participant 40, Condition 5)
- "Right, like I just follow the arrows." (Participant 45, Condition 5)

In sum, four frequent reasons for reviewing procedures on paper, rather than onscreen, were verbalized by participants:

First, participants felt it was quicker to refer to the paper than onscreen. This is actually true because (as a participant noted) the device "freezes up" when procedural information is displayed and becomes active again when the information is hidden. Given that shifting attention from the screen to the paper is not very difficult, using the paper reference was quicker than referring to onscreen information.[4]

Second, several participants noted that they did not need to reference the procedures much. This supports the "ceiling-effect" discussed earlier. Participants could remember the set of operational procedures related to the device displayed.

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[4] Of course individual differences come into play. Two of the participants who used the onscreen reference, verbalized that they preferred to keep the information-display medium constant.

Third, participants were in the habit of referring to paper; it is normal. It was unusual to refer to information onscreen when it is available on paper. Several participants couldn't verbalize their preference for the paper beyond comments like, "It [looking at the onscreen information] never occurred to me." Participants habitually worked with the paper.

Fourth, the presence of procedural indicators often made references unnecessary. This was the expected outcome of Hypothesis 3. The presence of procedural indicators eliminated time spent reviewing procedures. However, the measure of onscreen procedure review time cannot directly support the hypothesis since there were other reasons why participants did not review procedures onscreen. This measure might be more appropriate if the paper cannot be reviewed. In this case, participants will *have to* refer to the information onscreen at least until they remember the procedures (if they do) or, in Conditions with procedural indicators, until they realize the function of the arrows.

4.1.5. Hypothesis 4: Interactive Model

Participants in Conditions that interacted with the device models were expected to select fewer wrong trials than other groups. The complete "energy flow" information was available to participants in the Interactive Model Condition (Condition 4). This information was augmented with the procedural indicators in the "Procedural Indicators + Interactive Model" Condition (Condition 5) – group was expected to have shorter procedure times than the group without indicators. Table 4.12 displays the results of these contrasts. Conditions 4 and 5 were almost significantly different from the other

Conditions if we assumed equal variances. This result was expected due to interactions with the model. There was little difference between Conditions 4 and 5 on wrong trial.

Table 4.12: Contrasts of Conditions using variable: wrong trial. Contrast 1 is Conditions 4 and 5 versus the rest; Contrast 2 is Condition 4 vs. 5.

		Contrast	Value of Contrast	Std. Error	t	df	Sig. (2-tailed)
wrong trials	Assume equal variances	1	-1.33	.683	-1.950	1245	.051
		2	-.12	.529	-.227	1245	.821
	Does not assume equal variances	1	-1.33	.643	-2.072	932.630	.039
		2	-.12	.429	-.280	476.829	.780

Regardless of the differences in wrong trials for Conditions 4&5, the fact that wrong trials was lowest for Condition 1 begged the same question as above: Why did participants in Condition 1 outperform their peers?

In addition to procedural differences, there were conceptual differences between the presented model and the device promoted by the device only display. For example, the EB indicator and MA indicator were more related by proximity to the Energy Selector in the device only. These Indicators were associated with representations of the Energy Booster and Main Accumulator that had no other function. Some participants interpreted these boxes as buttons, and did not associate the indicators with the Energy Selector. It is reasonable to posit that participants selected fewer wrong procedures when they saw the device only (Condition 1) than when they were presented model only (Conditions 4 and 5) because they did not associate the indicators with the Energy Selector.

4.1.6. Similarities of Condition 1 and Condition 5

A clear, but unexpected result was the similarity of performance between Conditions 1 and 5. The Conditions differed little in wrong trials and overall time. The data used in Figures 4.2 and 4.3 is plotted again in Figure 4.5 to highlight these similarities. While line-graphs were not typically used for these types of data, the similarity of values for Conditions 1 and 5 standout more in the line-graphs portrayal.

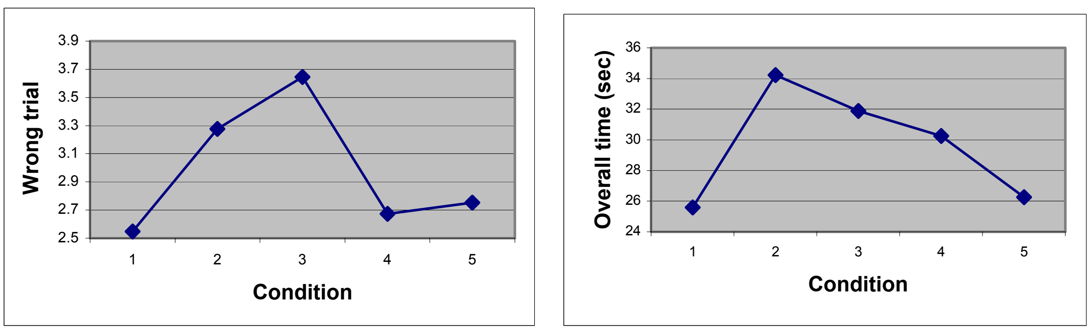

Figure 4.5: Line graphs of mean performance measures by Condition.

Condition 1 supposedly presented minimal operational support to participants while Condition 5 supposedly presented maximal support. Therefore, it was expected that Condition 1 would score worst on performance measures (high wrong trial and high overall time). It was expected that Condition 5 would score best. Condition 5 did score very close to best (the difference in wrong trial between 4 and 5 is negligible, as discussed above), but Condition 1 was not expected to perform as well. Overall times for Conditions 1 and 5 were significantly similar, and formed a distinct subset of Conditions.

Several reasons have been given above about why participants in Condition 1 performed so well, including the layout of the device, visual clutter, inconsistencies of the given model, and the formation and preference of one's own model. Looking at the pattern of effects across Conditions, it seems as if Conditions 1 and 5, but not the others, captured an aspect of the device that improved participants' interactions with it.

The performance of Conditions 1 and 5 were what we would expect from participants with a good mental model – faster performance and fewer errors (Kieras and Bovair, 1984). Participants were given a model of the device in Condition 5, and possibly developed their own model in Condition 1. Perhaps the device was conducive to the development of a mental model due to its consistent modes of operation, and the preference for a self-made model led to performance that was just superior to that resulting from a given model.

It is noteworthy that performance measures might be biased by the simplicity of the task; the experimental task was so easy that every participant did either very well, or hit the limit (ceiling) on how well one could do. This kind of clustering of performance times and overall trials on one end of the response scale obscured any glimpse of differences related to Conditions. The nature of the experimental task is likely to have made significant variations impossible to see. When all participants score as well as possible, one cannot observe systematic variations by Condition.

4.1.7. Summary of Hypotheses

The first research question was: How does displaying to operators a device model at the same time as the device itself influence performance relative to operators exposed to the device only? It was expected that fewer selections of nonworking procedures (wrong trials) would be made by participants in Condition 2 (device + model) than Condition 1 (device only). However, the present data did not support this hypothesis;

significantly more wrong trials were selected in Condition 2 (3.27) than in Condition 1 (2.55; see Table 4.4). These results could be due to the "visual clutter" present in Condition 2, as well as a discrepancy between the model and the device displayed. The display in Condition 1 was much simpler and may have been conducive to the development of a mental model by individual operators.

The second research question was: Is there a difference in performance between conditions using abstract, generic device models and models tailored to the specific device being controlled? The expectation was that operation time (overall time) differed among display Conditions. Conditions with superimposed augmentation (Conditions 3 and 5) were expected to lead to the lowest operation times. The data supported the hypothesis that participants in Condition 5 achieved low times, but the data did not support the hypothesis that participants in Condition 3 would achieve low times. The results showed that the overall time recorded was lowest for Condition 1 (mean = 25.59sec), followed closely by those for Condition 5 (mean = 26.25sec). Mean overall times for the other Conditions (Condition 2 = 34.23sec; Condition 3 = 31.87sec; Condition 4 = 30.26sec) were obviously greater. A contrast of the means of Conditions 1 and 5 versus the remaining Conditions indicated that they together are significantly different (see Table 4.11). These results might have been due to the simple, flowing layout of the device in Condition 1 and an overshadowing of the advantages of Condition 3 by the presentation of the procedural definitions on paper.

The third hypothesis proposed that Conditions differ in operation times due to the decrease in procedure review times in Conditions with procedural indicators. However, the relevant data (procedure review times) were not collected because the overwhelming majority of operators (48 of 50) never used the procedure review function on the display. Why almost every participant preferred to review the descriptions of the procedures on paper became the intriguing question. Verbal data indicated four frequent reasons for preferring to review the paper: referring to paper was quicker; participants did not need references; participants were not in the habit of using online material when material is available on paper; participants in Conditions with procedural indicators followed the indicators and did not need references.

According to Hypothesis 4, participants in Conditions that interacted with the device models were expected to select fewer wrong trials than other groups. The complete “energy flow” information was available to participants in the Interactive Model Condition (Condition 4). This information was augmented with the procedural indicators in the “Procedural Indicators + Interactive Model” Condition (Condition 5) – we would expect this group to have shorter procedure times than the group without indicators. Table 4.11 displays the results of these contrasts. Conditions 4 and 5 were almost significantly different from the other Conditions if we assumed equal variances. This result was expected due to interactions with the model. There was little difference between Conditions 4 and 5 on wrong trial.

4.2 Subjective Measures

Recall the subjective measures gathered included general questionnaires, condition-specific questionnaires, workload measurements (NASA-TLX), and verbal responses to open-ended questions. These were described in Section 3.5.2.2.

4.2.1. General Questionnaire

The fifth question (or set of questions) addressed with the subjective experience of participants. Subjective experiences were, in part, assessed by follow-up questionnaires. The general questionnaire was administered at the end of the experiment (following all conditions and all condition-specific questionnaires). It is presented with the Condition-specific questionnaires in Appendix A. Patterns of responses to the eight general questionnaire items are presented in Figures 4.6-4.13.

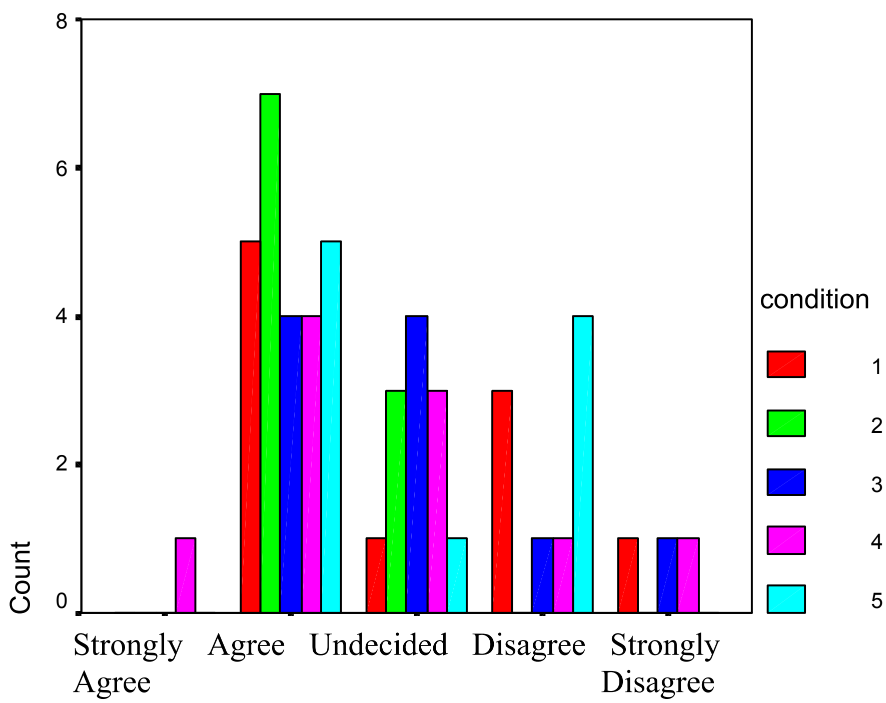

Figure 4.6: Responses to questionnaire Item 1: I believe the device displayed actually controlled the process.

The intent of Item 1 was to assess a type of realism or external validity regarding the device. Agreeing that the display controlled the process indicated that participants related the display to the underlying process described to them, rather than considering the device as separate from that process. That the majority of participants saw the display as related to the underlying process bodes well and suggests that participants had some sort of mental model of the process.

It is worth noting that no participants in Condition 2 considered the display and process as distinct. Despite comments by these participants that they usually did not interpret the device and the model of the process a group, they saw the device related to the process.

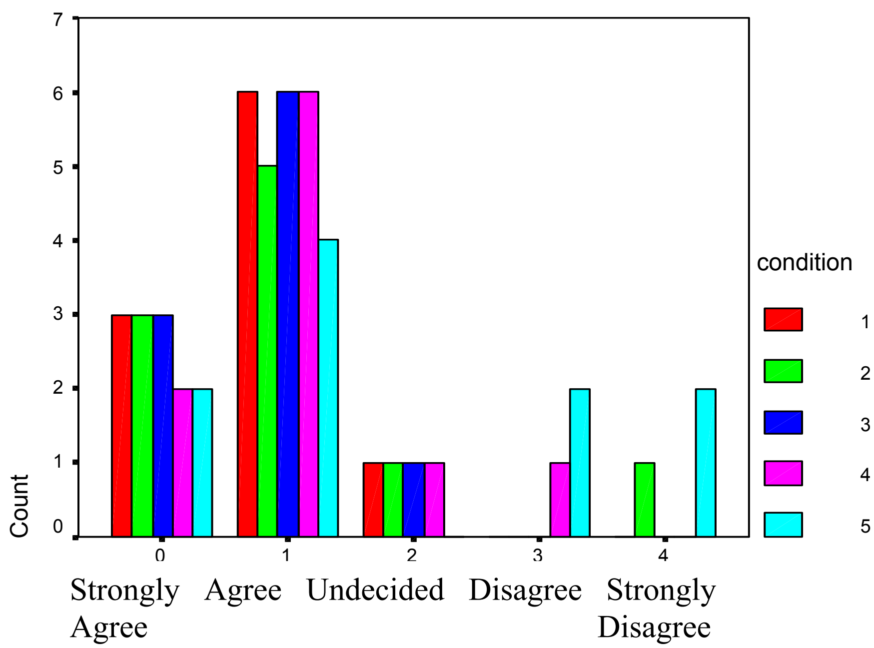

Figure 4.7: Responses to questionnaire Item 2: I felt supported/able to operate the device

Item 2 was intended to assess participants' impression of how useful the display was; the underlying question is: How helpful was the display? The majority of participants felt well supported in operations of the device. Note, however, the disagree-end of the scale; no participants in Conditions 1 or 3 felt unsupported, but several from

Condition 5 did. Conditions 1 and 3 both displayed the same device, so it is not surprising that they were rated similarly here. However, this pattern of results is interesting when we consider the similarities in performance of Conditions 1 and 5 discussed above. Participants felt more supported by the device than the model.

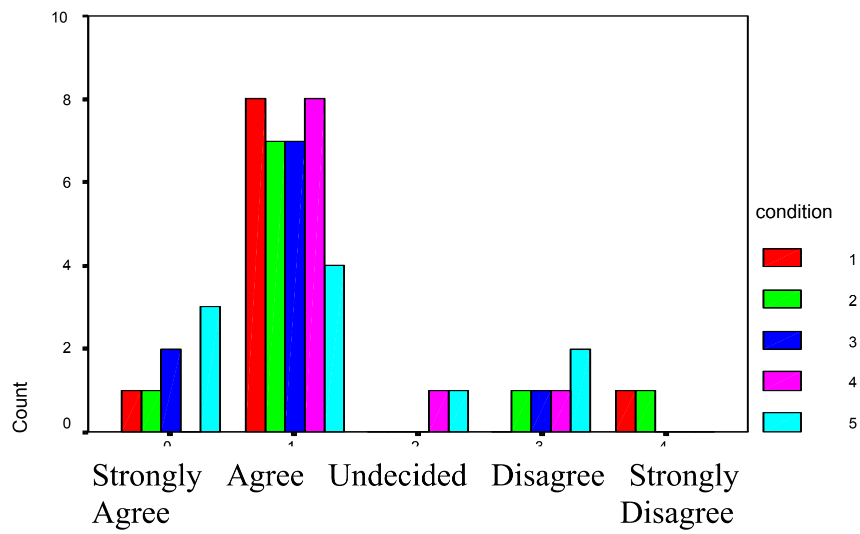

Figure 4.8: Responses to questionnaire Item 3: I felt involved in the task.

The majority of participants agreed with Item 3. Engagement in the task is worth assessing because disengagement suggests difficulties in understanding the display. Because engagement in a task is often associated with understanding the task (Csikszentmihalyi, 1990), and the user interface makes the task more or less understandable (Rosson and Carroll, 2002), the engagement (involvement) of participants in the task may shed light on participants' understanding of the task. Although understanding the task is not the same as understanding the device displayed, but it is related.

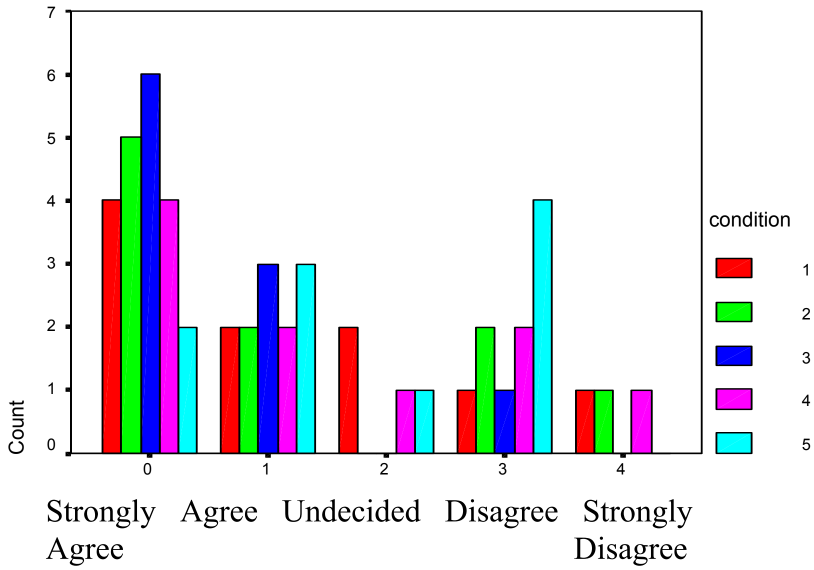

Figure 4.9: Responses to questionnaire Item 4: The indicator lights on the device helped me determine the working procedures.

Item 4 was intended to ascertain the approximate extent of participants' processing of the indicator light elements of the displays and integration of system elements. The states of the indicator lights served as cues to non-working procedures (Table 3.1). Although this item referred to the multiple lights in the display, several participants verbalized that they only considered the PF indicator light, which informed them whether a procedure worked. Regardless of this point, it is worth noting that several participants in Condition 5 did not find the indicator lights helpful. It is possible that they did not easily associate indicator lights with their related system elements, although this possibility is as likely, perhaps more expected, for Conditions 1 and 3 (recall the layout of each display, Figures 3.5–3.9).

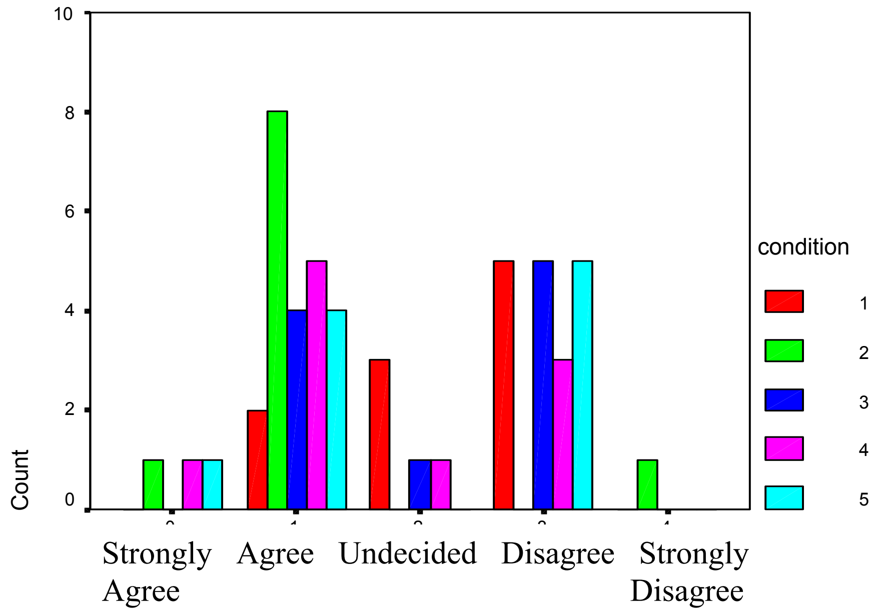

Figure 4.10: Responses to questionnaire Item 5: The route of energy flow to the phasers was clear.

The aim of Item 5 was to assess the extent to which each display represented the overall flow (function) of the device. Participants in Condition 2 almost entirely agreed that the route of energy flow to the phasers was clear. As with Item 1, their responses indicate that the process of the device was clear.

It is worth noting that participants in Conditions 1 and 5 equally disagreed that the route of energy flow to the phasers was clear. It was not surprising that these Conditions responded similarly, given what has been discussed above, but it was surprising that a large proportion *disagreed*.

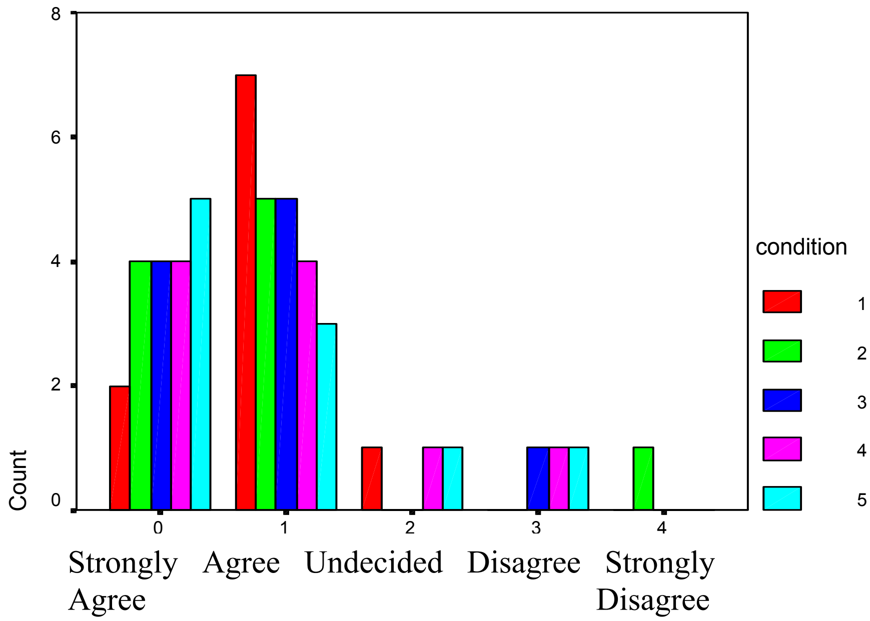

Figure 4.11: Responses to questionnaire Item 6: The task was easy to do.

A perceived difficulty item, like Item 6, was included in order to assess the general ease of the task. A clear majority of participants agreed that the task was easy. It is worth noting those few participants who disagreed. Note that *no one* in Condition 1 disagreed and 1 participant in Condition 3 disagreed (perhaps this one disagree in Condition 3 evens out with the one undecided in Condition 1). Neither of these Conditions presented a model, yet both were rated about as easy. The performance data suggested that Condition 1 was actually easier. Since the only difference between these Conditions was the presence of procedural indicators, and it was theorized above that an advantage of Condition 1 was that it helps the formation of a mental model; it follows that the presentation of procedural indicators somehow hindered this process. The other Conditions to disagree that the task was easy to do all displayed the given model.

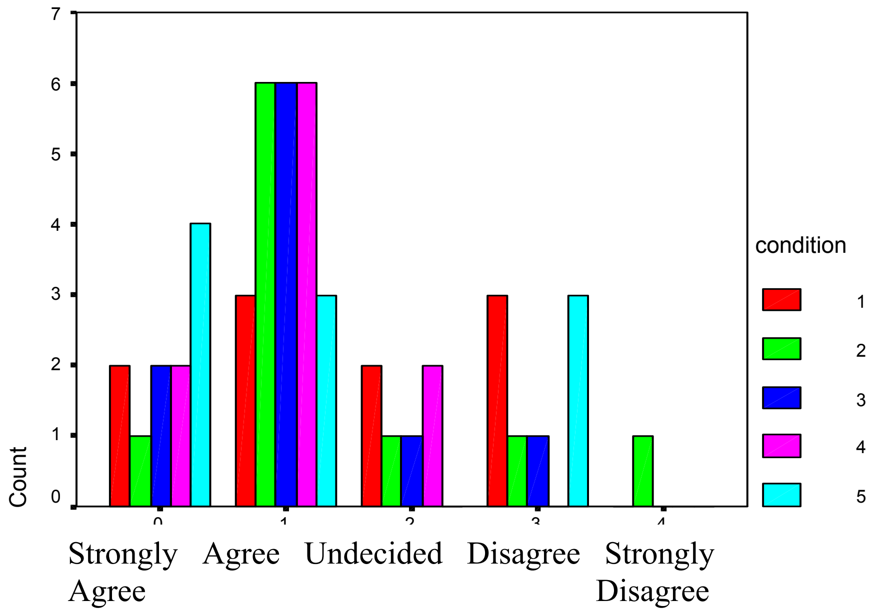

Figure 4.12: Responses to questionnaire Item 7: The task was easy to understand.

Similar to Item 6, Item7 intended to assess participants' understanding and comfort with the task. Of note is that a large proportion of participants in Conditions 1 and 5 agreed (or strongly agreed) and disagreed that the task was easy to understand. The performance data suggested that most participants in these Conditions would agree, but those who disagreed performed as well. This result suggested that, in these Conditions, understanding the task was not necessary for good performance.

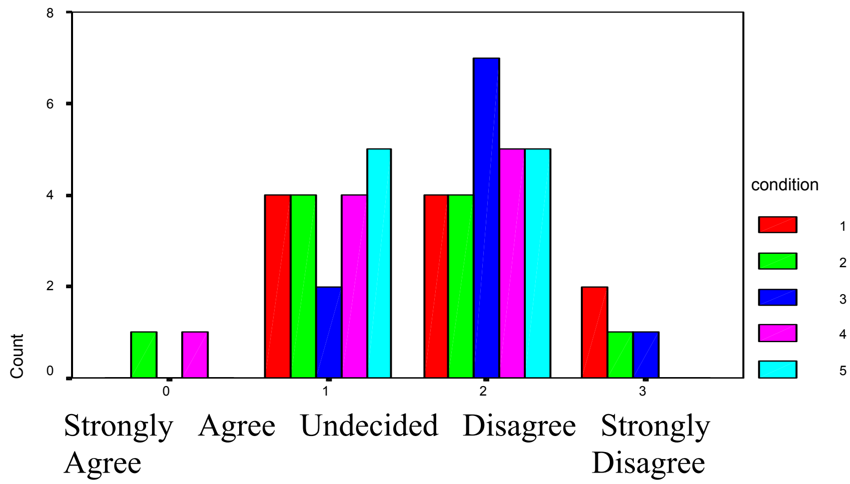

Figure 4.13: Responses to questionnaire Item 8: The layout of the device matched my model of it.

The pattern of responses to Item 8 was difficult to interpret. One difficulty was the large amount of "Undecided" responses - more than for any other Items. It is likely that most participants did not understand the item; subsequently, they chose "Undecided". The second difficulty was that the item presupposes a model to compare to the layout. The pattern of "Disagree" responses suggested that participants in every Condition developed an individual model of the device.

Despite the patterns of responses to individual items discussed above, no statistically significant difference in responses was found across Conditions. The mean responses for each Condition and item are summarized in Table 4.13. Responses to the general questionnaire were compared by Condition using the Kruskal-Wallis test (see Table 4.14). The lack of statistical significance might be due to the sample size (10 responses per item, per Condition) or significant differences among Conditions might have been overwhelmed by the fact that the majority of participants agreed with all statements, regardless of Condition.

Table 4.13: Summary of responses to general questionnaire items

	Condition	N	Mean	Mean Rank
Item1 I believe the device displayed actually controlled the process.	1	10	2	28.05
	2	10	1.3	19.55
	3	10	1.73	27.80
	4	10	1.7	24.65
	5	10	1.9	27.45
Item2: I felt supported/able to operate the device.	1	10	0.8	22.55
	2	10	1.1	24.75
	3	10	0.9	22.55
	4	10	1.1	26.45
	5	10	1.8	31.20
Item3: I felt involved in the task.	1	10	1.2	24.95
	2	10	1.4	27.10
	3	10	1.2	22.55
	4	10	1.3	28.45
	5	10	1.2	24.45
Item4: The indicator lights on the device helped me determine the working procedures.	1	10	1.3	26.15
	2	10	1.2	24.40
	3	10	1.0	19.10
	4	10	1.4	26.85
	5	10	1.7	31.00

Item5: The route of energy flow to the phasers was clear.	1	10	2.3	31.95
	2	10	1.2	17.20
	3	10	1.9	29.15
	4	10	1.6	22.75
	5	10	1.9	26.45
Item6: The task was easy to do.	1	10	0.9	28.55
	2	10	0.9	24.75
	3	10	0.9	24.55
	4	10	0.9	25.90
	5	10	0.8	23.75
Item7: The task was easy to understand.	1	10	1.6	29.60
	2	10	1.5	28.10
	3	10	1.4	23.70
	4	10	1	23.00
	5	10	1.2	23.10
Item8: The layout of the device matched my model of it.	1	10	1.8	28.10
	2	10	1.5	23.40
	3	10	1.73	31.05
	4	10	1.4	21.95
	5	10	1.6	23.00

Table 4.14: Test Statistics of Questionnaire Responses by Conditions (Kruskal-Wallis)

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Chi-Square	2.845	2.932	1.475	3.888	7.280	.789	2.092	3.491
df	4	4	4	4	4	4	4	4
Asymp. Sig.	.584	.569	.831	.421	.122	.940	.719	.479

A correlation of performance measures (wrong trials and overall time) with responses to general questionnaire responses was performed (see Table 4.15) in order to corroborate the pattern of results in the performance data with questionnaire data. There was no significant correlation between performance measures and subjective responses to the follow-up questionnaire items. While the performance measures alone differed by Condition, responses to questionnaire items did not show such differences. Several questionnaire items were correlated and obviously overlapped. Significant correlations include:

- Item 1 (I believe the device displayed actually controlled the process) with Item 3 (I felt involved in the task), $p < .01$ and Item 8 (The layout of the device matched my model of it), $p < .01$.
- Item 2 (I felt supported/able to operate the device) with Item 3, $p < .001$, Item 6 (The task was easy to do), $p < .001$, and Item 7 (The task was easy to understand), $p < .01$.
- Item 3 (I felt involved in the task) with Item 6 (The task was easy to do), $p < .001$, Item7 (The task was easy to understand), $p < .01$, and Item 8, $p < .01$.
- Item 5 (The route of energy flow to the phasers was clear) with Item 6 (The task was easy to do), $p < .01$.

- Item 6 (The task was easy to do) with Item 7 (The task was easy to understand), $p<.001$.

Table 4.15: Correlations of overall time, wrong trials, and general questionnaire items

		overall time	wrong trials	ITEM1	ITEM2	ITEM3	ITEM4	ITEM5	ITEM6	ITEM7	ITEM8
overall time	Pearson Correlation	1	.895	-.072	-.066	-.205	.023	-.007	-.106	-.159	-.152
	Sig. (2-tailed)	.	.000	.611	.651	.153	.871	.964	.465	.270	.293
	N	1250	1250	52	50	50	50	50	50	50	50
wrong trials	Pearson Correlation	.895	1	.051	-.031	-.165	.103	.041	.029	-.034	-.039
	Sig. (2-tailed)	.000	.	.721	.829	.252	.478	.776	.842	.816	.787
	N	1250	1250	52	50	50	50	50	50	50	50
ITEM1	Pearson Correlation	-.072	.051	1	.283	.385	.322	.310	.254	.086	.431
	Sig. (2-tailed)	.611	.721	.	.046	.006	.022	.028	.075	.551	.002
	N	52	52	52	50	50	50	50	50	50	50
ITEM2	Pearson Correlation	-.066	-.031	.283	1	.497	.264	.291	.474	.427	.063
	Sig. (2-tailed)	.651	.829	.046	.	.000	.064	.041	.001	.002	.664
	N	50	50	50	50	50	50	50	50	50	50
ITEM3	Pearson Correlation	-.205	-.165	.385	.497	1	.228	.362	.521	.426	.405
	Sig. (2-tailed)	.153	.252	.006	.000	.	.112	.010	.000	.002	.004
	N	50	50	50	50	50	50	50	50	50	50
ITEM4	Pearson Correlation	.023	.103	.322	.264	.228	1	.116	.256	.211	.164
	Sig. (2-tailed)	.871	.478	.022	.064	.112	.	.422	.072	.142	.254
	N	50	50	50	50	50	50	50	50	50	50
ITEM5	Pearson Correlation	-.007	.041	.310	.291	.362	.116	1	.368	.192	.209
	Sig. (2-	.964	.776	.028	.041	.010	.422	.	.009	.181	.145

	tailed)										
	N	50	50	50	50	50	50	50	50	50	50
ITEM6	Pearson Correlation	-.106	.029	.254	.474	.521	.256	.368	1	.608	.327
	Sig. (2-tailed)	.465	.842	.075	.001	.000	.072	.009	.	.000	.020
	N	50	50	50	50	50	50	50	50	50	50
ITEM7	Pearson Correlation	-.159	-.034	.086	.427	.426	.211	.192	.608	1	.260
	Sig. (2-tailed)	.270	.816	.551	.002	.002	.142	.181	.000	.	.068
	N	50	50	50	50	50	50	50	50	50	50
ITEM8	Pearson Correlation	-.152	-.039	.431	.063	.405	.164	.209	.327	.260	1
	Sig. (2-tailed)	.293	.787	.002	.664	.004	.254	.145	.020	.068	.
	N	50	50	50	50	50	50	50	50	50	50

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

4.2.2. Condition-Specific Questionnaires

Responses to the Condition-specific questionnaires were not comparable among Conditions; rather, they might give some insight into the subjective impressions of features of each display. Responses to questionnaires for each Condition are presented visually in Figures 4.14 - 4.18.

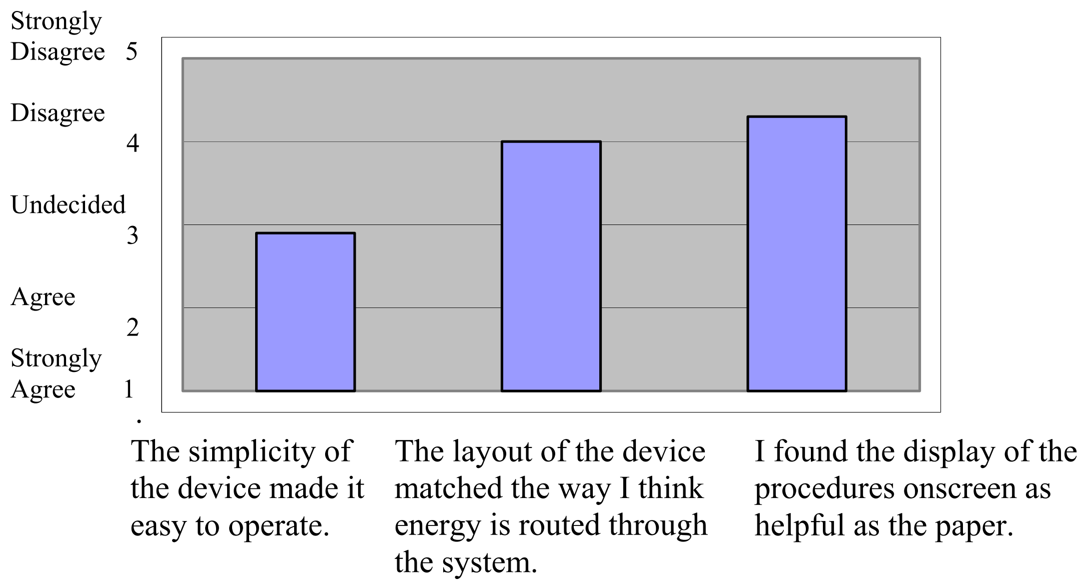

Figure 4.14: Responses to questionnaire items for Condition 1.

Mean responses to the first questionnaire item for Condition 1 suggested that the simplicity of the device played a role in making it easy to operate. Many participants disagreed with the statement that the layout of the device matched the way they thought energy was routed through the system. This result is not in line with performance data or verbal data (discussed later).

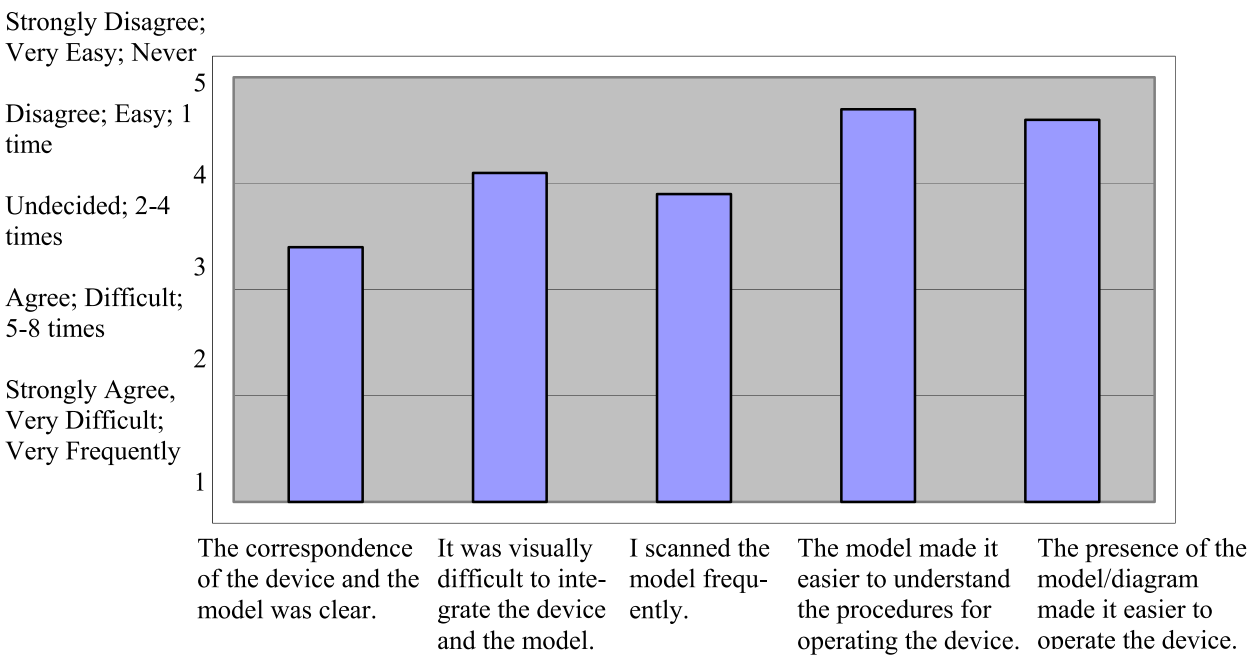

Figure 4.15: Responses to questionnaire items for Condition 2.

The general feeling among participants in Condition 2 was that the model presented was confusing and not very helpful.

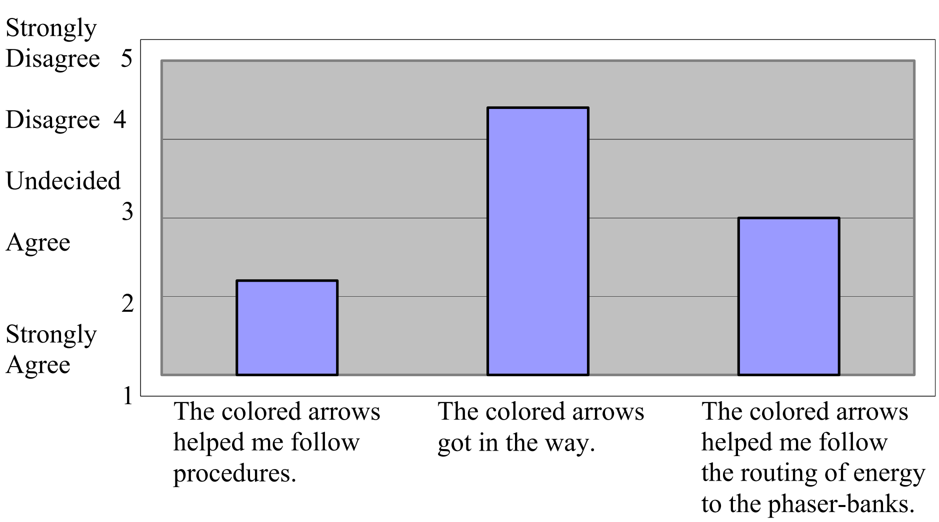

Figure 4.16: Responses to questionnaire items for Condition 3.

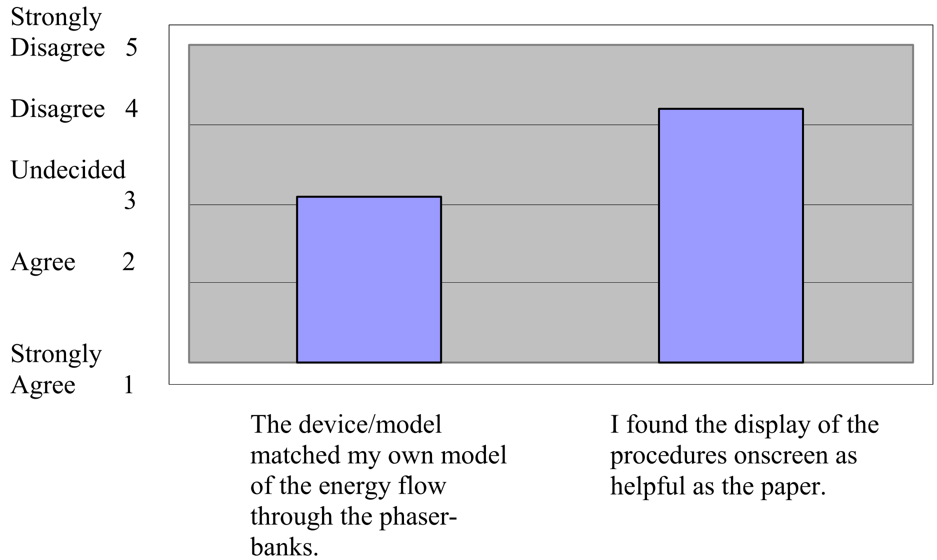

Figure 4.17: Responses to questionnaire items for Condition 4.

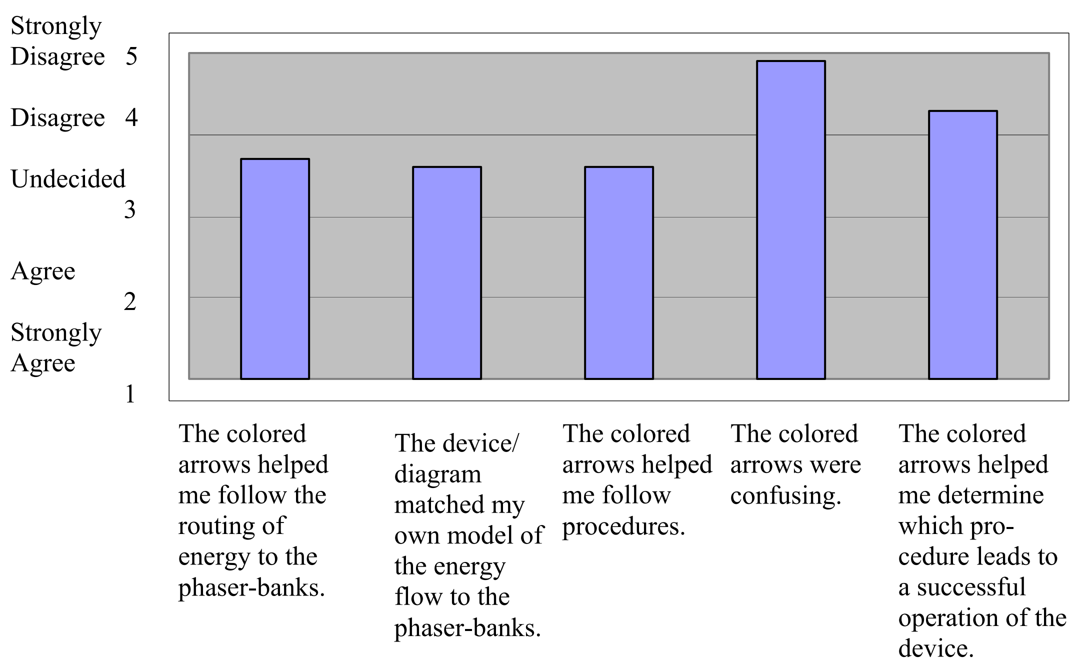

Figure 4.18: Responses to questionnaire items for Condition 5.

4.2.3. Workload

Scores on the NASA TaskLoad Index were recorded for all participants (see Figure 4.14).[5] Analyses of these scores might indicate any effect that the different display Conditions had on the experimental task. Although a Kruskal-Wallis test of differences among Conditions did not indicate any statistically significant (see Table 4.16) differences, trends in the pattern of results were as expected.

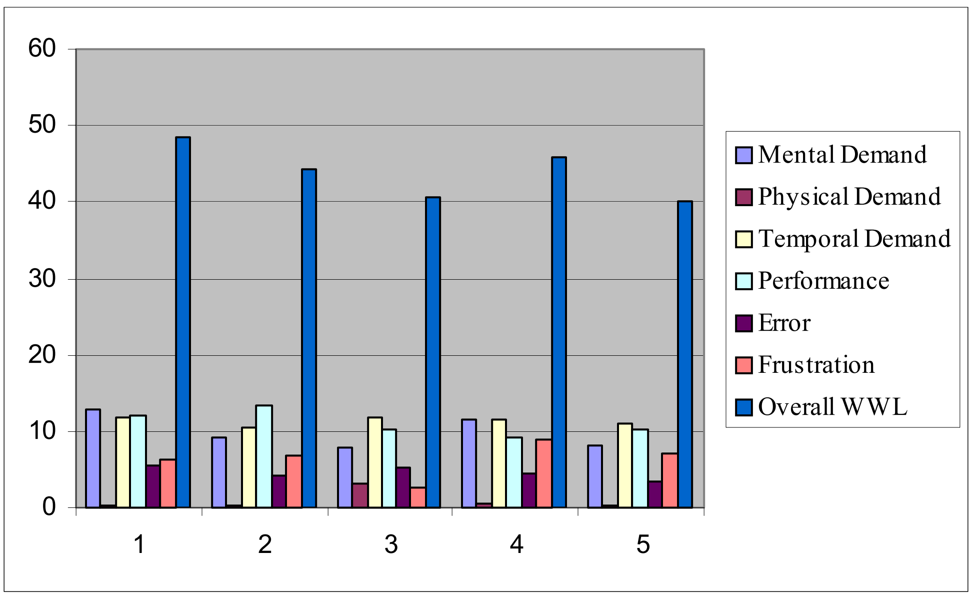

Figure 4.19: NASA TLX Workload Scores: Sub-Scales and Overall Workload.

[5] English was not the native language of many participants, and several mentioned that the wording of the NASA TLX was not always clear.

Table 4.16: Test Statistics of TLX scores by Conditions (Kruskal-Wallis)

	Mental Demand	Physical Demand	Temporal Demand	Performance	ERROR	Frustration	Overall WWL
Chi-Square	3.184	9.144	.343	2.179	1.283	4.981	1.696
df	4	4	4	4	4	4	4
Asymp. Sig.	.527	.058	.987	.703	.864	.289	.791

The NASA TLX scores related to subjective perceptions of the experimental task, so the nature of the task should be taken into consideration as well as the display Conditions when interpreting them. In particular, the subscales physical demand, temporal demand (the extent to which participants felt operation time was important to the task), performance demand (the extent to which participants felt accurate performance was important to the task), and error (the extent to which participants felt avoiding errors was important to the task) primarily reflected participants impressions of the task, and, incidentally, Condition-specific features. Therefore, it was understandable that there was little variation in these scores among Conditions since the task itself was consistent.

The frustration and mental demand subscales were seen as relating to Condition features. Frustration arises when one is hindered from accomplishing a goal. A poor display can certainly be frustrating. A display that is easy to follow, easy to understand, and does not hinder accomplishing goals is less frustrating. Because the procedural indicators presented in Condition 3 supposedly afford these things, it was understandable that this Condition would score lower on Frustration.

The procedural indicators also reduced participants' need to remember procedures; therefore, we expected Conditions with procedural indicators to score lower than others on mental demand. Conditions 3 and 5 (both with procedural indicators) did, in fact, score slightly lower than other groups on mental demand.

Perhaps significant differences among Conditions were not measured by the NASA TLX. The NASA TLX involves subjective assessments of six broad sources of workload. It was possible that significant differences among Conditions could be identified by a finer instrument. It was also possible that the specific sources of workload that varied among Conditions were not considered. For example, shifts in attention may have been a significant source of workload. Future research might include helping operators' efficiency by reducing cognitive load relative to particular components.

4.2.4. Verbal responses

Verbal responses of each participant to questions similar to the following were recorded and transcribed:

  - Was operating the device easy/difficult?
  - What was easy/difficult?
  - What additional information would have made your task easier here?
  - Was it apparent what the different buttons and switches did? If not, what additional info would have helped clarify their function?
- Did you understand the role / function of all buttons? If not, which ones were confusing? How did this affect your performance?
- Did you find yourself using any strategy for selecting procedures?
- Did you seem to have some sort of model, concept, or picture in your mind of the system or its function?

The recordings were transcribed and particular phrases were assigned to coding categories. It is worth noting that these data were qualitative in nature, and were meant only to supplement the other data collected in this study. It is arguable whether such qualitative data can be made more credible by statistical analyses. In the present case, observational inspection was preferred to statistical analyses for several reasons. First, observations maintain veracity to what is actually recorded. Second, the data were not collected according to the rigor required for statistical analysis. The questions and their order were not kept constant. Third, in most cases, the sample size for occurrences of a particular code was too small for generalizable statistical analyses.

The phrases were considered thematic units (Krippendorff, 1980) in that they shared the theme of an item of interest in this study (i.e., mental models). A list of the codes and their frequencies can be found in Table 4.17.

Table 4.17: Codes used for verbal responses and frequencies.

Code	**Frequency**
Attempt at individual model	**12**
Did not associate given model with device	5
Did not relate buttons and switches	10
Easy to do	39
Indicator arrows helped	17
Indicator strategy	18
Individual model	**17**
Interface issue	18
No individual model	**16**
Paper definitions only	21
Preferred visual	7
Procedure strategy	14
Random order	8
Random strategy	12
Reliance on model	1
Remembered procedures	23

Sequential strategy	17
Not easy to do	9
Identified causal relationships	**27**

The codes in bold are most related to the main topic of this study, namely, mental models. Therefore, only those codes and their frequencies will be discussed. A particular code was counted only once per subject. For example, in cases where a subject referred to an individual model more than once, the code was counted only once. The definition of each code, and its criteria will be explained below. The frequency of each code for each Condition is also discussed.

The "Attempt at individual model" code was assigned to phrases or responses that suggested the responder had an approximation of, but not a complete, model of the system. This code was also assigned when responders claimed to have no model (or "picture in their minds") of what the system-function looked like, but mentioned some kind of image. For example, consider the following excerpt:

> "I: Did you picture it kind of a like a flow of the energy that you were routing?
>
> R: Oh, the flow of energy...*I kind of understood that, but I couldn't get the whole concept behind that.*
>
> I: Okay, so you really didn't have a picture of that?
>
> R: Right. " (Participant 23, Condition 3)

This excerpt deserved the code because the responder claims to have an inkling of how to form a model, but claims not to have formed it.

The pattern of occurrences of this code across experimental Conditions is illustrated in Figure 4.20. There was no obvious pattern, but it was interesting that participants in Condition 2 seemed to make more attempts to form an individual mental model than their peers. Recall that in Condition 2, the device and a model were displayed. It was possible that such a display prompted participants to explicitly comment on their individual attempts to develop a model.

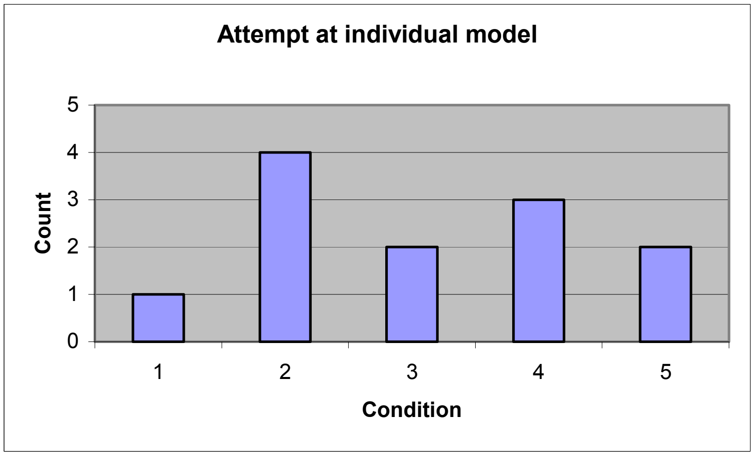

Figure 4.20: Pattern of verbal response code: Attempt at individual model.

The code "Individual model" was assigned to references by a responder to a firmly established model. An analogous image or a clear representation of a model constituted a firmly established model. For example, consider the following excerpt:

> "I: Okay. Did you find that you had an idea or a concept of what the machine was?
>
> R: Yeah, I think I do. It was...I think it was like a ship power system then the power was actually temporarily stored in one of the two subsystems. And then the power was like triggered, you accumulated the power, then triggered it whatever to a cannon." (Participant 20, Condition 5)

Some of the analogies mentioned included gates, pipes, and railroad tracks. It appeared that some operators attempted to fit the energy flow into existing patterns.

The pattern of occurrence of this code across groups is illustrated in Figure 4.21. No truly remarkable features of this pattern jumped out; however, a couple of interesting observations were made. First, the low frequency of occurrence in Conditions 2 and 4 suggested that presenting participants with a model *decreased* the likelihood that participants formed individual models. This trend seemed to be ameliorated when the given model was augmented with procedural indicators. Recall that the performance data for Conditions 1 and 5 suggested the same effect. The highest occurrence of this code was in Condition 3. This result supported the hypothesis that the procedural indicators support model building, and it supported the supposition that the device itself supported model building.

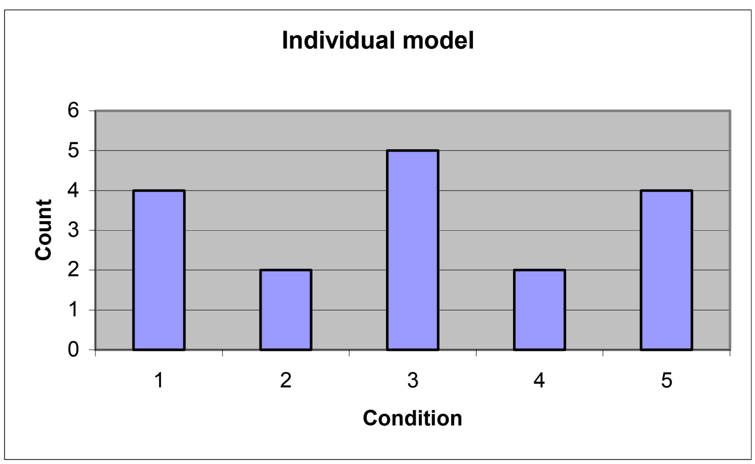

Figure 4.21: Pattern of verbal response code: Individual model.

The code "No individual model" was assigned to situations where the responder explicitly denied having any sort of model of the system. In many cases, these responders usually noted that they were too focused on the task and time to consider the system as a whole. For example, consider the following excerpt:

"I: Did you find yourself developing a picture in your mind or something of what the system would look like in terms of the energy flow that you were directing?

R: No I really didn't. I was just trying to get the light to blink. I really didn't worry about what it was doing." (Participant 43, Condition 3)

Occasionally, this code was assigned when responders, in Conditions where they were given a model (Conditions 2, 4, and 5), referred to the given model without suggesting their own individual model. For example, consider the following excerpt from a responder in Condition 4:

"I: Did you think you had a picture in your mind or a model of what the system looked like?

R: Possibly but not really. If it wasn't in front of me, I don't think I could have pictured it." (Participant39, Condition 4)

The pattern of occurrence of this code across groups is illustrated in Figure 4.22. Groups were not very well differentiated in this pattern. It was notable that the most occurrences of "no individual model" were found in Condition 4, while the least were found in Condition 5. This result supplemented the hypothesis posited above that the augmenting procedural indicators increased the likelihood of model building. The presence of such arrows was the difference between Condition 4 from 5.

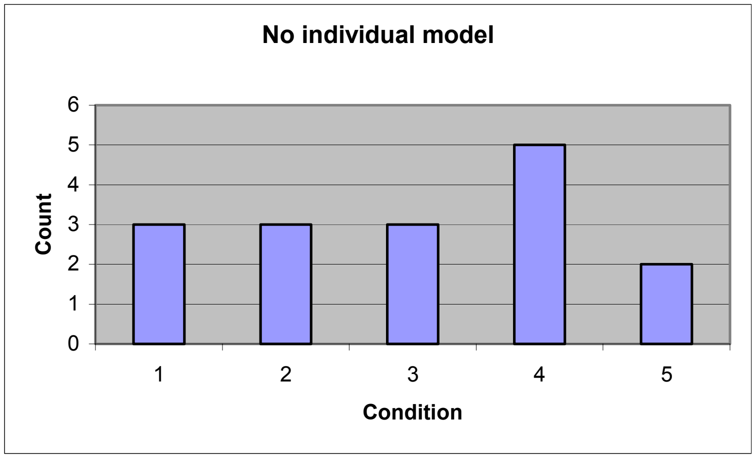

Figure 4.22: Pattern of verbal response code: No individual model.

The code "Identified causal relationships" was assigned to responders who explicitly commented that they were aware of how the state of a particular button or switch on the device affected the system. Operating procedures differed according to these states. For example, consider the following excerpt:

> "I: Okay. All right. Do you think you had any idea or concept of what the buttons did in relation to each other?
>
> R: No. I don't, not really. I mean I knew that when you pressed SA, you usually pressed FS, and when you pressed the one on, MA, you usually pressed FM. I correlated those together." (Participant 42, Condition 2)

The pattern of occurrences of this code across groups is illustrated in Figure 4.23. As can be seen in the Figure, responders identified causal relationships almost to the same extent in all Conditions. The code appeared a couple of more times in Condition 2 than the others, but this was a negligible difference that would be expected according to Hypothesis 1. It was interesting to note the co-occurrence of the code "Identified causal relationships" and the code "Individual model". In 12 of the 17 times (71%) the code

"Individual model" occurred, the code "Identified causal relationships" also occurred. This supplemented the notion posited earlier (see Section 2.4) that the relation of system elements is a feature of well- formed mental models.

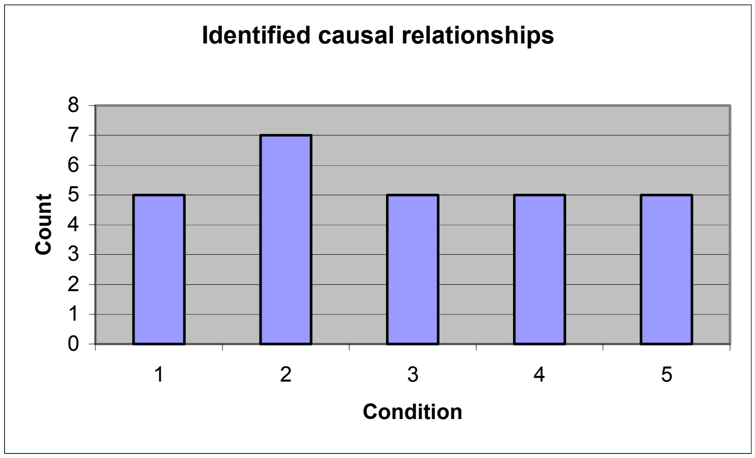

Figure 4.23: Pattern of verbal response code Identified causal relationships.

4.2.5. Hypothesis 1 revisited

In addition to the previous evaluation of Hypothesis 1, further points for consideration arose from other types of data collected. Recall that the display of the model and the device in Condition 2 was hypothesized to lead to a decrease in overall time and wrong trials; this was not the result. Participants in Condition 2 achieved the longest overall time and the second most wrong trials among the Conditions (see Figure 4.5). Responses to the Condition-specific questionnaire items referred to the lack of aid in operation of the device provided by the model. While most participants responded "Agree/Undecided" to Condition 2, Questionnaire Item 1 ("The correspondence of the device (top) and the model diagram (bottom) was clear"), most participants responded

"Undecided/Disagree" to Condition 2, Questionnaire items 4 (“The model (bottom) made it easier to understand the procedures for operating the device (top)”) and 5 (“The presence of the model/diagram (bottom) made it easier to operate the device (top)”). This suggested that participants saw some relationship between the device and model, but failed to relate them in a deeper sense, that is, understanding the displays as different representations of the same thing. This idea was supported by participants' comments: several participants noted while addressing follow-up questions that they did not relate the device to the model presented in Condition 2.

It seemed participants in Condition 2 mostly ignored the model. Since Condition 2 without the model is the same as Condition 1 (Device Only), the question arose why wasn't performance for Condition 2 as good as that of Condition 1? Perhaps the model was ignored, but still distracting. The mere presence of a second display of the model in addition to the device might have increased both wrong trial and overall time. Several respondents mentioned that the model + device display was confusing and cluttered. It is likely that participants in Condition 2 committed more wrong trials than those in Condition 1 because they were confused and misled by their attempts to integrate the device with the model.

Longer overall time for participants in Condition 2 compared to those in Condition 1 were attributed to the extra time required to scan the model. Most participants scanned the model at least twice (see Condition 2, Questionnaire Item 3). This claim was supported by overall times across Conditions (see Figure 4.5); they were clearly highest for Condition 2. The confusing display and dual nature of the display in Condition 2 were likely to have hindered performance in this Condition

4.3. Data Summary

As noted at the beginning of this chapter, performance measures and subjective measures were brought to bear on four research questions. These measures highlighted unexpectedly similar patterns of behaviors of participants in Condition 1 and Condition 5. A review of the questions and their associated data are summarized in Table 4.18 below[6]:

[6] Workload scores did not vary systematically among conditions, so they are not discussed.

Table 4.18: Summary of hypotheses

Research question	**Hypothesis**	**Performance Data**	**Questionnaire Data**	**Verbal Data**	**Support of Operator Performance by the Display?**
How does displaying to operators a device model at the same time as the device itself influence performance relative to operators exposed to the device only?	Displaying a model along with a device (Condition 2) helps operators to remember procedures and will interact with a device more efficiently than operators without a model (Condition 1).	Performance measures (overall time and wrong trials) were *lowest* for participants in Condition 1 (Device Only).	• Participants in Condition 2 agreed that the energy flow controlled by the device was clear. • The questionnaire responses for Condition 1 suggest that the simplicity of the device played a role in ease of operation, while those for Condition 2 suggested that the model was not very helpful.	More participants in Condition 2 attempted to form an internal mental model, but more participants in Condition 1 had formed a model. The same number in both conditions had no models. More participants in Condition 2 identified causal relationships.	Performance measures *do not* support the hypothesis. Condition-specific questionnaires support performance measures, and offer insight into why performance in Condition 1 was superior. Verbal data suggests that actually having an individual mental model is more beneficial than attempting to individualize a model provided by the experimenter.

Does superimposing augmenting information decrease operation time?	Conditions with superimposed augmentation (Conditions 3 & 5) will incur lower operation times.	The overall time recorded was *lowest* for Condition 1, followed closely by those for Condition 5.	• There were no relevant patterns among the general questionnaire data. • Condition-specific questionnaire data indicates that participants found the superimposed arrows helpful.	Many participants verbalized that the superimposed arrows were helpful, and reduced reference times.	Performance data *do not* support the hypothesis, but they *do* support the performance of participants in Condition 5. The questionnaire data and the verbal data conflict with performance data.
Do Procedural indicators lead to shorter procedure review times?	Conditions with superimposed augmentation (Conditions 3 & 5) will incur shorter procedure review times.	There were no relevant performance data collected.	• NA • NA	Reasons for the preference to review paper were associated with 4 themes: referring to paper was faster; not much need for reference; it is more normal to refer to paper; the presence of procedural indicators often made references unnecessary.	This hypothesis is *not clearly supported or not supported* by the performance data. The verbal data can offer anecdotal support as well as highlight the preference for the review paper.

Does interacting with the device model alone improve operators' understanding of the device?	Participants in Conditions that interacted with the device models (Conditions 4 & 5) were expected to select fewer wrong trials than other groups.	Conditions 4 & 5 were marginally significantly different from the other Conditions. There was little difference between Conditions 4 & 5 on wrong trial.	• There were no relevant patterns among the general questionnaire data. • Participants found the colored arrows helpful in Condition 5.	Individual models were more frequent for participants in Condition 5.	Performance data *supported* this hypothesis, although *the fewest* wrong trials were incurred in Condition 1. The questionnaire data and verbal data taken together suggest that the colored arrows in Condition 5 supported the development of individual models; this *supports* the hypothesis.
Are interactions with the device only condition significantly different from those with and interactive model with procedural indicators?	Data of Condition 1 are equivalent to data of Condition 5.	Participants in Conditions 1 & 5 achieved the fewest wrong trials and the shortest overall times; these values were not significantly different.	• Participants in Condition 5 felt more supported in the task. • The simplicity of the device (Condition 1) and the procedural indicators (Condition 5) helped participants in these Conditions.	The same number of participants in both Conditions reported having individual mental models.	All of the data sources *support* this unanticipated hypothesis.

The hypothesis that displaying a model along with a device (Condition 2) helps operators to remember procedures and will result I more efficient interaction with a device than operators without a model (Condition 1) was based on the results of the Kieras and Bovair (1984) study. Their results suggested that this hypothesis would be supported, but it was not supported by the present results. Several reasons for this unanticipated outcome have been discussed, but let us consider the Kieras and Bovair study more deeply.

As was mentioned when the study was first discussed in Chapter 1, Kieras and Bovair focused on the role of mental models in *learning* how to operate a device. Accordingly, their experimental procedures differed from those employed here in that they involved explicitly teaching participants about the model and the results reported by Kieras and Bovair (Table 4.19) were from participants' operation of the device a week after initial exposure to it.

Table 4.19: Summary of results on learning procedures with and without a device model from Kieras and Bovair (1984, Table II, p263).

	Group		
	Rote	**Model**	**Improvement**
Mean correct procedure retention	67%	80%	19%
Mean correct retention after 1 week	71%	78%	11%
Proportion of "short-cuts" (more efficient procedures done when possible)	8%	40%	400%
Mean execution time of retained instructed procedures (sec)	20.1	16.8	17%

Since the present study did not involve a one week retention period, their data could not be directly compared to the present data. However, it was notable that the benefits in execution time (analogous to *overall time* in the present study) and proportion of "short-cuts" (analogous to *wrong trial* in the present study) that Kieras and Bovair attribute to their model group were significant, but they were opposite in the current study. The performance benefits of exposure to a mental model seemed to relate more to recall than online reasoning. The assumption of the present study that performance benefits were available immediately was not justified.

Mental models have been described as memory structures previously (Endsley, 1995), and the present study has supported this idea; benefits of presenting expert mental models to novices, as in Kieras and Bovair (1984) are likely to have been related to the functions of this memory structure. A mental model provides an organizational structure for organizing and retrieving information. Therefore, a novice who has committed the model to memory is likely to be able to organize and retrieve related memories more easily than those without a model. The expert's mental model is assumed to reflect a optimal model that has been shaped by experience. Familiarization to an expert's mental model can equip a novice with the memory structure to optimally organize novel information. Hanicsh et al. (1991) make the practical suggestion that training materials that are organized similarly to expert mental models may improve training and operating efficiency.

Chapter 5: Summary and Conclusions

This chapter provides a summary of the experiment (section 5.1), and discusses the unexpected results – that is, the fact that augmented displays did not yield the expected improvements in performance (section 5.2). Since this experiment was motivated in part by the work conducted by Kieras and Bovair (1984), and obtained results that do not match those obtained by them, some time is devoted to discussing this apparent anomaly (section 5.3). Several avenues of future research motivated by this study are discussed section 5.4. Finally, a few general conclusions are discussed in section 5.5.

5.1. Summary

The basic purpose of this study was to gain insight into the use of models of a system or device, projected via augmented reality, in the operation of that system or device. The model was expected to decrease the time operators need to react appropriately in malfunction situations compared to situations when a model is not available. The device displayed in this study was a simple control panel and the device-model that augmented the device display was a flow diagram of the function of the device.

Display-type constituted the independent variable with five levels (Conditions): device only; device + model; device+ procedural indicators; interactive model; interactive model + procedural indicators. The dependent measures collected were:

- Operation times
- Incorrect procedures selected (errors)

- Number of support references required – how often did participants review support material?
- Reference times – how much time was spent processing additional reference information?
- General and condition-specific questionnaire responses
- NASA-TLX scores
- Responses to open-ended questions

A summary of the results and hypotheses can be found in Table 4.19.

5.2. Augmented Reality and Context

Condition 3 (Figure 3.7) in the present study was the most similar of the conditions to an augmented reality type of display. The physical world (the device) was augmented by superimposed computer graphics (procedural indicators). Many reasons were given for why such an augmented reality display should improve performance, but the experiment and performance measures used in this study suggested the opposite. It could be argued that under some circumstances the application of an AR display might be merely an application of technology for technology's sake. An elaborate AR display with assorted bells and whistles may attract attention, but offer no benefit in operator performance.

A more preferable argument would be that an appropriate AR display benefits the operator, but only in appropriate contexts or situations, and only for certain types of AR displays. A specific augmenting display was used in a specific context in this study; therefore, one can only draw inferences about *that* augmentation in *that* context, not AR displays in general. If one assumes that AR in general is helpful, then one way to explain the results obtained here is that the context of this study, the specific operation of the device used, apparently proved to be inappropriate for two main reasons. First, the task was not sufficiently complex. Participants did not have to expend too many cognitive resources or distribute cognitive resources among elements of the task. An AR display may have been more valuable if participants had been required to operate multiple systems simultaneously, where such a display could have alerted the operators to the status of a system while they are busy with another aspect of the system.

A second shortcoming of this experimental context was the lack of a dynamic system or elements of the system. The current system is composed of elements in static or determined states (e.g., SP is on or off, ES is set to N, SA, or MA) that did not change without some action by the operator. This situation allowed the AR display to offer only very simple mappings of procedures, which were easily remembered by operators without the display. It is true that a benefit of AR is the facilitation of these types of mappings, such as the medical applications shown in Figure 2.2, but these applications are much more complex than a simple device. These kinds of applications usually involve adjusting the display to account for movements in the environment (e.g., surgeon or patient movements). The experimental context in this study did not really measure some of the main benefits of AR demonstrated in the literature; such as, providing information on changing elements or scenes.

The present study illustrates the importance of identifying how a model is represented in order to be mapped onto the real world. Presenting a pre-defined model with the device, as in Condition 2, did not benefit operators as much as presenting a pre-defined model with procedural indicators, as in Condition 5. Presenting the device only (Condition 1) led to the best performance. One possible explanation of these results might be that the device itself constituted a better model of the system during operation than the pre-defined model and the procedural indicators in Condition 5 made up for the difference. Another explanation might be that the device was not sufficiently complex to make up for the additional cognitive processing required to understand the pre-defined model. We would expect the benefit in performance that is afforded by the arrows to benefit operators with a better model to the same extent when the model was not present. However, operators in Condition 3 who had the device and the arrows did not demonstrate this expectation. It is possible that a different type of model that is designed to fit the procedures and arrows would result in better performance.

5.3. Kieras and Bovair (1984)

Kieras and Bovair noted several benefits of exposure to a device model for operators of the device, such as, decreased operation time, use of short cuts, and easy recall of operations. Following Kieras and Bovair, a general definition of a device model was used here (although alternate definitions were reviewed in Chapter 2). A flow diagram of a device was identified as a representative mental model of the device. Participants with the model used in this study, however, did not exhibit the superior performance Kieras and Bovair lead us to expect.

A key difference between the present study and that of Kieras and Bovair is their focus on learning. Their study focused on the role of learning a model in operating a device and the benefits were observed after a one-week retention period. These benefits might reflect effects of the model on the organization of long-term memory, rather than working memory. Participants in the present study did not benefit from exposure to the model when the model and device were presented simultaneously. Memory effects were not tested in this experiment. In other words, the effects on operation of a device during original exposure to the device and model were studied here, rather than the operation of a device following recalled experience with it. This study did not demonstrate that the benefits were available to novices.

In the Kieras and Bovair (1984) study, the model might have provided a kind of *script* (cf., Schank and Abelson, 1977) that enabled Kieras and Bovair's participants to organize their memories of the device and procedures during the retention period. They were therefore better prepared to interact with the device after one week than those without the model by virtue of an organizational script that organized information about the device. Participants in the present study were not able to exploit the model in this way. In order to exploit a mental model in this way, participants need memories (usually provided during training) to support the model; memories of learning about the device. It follows that structuring the content of training that best conveys an expert mental model to a novice is a critical step in acquiring expertise. This is an important question for future research.

5.4. Research Implications

The results obtained here suggest a number of areas in which this study can be extended and enhanced in future research to explore the applicability of displaying mental models to operators via AR techniques, and the nature of mental models and expert/novice differences. These include the following:

Can a mental model be exploited beneficially if it is not acquired through personal experience and individual effort?

- What are the best means of conveying expert mental models? Can one operator understand and benefit from the mental model of another operator?
- Can novices benefit from experts' mental models?
- Are there shortcuts for developing beneficial mental models?
- What is required to supply a novice with a beneficial mental model?
- Is an experts' mental model beneficial to a novice only in recalling knowledge?

What is the best means of effectively visually conveying a mental model?

- Can a graphical figure represent a mental model?
- Is a still image more effective than video?
- Is a two-dimensional image more effective than a three-dimensional image?

Task Context

- How complex does a task or environment need to be in order to require that an operator have a mental model of it?
- What is the role of environment (e.g., do continuously and autonomously changing aspects of the environment require that an operator have a mental model of it)?
- At what level of detail of a given task is expertise necessary for successful performance?

Performance Assessment and Data Collection

- What is an appropriate method for assessing an operator's level of understanding?
- What is an appropriate method for eliciting a mental model?
- What is an appropriate method for assessing workload?

Each of these areas is discussed briefly below.

Can a mental model be exploited if it is not acquired through personal experience and individual effort? Experience and the accuracy of mental models are correlated; experienced operators usually have more accurate mental models than less experienced operators. The benefits of a well-formed model go to the more experienced operator, but how can the source of these benefits be shared? This research presented novice operators of a device with a figure that was intended to represent a well-formed mental model, in order to make it available to them. A motive underlying sharing mental models is saving the time and effort required to accrue the personal experience to develop a well-formed mental models. Consider a task environment that requires expertise in many domains, for example, an astronaut on a long-duration mission to Mars. This individual may need to be fluent in aerospace technology, electronics, computer systems, biology, medicine, and more. The capacity to develop expertise in all of these areas is beyond any individual. Future research may investigate other means of sharing mental models.

It is worth considering whether an individual's mental model makes sense to other individuals before we attempt to share it. Mental models are very internal structures that are replete with idiosyncrasies. Individuals are likely to conceptualize features of a system so differently that they are beyond recognition. In this study, some operators' individual mental models and analogies (gates, pipes, and railroad tracks, see section

4.2.4) did not make obvious sense to others. The situation gets more complicated when we want to expose experts' mental models to novices. Perhaps some training is required to understand an expert's mental model.

What is the best means of effectively visually conveying a mental model? The means of representing mental model is a critical issue. The results of this study suggest that the graphic used is not equivalent to a mental model. No one knows what a mental model looks like; as a memory structure in the mind, it probably doesn't really *look* like anything recognizable. We can employ graphics as metaphors of mental models, but we cannot guarantee the graphics are truly representative. Future research may consider alternative means of representing mental models. More abstract or a redesigned graphic are possibilities. Several participants in this study suggested that a dynamic graphic, like an animation, might help; this is a dimension of mental models that future research can investigate.

Task context: How complex does a task or environment need to be in order to require that an operator have a mental model of it? The task (operating a device) studied in the current study might not have been complex enough to illustrate the development and benefits of an appropriate mental model. Several participants commented on the ease of the task and that they memorized it; the performance measures reflect this also. If the entire task and task environment can be easily memorized by rote, then there is no obvious need for a mental model. Future research may consider the role of mental models given a more complex task or task environment. More complex procedures or device can make the task more complicated. Operating multiple devices or performing secondary tasks are ways to make the task environment more complex. Increasing the complexity of experimental tasks is likely to increase the development of mental models and the utility of their presentation during task performance.

Performance Assessment and Data Collection The number of wrong trials chosen by an operator was a primary measure of understanding in this study. As noted earlier, future research may experiment with alternate assessments of understanding. An operator's sketch of how the device works may reflect understanding. The experimental task here may have been too simple to produce varying levels of understanding, but differences in understanding are likely to emerge with a more complex task. Given a sufficiently complex task, participants can be asked about relationships among features of the task.

What is an appropriate method for eliciting a mental model is a frequent question among knowledge engineers, and this research certainly cannot provide an answer, but reiterates the question. The use of various data sources (performance data, questionnaire data, verbal data, and so on) is an approach that offers a more thorough perspective than any one source. Future research may employ more extensive measures such as thorough verbal protocols and concept mapping (Hoffman, 2003). Langan-Fox, Code, and Langfield-Smith (2000) provided an excellent resource in the form of a table summarizing various techniques for eliciting and representing mental models, including, cognitive interviewing techniques, verbal protocol analysis, content analysis, task observation, visual card sort, repertory grid, ordered-tree, multidimensional scaling, distance ratio formulae, and path-finder.

5.5. General conclusions

A potential benefit of an augmented reality display using device or system models is its ecological validity. An augmented reality display involves a link between the real world (e.g., device / system control panel) and computer support (e.g., explicit model of device and procedure hints). Consider a system comprised of elements that do not easily lend themselves to an electronic display (e.g., actual people) and some that do, for example, a factory, including machines, materials, and personnel. A model of the factory system can be displayed using AR, and operators of the system can anticipate faults and reroute the flow through the system. Such a mapping of a model onto real world images should reduce the cognitive effort required to maintain abstract models and relate them to the real world where appropriate, if the right type of display is used. Models can also allow procedures to be inferred that are not standard or even expected. For example, consider a power-outage in a laboratory. A model of the laboratory's power usage may indicate the locations of main users of power and standard procedures may dictate that these units should be disconnected from the power source. However, standard procedures may not consider alternatives such as disconnecting most recently connected units or most volatile units first. Projected models that reflect the current laboratory set-up can help operators (electricians or lab workers) to quickly diagnose the cause of the outage and save any work that may be threatened by a loss of power.

This study considered the effects of augmenting a device with a device model on performance. Displays augmented with a model did not yield the expected improvements in performance. Perhaps the context of the experimental task was not complex enough to highlight performance improvements. In complex environments, model projections may significantly decrease operators' workload since the details of procedures will not need to be held in memory, but an experienced operator can infer them from the model. Analysis of verbal data suggested that operators often attempt to form their own model regardless of whether they are given a pre-defined model.

This study considered a novel application of AR – the provision of mental models of a device in order to improve operators' interactions with that device. Although the expected performance benefits were not demonstrated in this study, several research avenues were discussed that may lead to performance benefits. An entire technology (AR) cannot be evaluated by evaluating a specific task context and display, such as those used in this study. .

Chapter 6: References

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Appendix A: General and Condition-Specific Questionnaire Items

General items for all conditions:

1. I believe the device displayed actually controlled the process.

1	2	3	4	5
Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

2. I felt supported/able to operate the device.

1	2	3	4	5
Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

3. I felt involved in the task.

1	2	3	4	5
Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

4. The indicator lights on the device helped me determine the working procedures.

1	2	3	4	5
Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

5. The route of energy flow to the phasers was clear.

1	2	3	4	5
Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

6. The task was easy to do.

1	2	3	4	5
Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

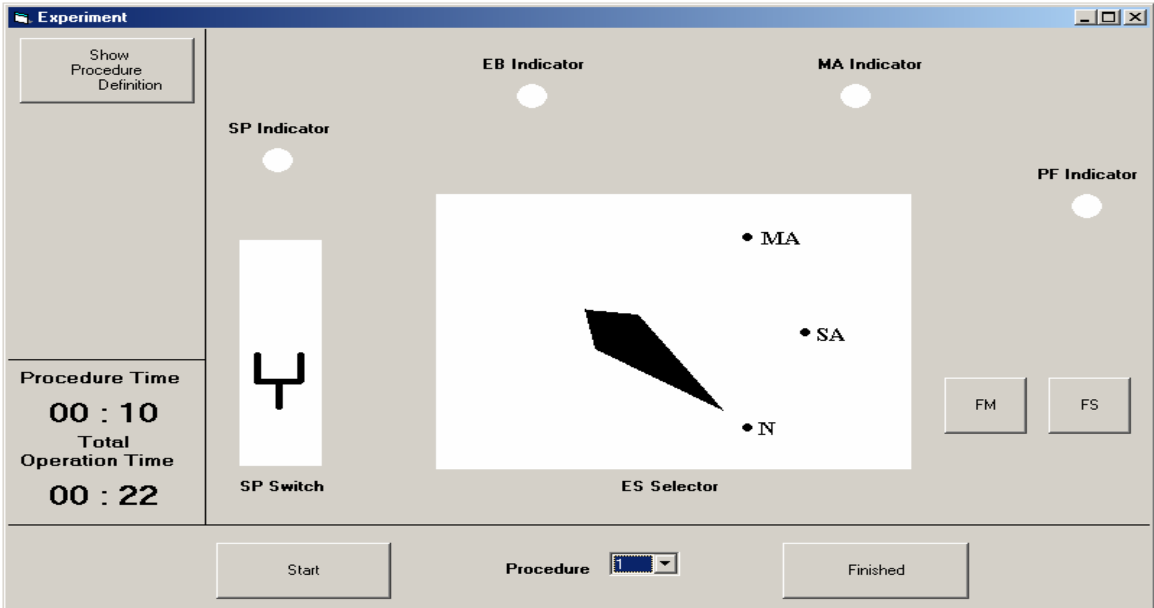
7. The task was easy to understand.

1	2	3	4	5
Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

8. The layout of the device matched my model of it.

1	2	3	4	5
Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

Condition 1:



Questionnaire items:

1. The simplicity of the device made it easy to operate.

|___________|___________|___________|___________|

1	2	3	4	5
Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

2. The layout of the device matched the way I think energy is routed through the phaser-banks.

|___________|___________|___________|___________|

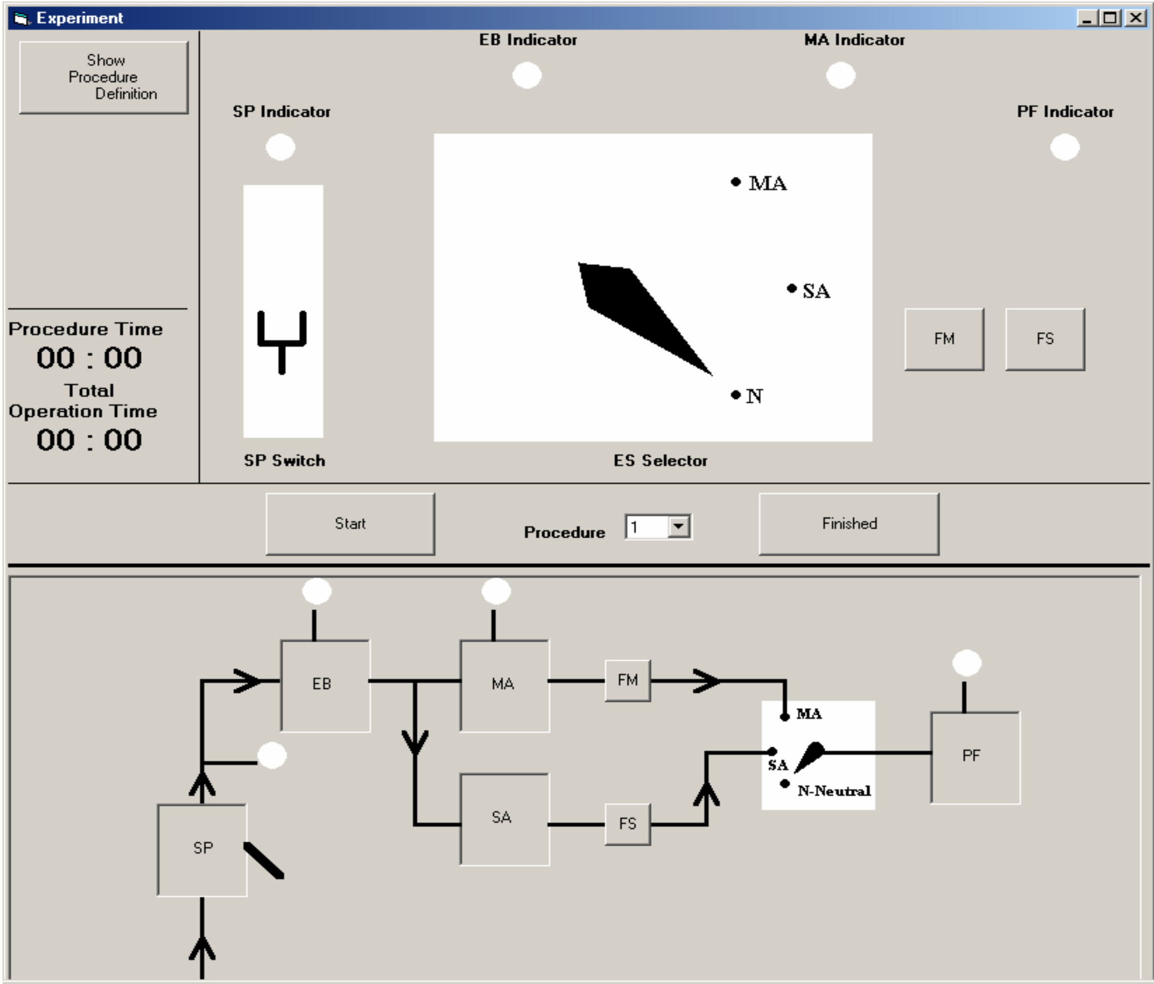
1	2	3	4	5
Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

3. I found the display of the procedures onscreen as helpful as the paper.

|___________|___________|___________|___________|

1	2	3	4	5
Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

Condition 2:



Questionnaire items:

1. The correspondence of the device (top) and the model diagram (bottom) was clear.

|_______________|_______________|_______________|_______________|

1	2	3	4	5
Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

2. It was difficult to visually integrate the device (top) and the model (bottom)

|_______________|_______________|_______________|_______________|

1	2	3	4	5
Very Easy	Easy	Undecided	Difficult	Very Difficult

3. I scanned the model (bottom) frequently.

|_______________|_______________|_______________|_______________|

1	2	3	4	5
Never	1 time	2-4 times	5-8 times	Very Frequently

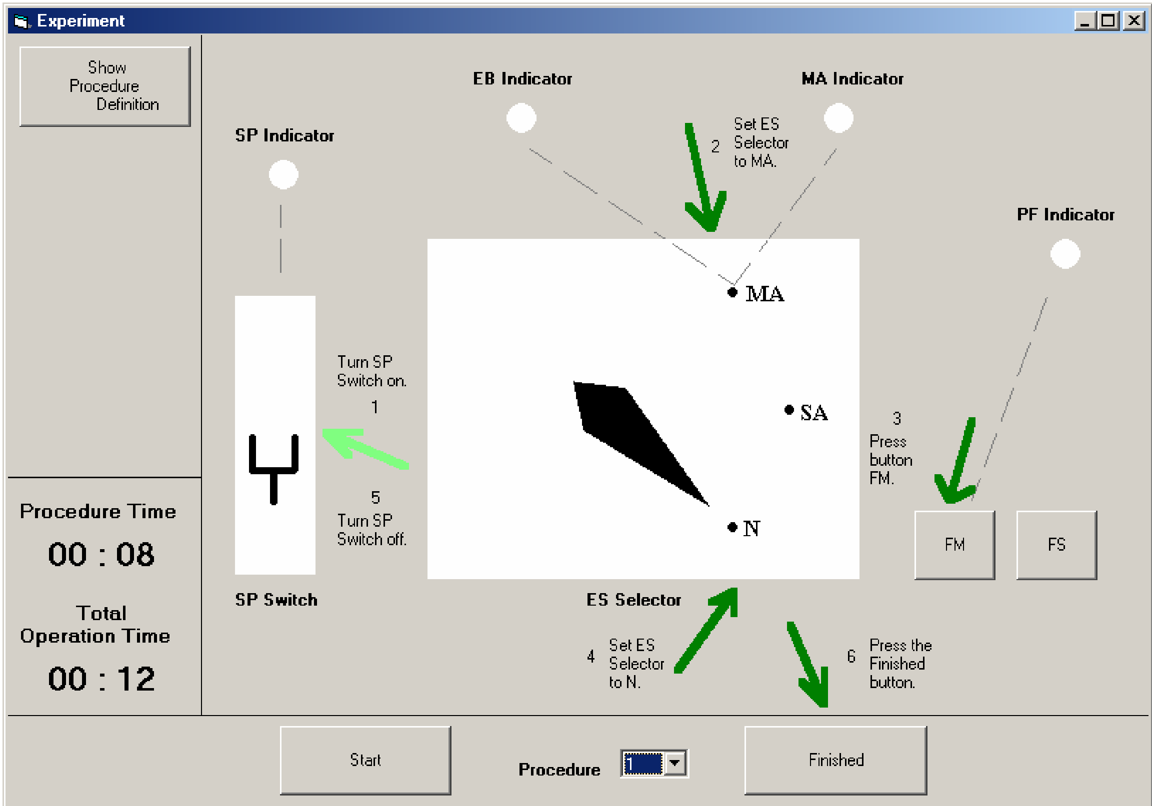
4. The model (bottom) made it easier to understand the procedures for operating the device (top).

1	2	3	4	5
Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

5. The presence of the model/diagram (bottom) made it easier to operate the device (top).

1	2	3	4	5
Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

Condition 3:



Questionnaire items:

1. The colored arrows helped me follow procedures.

1	2	3	4	5
Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

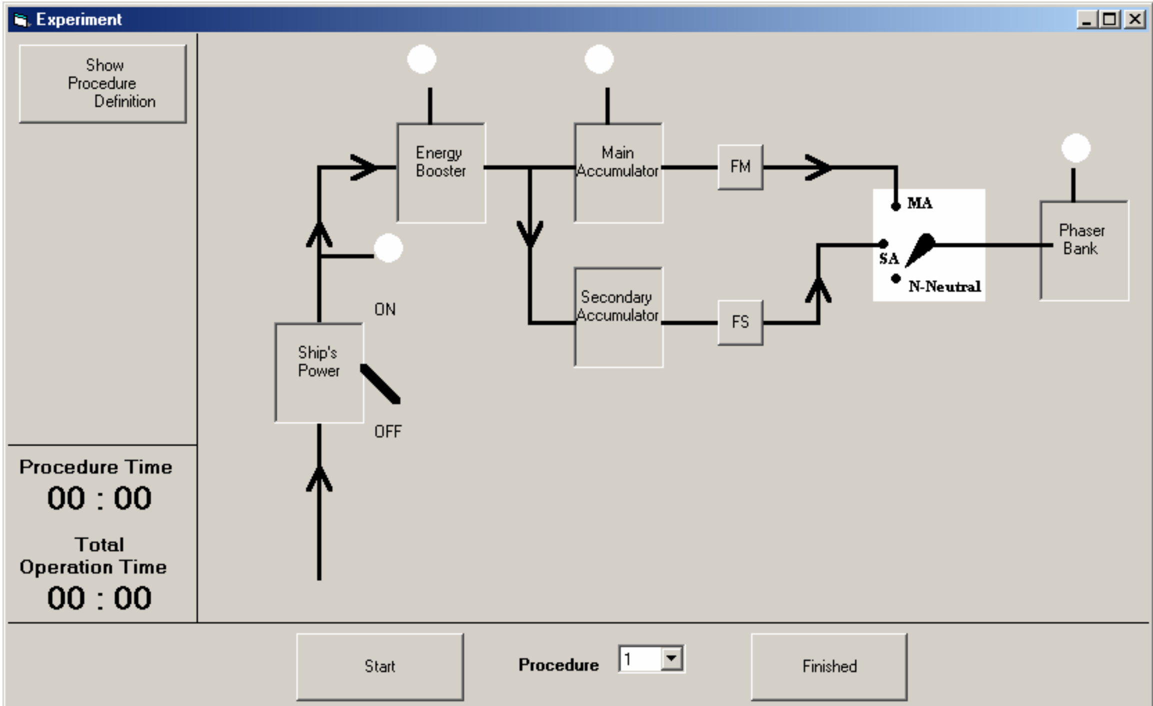
2. The colored arrows got in the way.

1	2	3	4	5
Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

3. The colored arrows helped me follow the routing of energy to the phaser-banks.

1	2	3	4	5
Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

Condition 4:



Questionnaire items:

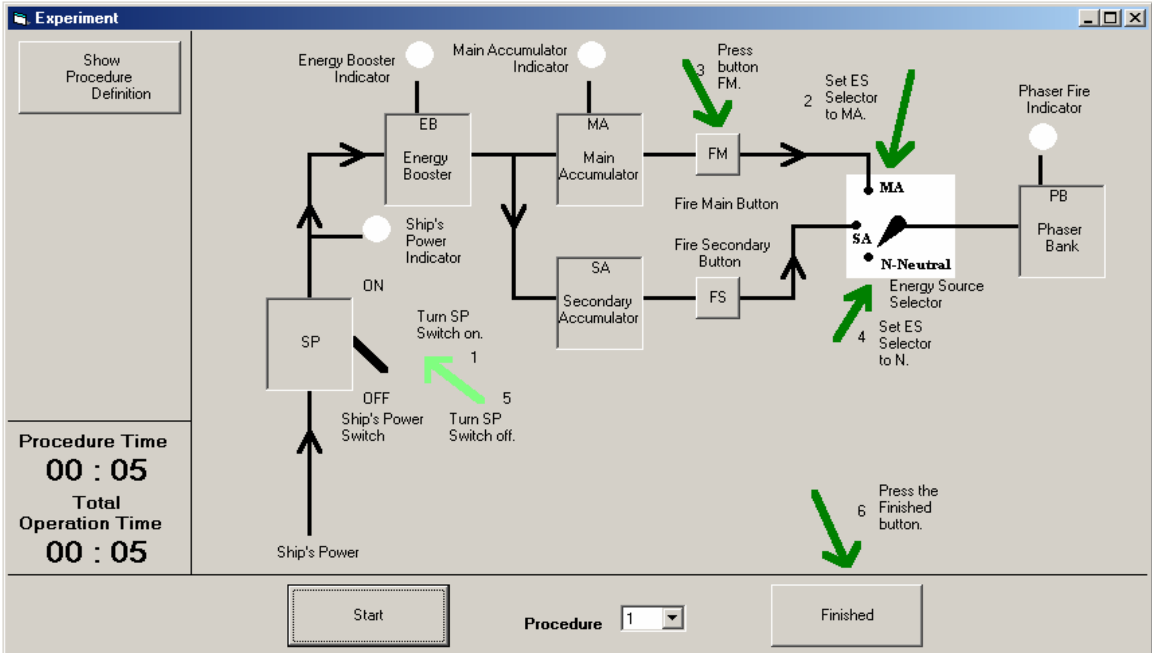
1. The device/diagram matched my own model of the energy flow through the phaser-banks.

1	2	3	4	5
Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

2. I found the display of the procedures onscreen as helpful as the paper.

1	2	3	4	5
Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

Condition 5



Questionnaire items:

1. The colored arrows helped me follow the routing of energy to the phaser-banks.

|_______________|_____________|___________|____________|

1 Strongly Agree — 2 Agree — 3 Undecided — 4 Disagree — 5 Strongly Disagree

2. The device/diagram matched my own model of the energy flow through the phaser-banks

|_______________|_____________|___________|____________|

1 Strongly Agree — 2 Agree — 3 Undecided — 4 Disagree — 5 Strongly Disagree

3. The colored arrows helped me follow procedures.

|_______________|_____________|___________|____________|

1 Strongly Agree — 2 Agree — 3 Undecided — 4 Disagree — 5 Strongly Disagree

4. The colored arrows were confusing.

|_______________|_____________|___________|____________|

1 Strongly Agree — 2 Agree — 3 Undecided — 4 Disagree — 5 Strongly Disagree

5. The colored arrows helped me determine which procedure would lead to a successful operation of the device.

|_______________|_____________|___________|____________|

1 Strongly Agree — 2 Agree — 3 Undecided — 4 Disagree — 5 Strongly Disagree

Open-ended questions:

Participants responded to the following open-ended questions asked by the experimenter:

- Was operating the device easy/difficult?
- What was easy/difficult?
- What additional info would have made your task easier here?
- Was it apparent what the different buttons and switches did? If not, what additional info would have helped clarify their function?
- Did you understand the role / function of all buttons? If not, which ones were confusing? How did this affect your performance?
- Did you find yourself using any procedure for selecting procedures?

Appendix B: NASA-TaskLoad Index Materials

Subject Instructions: Ratings

We are interested not only in assessing your performance but also the experiences you had during the task. Right now we are going to describe the technique that will be used to examine your experiences. In the most general sense we are examining the "workload" you experienced. Workload is a difficult concept to define precisely, but a simple one to understand generally. The factors that influence your experience of workload may come from the task itself, your feelings about your own performance, how much effort you put in, or the stress and frustration you felt. The workload contributed by different task elements may change as you get more familiar with a task, perform easier or harder versions of it, or move from one task to another. Physical components of workload are relatively easy to conceptualize and evaluate. However, the mental components of workload may be more difficult to measure.

Since workload is something experienced individually by each person, there are no effective "rulers" that can be used to estimate the workload of different activities. One way to find out about workload is to ask people to describe the feelings they experienced. Because workload may be caused by many different factors, we would like you to evaluate several of them individually rather than lumping them into a single global evaluation of overall workload. This set of six rating scales was developed for you to use in evaluating your experiences during different tasks. Please read the descriptions of the scales (printed on the laminated page) carefully. If you have a question about any of the scales in the table, please ask me about it. It is extremely important that they be clear to you. You may keep the descriptions with you for reference during the experiment.

Please evaluate the task by marking each scale at the point that matches your experience. Each line has two endpoint descriptors that describe the scale. Note that "own performance" goes from "good" on the left to "bad" on the right. This order has been confusing for some people. Please consider your responses carefully in distinguishing among the task conditions. Consider each scale individually. Your ratings will play an important role in the evaluation being conducted, thus your active participation is essential to the success of this experiment, and is greatly appreciated.

Subject Instructions: Sources-of-Workload Evaluation

Throughout this experiment the rating scales are used to assess your experiences during the task. Scales of this sort are extremely useful, but their utility suffers from the tendency people have to interpret them in individual ways. For example, some people feel that mental or temporal demands are the essential aspects of workload regardless of the effort they expended or the performance they achieved. Others feel that if they performed well, the workload must have been low, and vice versa. Yet others feel that effort or feelings of frustration are the most important factors in workload and so on. The results of previous studies have already found every conceivable pattern of values. In addition, the factors that create levels of workload differ depending on the task. For example, some tasks might be difficult because they must be completed very quickly. Others may seem easy or hard because of the intensity of mental or physical effort required. Yet others feel difficult because they cannot be performed well, no matter how much effort is expended.

The evaluation you are about to perform is a technique developed by NASA to assess the relative importance of six factors in determining how much workload you experienced. The procedure is simple: You will be presented with a series of pairs of rating scale titles (for example, Effort / Mental Demands) and asked to choose which of the items was more important to **your** experience of workload in the task that you just performed. Each pair of scale titles is printed separately on each of the cards. **Use the marker to mark the Scale Title that represents the more important contributor to workload for the Specific task you performed in this experiment.**

After you have finished the entire series we will be able to use the pattern of your choices to create a weighted combination of the ratings from that task into a summary workload score. Please consider your choices carefully and make them consistent with how you used the rating scales during the particular task you were asked to evaluate. Don't think that there is any *correct* pattern; we are only interested in your opinions. If you have any questions, please ask them now. Thank you for your participation.

SCALE TITLES FOR THE NASA-TLX

TITLE	ENDPOINTS	DESCRIPTIONS
Mental Demand	Low/High	How much mental and perceptual activity is required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low/High	How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low/High	How much time pressure did you feel due to the rate or pace at which tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

Performance	Good/Bad	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration Level	Low/High	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

NASA TLX RATING SHEET

Subject # _________ Condition # ________

MENTAL DEMAND

Low High

PHYSICAL DEMAND

Low High

TEMPORAL DEMAND

Low High

PERFORMANCE

Good Bad

EFFORT

Low High

FRUSTRATION

Low High

Subject #: _______________

Sources of Workload

Task #: ______ Document: ______ Condition: _______

Scale title	Tally	Weight	Raw rating	Adjusted Rating (Weight X Raw)
Mental Demand				
Physical Demand				
Temporal Demand				
Performance				
Effort				
Frustration				

Total Count = ____ (no weight can be greater than 5; total count can't be > 15).

Write the sum of the adjusted rating column _______. Weighted rating = Sum of adjusted ratings/15

Weighting pairs:

Physical Demand / Mental Demand

Temporal Demand / Mental Demand

Operator Performance / Mental Demand

Frustration / Mental Demand

Effort / Mental Demand

Physical Demand / Operator Performance

Temporal Demand / Operator Performance

Frustration / Operator Performance

Effort / Operator Performance

Physical Demand / Temporal Demand

Frustration / Temporal Demand

Effort / Temporal Demand

Physical Demand / Effort

Frustration / Effort

Physical Demand / Frustration

Appendix C: Informed Consent for Participant of Investigative Project

Virginia Polytechnic Institute and State University

Title of Project: Effects of the Presentation of a Device Model Using Augmented Realty

Principal Investigator: William Staderman

Co-PI: Dr. Brian Kleiner

I. THE PURPOSE OF THIS RESEARCH/PROJECT

This study involves operating a device that is simulated on a computer screen. The purposes of this study are to see how people interact with the simulated device and methods to improve these interactions. A total of forty participants will be involved in this project.

II. PROCEDURES

You will be asked to use a computer-based system, much like a simple video game, continuously for 45-minutes using operations (series of mouse clicks) that have been defined for you. Feel free to ask any questions before you begin interacting with the device, but do not ask any questions until you are finished. Your speed and accuracy are both important, but you are urged to try to operate the device as efficiently as possible. After working with the device, you will be asked to complete 2 questionnaires (5 items each) and complete a version of the NASA TaskLoad Index. Finally, you will be asked to verbally comment on their interactions with the device.

The operations pose no risks to you. The tasks are not very tiring and you may terminate your participation at any time, for any reason.

III. RISKS

There are no known risks to the participants of this study.

IV. BENEFITS OF THIS PROJECT

Your participation in this project will provide information that may be used to improve methods for supporting operators of various devices. No guarantee of benefits has been made to encourage you to participate. You may receive a synopsis summarizing this research when completed. Please leave a self-addressed envelope with the experimenter and a copy of the results will be sent to you.

You are requested to refrain from discussing the evaluation with other people who might be in the candidate pool from which other participants might be drawn.

V. EXTENT OF ANONYMITY AND CONFIDENTIALITY

The results of this study will be kept strictly confidential. Your written consent is required for the researchers to release any data identified with you as an individual to anyone other than personnel working on the project. The information you provide will have your name removed and only a subject number will identify you during analyses and any written reports of the research.

VI. COMPENSATION

Your participation is voluntary and you will be paid $10. You will still be compensated if you choose to withdraw.

VII. FREEDOM TO WITHDRAW

You are free to withdraw from this study at any time for any reason and still be compensated.

VIII. APPROVAL OF RESEARCH

This research has been approved, as required, by the Institutional Review Board for projects involving human participants at Virginia Polytechnic Institute and State University, and by the Department of Industrial and Systems Engineering.

IX. SUBJECT'S RESPONSIBILITIES AND PERMISSION

I voluntarily agree to participate in this study, and I know of no reason I cannot participate. I have read and understand the informed consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project. If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project

______________________________ __________________

Signature Date

____________________________ ____________________________

Name (please print) Contact: phone or address or

____

email address (OPTIONAL)

Should I have any questions about this research or its conduct, I may contact:

Investigator:	William Staderman	Phone (540) 552-9079
		Graduate student
		Department of Industrial and Systems Engineering
		email: wstade@vt.edu
Advisor:	Dr. Brian Kleiner	Phone (540) 231-4926
		Professor, ISE Department (540) 231-6656
		email: bkleiner@vt.edu

David Moore, IRB Phone (540) 231-9359

Research and Graduate Studies 301 Burruss Hall

Campus - 0244

Virginia Tech

Appendix D: Participant Operator Instructions

A control panel is displayed on the CRT. The control panel is made up of switches and buttons that can be changed, and indicators that automatically indicate if a feature of the panel is active. Your task is to operate the control panel. You are encouraged to operate it efficiently, accurately, and quickly. Operations involve clicking particular buttons and settings on the panel. A specified program of operations is called a procedure. Carrying out a successful procedure results in the PF indicator light on the panel to blink. The device you will be operating is a hypothetical phaser-firing control panel based on Star Trek. The function of the control panel is to route power from the ship to the phasers.

The energy booster takes in power from the ship and boosts it to the level necessary to fire the phasers. Power that has been boosted by the energy booster is fed into the two accumulators. Both accumulators store large amounts of power ready to be discharged to the phaser bank whenever the phasers are fired. Because the accumulators handle such large amounts of power, if they are used continuously they are liable to overload and burnout. To prevent continuous use of one accumulator, this system has two: the main accumulator (MA) and the secondary accumulator (SA).

The power coming in from the shipboard circuits is controlled by the ship's power switch (SP). When the switch is off, no power is being drawn from the ship. When the switch is turned on, power is drawn from the ship into the energy booster. To boosted power is then fed into the accumulators. The accumulator whose energy will be discharged to the phaser banks is selected by the energy source selector (ES). While the ES selector is set to neutral (N), no energy can be discharged from either accumulator to the phaser bank. If the ES selector is set to MA, then pressing the “fire main (FM)” button will use the main accumulator’s power to fire the phasers. . If the ES selector is set to SA, then pressing the “fire secondary (FS)” button will use the secondary accumulator’s power to fire the phasers.

There are 7 possible procedures in all. Most times, procedure 1 or procedure 2 is successful, but the panel occasionally malfunctions and procedures 3-7 work. **The states of the indicators can help you identify the procedure that works.** Here is a list of the procedures: (the list is available while the panel is displayed, so you don’t need to memorize the procedures now)

Operating Procedures

Normal procedures	
Procedure 1	Turn SP switch on; Set ES selector to MA; Press button FM; Wait until PF indicator finishes flashing; Set ES selector to N; Turn SP off; Press the “Finished” button
Procedure 2	Turn SP switch on; Set ES selector to SA; Press button FS; Wait until PF; indicator finishes flashing; Set ES selector to N; Turn SP off; Press the “Finished” button
Malfunction Procedures	
Procedure 3	Turn SP switch on; Set ES selector to MA; Press button FM; Wait until PF indicator finishes flashing; Set ES selector to N; Turn SP off; Press the “Finished” button
Procedure 4	Turn SP switch on; Set ES selector to SA; Press button FS; Wait until PF; indicator finishes flashing; Set ES selector to N; Turn SP off; Press the “Finished” button
Procedure 5	Turn SP switch on; Set ES selector to MA; Press button FS; Wait until PF; indicator finishes flashing; Set ES selector to N; Turn SP off; Press the “Finished” button.
Procedure 6	Turn SP switch on; Set ES selector to SA; Press button FM; Wait until PF; indicator finishes flashing; Set ES selector to

	N; Turn SP off; Press the "Finished" button.
Procedure 7	Turn SP switch on; Set the ES selector to N; Turn SP off; Press the "Finished" button.

In order to operate the panel, click the 'Start" button, and then select the number of the procedure you want and carry out that procedure. **If a procedure is not successful, then select a different procedure and follow it.** You can select a different procedure at any time without clicking the 'Start' button again.

To operate:

- **Click 'Start" button.**
- **Select procedure.**
- **Follow procedure.**

If you want to review a text description of a selected procedure, press the 'Procedure Definition' button. When this button is clicked and the description is displayed, the panel is disengaged; clicking the button again hides the description and re-engages the panel. You are encouraged to use the most efficient procedures. Consider the indicators as you go through an operation.

Following a successful operation (the PF indicator blinks) 'Operation successful. Click Start to begin Operation x' is displayed in a small window in the top left corner of the CRT. After a brief pause, the panel is refreshed and you should begin again. The default procedure and the successful procedure may be changed.

After completing several operations, you will be asked to respond to a few questionnaire items and complete the NASA TaskLoad Index. Finally, I will record your responses to a couple of questions regarding your overall experience with the device you operated.

Appendix E: Transcripts of post-experiment interviews

<u>PARTICIPANT TWO</u>

<u>I</u>: We are going to record a couple of things about, in general, your experience with that thing; how you felt about it. There are some questions here that are pretty general. First of all, was it pretty easy or difficult to operate it?

<u>R</u>: I think it was easy; I felt easy.

<u>I</u>: Did you get the impression that you were actually controlling the system or just using that computer program?

<u>R</u>: I felt like using the computer program because some of the procedures were working; I mean it was kind of selected randomly, the operation procedure, so I had to, like, instead of like controlling the program, the program was controlling…me what to do.

<u>I</u>: Do you think any additional information would make it easier to do it?

<u>R</u>: If the diagram at the bottom part was important, there should be like an indication of watching that part more often, like doing each operation.

<u>I</u>: How do you mean?

<u>R</u>: I didn't look at the bottom part a lot. Instead of just…try to find the right procedure and…I tried to, like, find the right procedure and doing the operations; I didn't, like, look at the bottom part.

<u>I</u>: Okay. Was the role or function of each one of the buttons clear? Do you know what they did?

<u>R</u>: Yes.

<u>I:</u> Okay. Did the indicators help you figure out which procedure to use?

<u>R</u>: You mean the indicators at the bottom?

I: No, the lights along…

R: Yea, sort of.

I: How did you choose which procedure to use?

R: I actually did it randomly.

I: You did it randomly? Okay.

R: Yes sir.

PARTICIPANT THREE

I: Now the last thing we're going to do is I'm going to go over a few questions about your general experience with the device; how you felt about it and I have a few questions. The general questions, just fill in whatever you think is appropriate. In general, was operating the device pretty easy or difficult?

R: Easy.

I: Easy? What do you think made it so easy?

R: The arrows.

I: The arrows? What about the arrows?

R: They changed colors when you were supposed to do different operations.

I: Okay….so they pointed out steps as you go

R: Right.

I: Okay. Do you think anything additional would have made it easier to go through?

R: If they had a light that said one of the operations didn't work.

I: Was it clear what different buttons and switches did?

R: What they meant?……or which ones to press?

I: What they meant.

R: No.

I: It wasn't clear what they meant. Was it clear, how they related?

R: Not really. I don't think I read through that thoroughly.

I: Uh-huh. How did you select the appropriate procedures?

R: I started out on one; or I started on an arrow where they started at, and if that didn't work, I started out on one and went through it from there.

I: So you kind of went sequentially?

R: Right

I: Okay. Did you build up an idea in your head about what the system looked like; what you were doing with it?

R: No.

I: Okay. That's all. Do you have anything to add?

R: No.

PARTICIPANT FOUR

I: Well, first of all, did you feel that, did you get the impression that the device actually did something or was just a program?

R: No, just a program. I was trying to figure out what the order was, in my head, but I couldn't keep all the numbers down and what order they came in.

I: The order of procedures that worked?

R: Yeah.

I: Okay. Did you find yourself developing some kind of model of the way the thing worked?

R: I didn't, well, at first I was thinking it was random but then after a while I thought there was some kind of order but I couldn't keep the order in my head; that many, by the time I had kept that many in order I just couldn't figure out what the order…so no, not really.

I: Did you find operating the device easy or difficult?

R: Sort of difficult because when you put the cursor you can't tell where the buttons really were, so sort of clicking around to figure out.

I: The target-space was not always obvious.

R: Right

I: Okay then. What additional information would make it easier for you?

R: I guess if I knew what order they were going to go in – if there was like a some sort of set, I could just follow that immediately, or if I knew that …..I think also making like a target that you actually had to hit as opposed to just a line or something that it would have gone a little faster or something.

I: I noticed that you kept looking at the paper rather than using the…

R: Yeah, I guess I didn't really think about even…by the end I had memorized which order they went in, but at first I was sort of reading off the form.

I: Do you think the paper was easier than the on-line thing?

R: I don't know. I didn't look at the on-line thing. Maybe if I had looked at it before, then I would have seen what it looked like; then I would have used it more. But I guess you didn't really have to use the paper that much; that's why I didn't click on the on-line.

I: So you didn't have to use the paper too much?

R: I mean, after I did the first couple…went up there and did a couple of them that I figured out, you know, what each operation was, seemed to have sort of an order to them, so….

I: Okay. Was it pretty apparent what each button and switch on the device did?

R: Yeah, I think so. I knew what they were controlling, at least. Except when you read the procedures – it's sort of backwards on the procedures, so then I kind of knew that it's probably just the computer was running the program.

I: That was the tip…..

R: The key, yeah…..

I: So you felt that you understood the role of each button?

R: I think so; sort of opening the gates and then letting the power accumulate and shooting it out.

I: So from what you read at the beginning, you were able to make sense of that?

R: The reading was kind of confusing; the picture helped me more; the actual seeing the demonstration. I'm not very good at comprehensive reading, though, so I'm much better on the screen.

I: You're not alone.

R: Yeah, that's the kind of learner I am.

I: Well, I suppose that's all I have to go through.

R: Good.

PARTICIPANT FIVE

I: In general, do you find operating that device difficult or easy?

R: It was difficult at first. It gets easier, but not as easy as can be.

I: Okay; it starts out really difficult and it gets easier but it never gets all the way simple.

R: Yeah.

I: Okay. What do you think made it difficult?

R: The instructions, the instruction itself and sometimes you weren't clear what happened, so I found this difficult.

I: So the written instructions, like definition of each procedure?

R: Both

I: The whole thing.

R: Yeah.

I: Okay. What additional information do you think would have made it easier?

R: Have better instructions and step-by-step should be better.

I: And you mentioned before that it was hard to figure out what was going wrong. Do you think feedback would have been good?

R: It could be better, I'm thinking, like an error function or something like error 2, error 3, error 4.

I: As in a kind of an error definition? Okay. Was it pretty obvious what each button did, what the function of that was?

R: No.

I: No, wasn't clear at all?

R: Uh-huh

I: Do you think any kind of additional display would have made it more clear what they did?

R: Not very… I guess the graphic could have been better, like better visualization. Yes, make it look more clear, not too many things going on the same screen. At one point, there was so many arrows and so many lines…

I: The arrows kind of cluttered the screen?

R: Yeah and the colors can be better – like do a contrast…..

I: Did you feel that it was a real device or just a computer simulation?

R: Just a computer simulation.

I: So did you pay attention to the way the device was supposed to work?

R: Yeah.

I: Okay. Although you found the instructions confusing as to how it was supposed to work.

R:

I: Did seeing it like that – the device you were looking at was like a diagram - Did that help you understand the way it was described in the text?

R: Uh…no. It wasn't exactly the same. It doesn't have, like, exact button; there was like no button on some …, just like the switch you had to find a way to – you had to click on the edge of the switch to…

I: The target areas kind of small. I noticed that you never used the online definitions. You never looked at them on the screen. Do you have a reason why?

R: __________.

I: I think almost everybody is just looking at the paper. I'm trying to figure out why you would rather look at the paper.

R: It's because when you start, you didn't care about it is why. You know that it works and we'll concentrate on the task, not look at the instructions.

I: Okay. So you would rather just begin the task….

R: By looking at the instructions first. I actually click on the instructions before I press the start button and the instructions did not show up. So nothing showed up, so I thought well, that thing has malfunctioned, so that's what happened. I didn't know you first press start, then showed up. Because I pressed it before I pressed start and nothing showed up so I thought it's not working.

I: And by then you were into the routine of using the paper.

R: Yeah, by that time I would say Oh I don't know how so I'll just use the paper. I assume the buttons are not working.

I: Okay. Did you understand what all the buttons were supposed to be doing?

R: No.

I: Just randomly went through.

R: Just do what they say.

I: You were just randomly clicking through them and seeing how they worked out?

R: I mean, I click on the button that says what they're supposed to do but then I know what exactly they do in the program, you know, like in the real operations. It just says click on that yes button. I click on that yes button and I didn't know what that yes button is.

I: Okay. So you didn't really know what you were doing as you were going through the task.

R: Yeah.

I: Because the visualization didn't really match up with a real device somewhere. Okay.

PARTICIPANT SIX

I: I have a few general questions I just want to ask you about your experiences with this thing. Did you find operating it overall easy or difficult?

R: In the beginning, I found it confusing, but after I started recognizing when the lights, when the different buttons or whatever would light up and the relationship between them it got easier, I would get them right more quickly rather than going through each and every one of them.

I: Using the indicators. What additional information might help?

R: I saw different … because looking at it at first glance, you might see one light and mistake it for a different indicator if you had just glanced at it quickly, so a different color was designated for each indicator.

I: Okay. I noticed that when you were doing it you looked at the paper all the time and you never looked at the definitions on the screen…

R: I just don't like reading off a computer screen, so a lot of times even with school work, I print things off and then read them, cause I just don't like reading off of a monitor.

I: Was it pretty clear what the different buttons did or do you think their function could have been clarified?

R: Initially….I mean, I read the instructions but I didn't really see where it was going in the long run, so I probably had a slower learning curve because I didn't know it, but once I figured out those relationships, it was easy to pick up. It wasn't as much of a mental demand. You know, I was a little bit more familiar with the indicators and where they were going to I noticed that they changed, like odd number between and also I noticed the arrow between. There was a relationship between procedure one and procedure three and two and four.

I: Do you think not being familiar with the contex had bad affects on your performance?

R: I think if I would have noticed the differences between procedures earlier on, it would have affected it, but I don't think the fact that I didn't know what they really did – I don't think that was a big issue.

I: Did you have any impression that there was a genuine system?

R: Yeah, I mean, I thought it had a purpose. It was, I guess, the supply of power.

PARTICIPANT SEVEN

I: For the last part I have some questions. We're going to talk about, first of all, in general, was operating the device easy or difficult?

R: Initially, it took a couple runs to get used to it, to get a feel for where in the process something was going wrong and then you'd have to look for a procedure that would pick up where that process was not functioning properly. So it took me a good number of runs through it to get an idea of how to work it properly.

I: How do you think you figured out what procedure to go for next?

R: After a while I got a pretty good idea of which procedure did what. So I'd follow the lights and where something wasn't lighting up, I'd try, for instance, procedure three was kind of like procedure one, yet you hit a different button at the end and if procedure one didn't work up to a certain point, I'd try procedure three to see if that would work. Sometimes that would work; sometimes that would not work. If it didn't, for instance, if procedure three didn't work, then I'd try procedure five to kind of be like procedure three, but if that didn't work, then I'd get a little flustered, actually, and just try whatever.

I: What additional information or display do you think would have made it easier to do?

R: If there were a light telling you that I believe the main accumulator was not working, then that would tell you to automatically jump to the secondary accumulator because sometimes the secondary wouldn't light up and then you'd have to switch accordingly.

I: Okay. So would it help more if it displayed which accumulator was not working?

R: Yeah, because if the main is working then it shows the main and the secondary both lit up and if the main is not working, then neither light up so you need like an intermediate step to tell you which one.

I: So it's more important for you to know which one is not working than what are working?

R: Actually to keep it all consistent across board, the lights indicate if it's working, so I guess it would be better to tell you which one is working and that could tell you where to try next.

I: Okay. I noticed that you only used the paper procedure definitions, didn't look on the screen. Why do you think you didn't look on the screen?

R: I don't know. I just think sometimes it's quicker for me. I was trying to get an idea in my head so I could eventually after a couple trials have a pretty good idea in my head of which one was which.

I: Well, so far I think everyone opts for the paper too.

R: Really? Honestly, initially, I forgot that it was there and then I saw it and I just kind of kept going.

I: Some people have said that it didn't work right away, so they get used to using the paper.

R: Yeah, I started out and I honestly initially forgot that it was there and then just kind of kept going with it, so…

I: Yeah, I think people might just be used to paper. It's easier to look at the paper and then see the thing rather than having to change the entire thing. Was it pretty apparent what the different buttons and switches did in terms of the entire process?

R: It was. Initially when I first sat down before I even did it, I was a little confused, but, I mean, after reading through the directions and doing it once or twice, you do get used to it and it is pretty effective in terms of telling you what's going on.

I: Do you think it was useful to have the diagram below the display?

R: In the beginning I didn't start using it and then towards the end, I did. It was okay. I mainly used, went by the lights that were on the display where I was making the changes to the different procedures, just because it was there, than to, like, go back and forth and to go back and forth between the paper and switch procedures. I did try that once or twice but it kind of got a little tedious so I just mainly stopped with the top one.

I: Do you think you developed your own diagram in your head?

R: Yeah, just like an idea of how the process was working. I think I did. I kind of pictured it like if I were doing it, you'd have to turn it on and then you'd have to switch it and then you'd have to hit a button and then if it doesn't work, you'd have to reset, turn it on and switch between like the neutral, the secondary and main. So I kind of pictured it in terms of if it were laid out in front of me how I would do it.

I: Okay. So did you actually figure it in terms of the hardware of the actual system as opposed to just a collection of buttons itself on the screen?

R: Like in terms of me interacting with it?

I: In terms of all of it, like while you were doing it, did you think you were controlling the actual device rather than just random….

R: Sometimes I did, but then if, well like, one or two times I'd get with a system that would work, like I was saying earlier, if up until a certain point procedure one was working, and procedure three is kind of like procedure one, then I'd try procedure three, and actually sometimes that would work and sometimes it wouldn't. So then, I'd go, like with procedure five if that was kind of like procedure three and procedure one and if that wasn't working, then I'd just try whatever.

I: Just shoot around..

R: Yeah.

I: Okay.

PARTICIPANT EIGHT

I: In general, did you find operating this device easy or difficult?

R: I thought it was pretty easy.

I: What in particular did you find easy about it?

R: I think the best parts of it was the little green arrows. Those really helped in telling you what to click.

I: Do you think any kind of additional kind of information would have made it easier?

R: I don't know – maybe if you used circles instead of arrows. I don't know; that's just a personal preference.

I: Okay. I saw you never used the online definitions. Why do you think you didn't use those; you preferred paper?

R: I thought it was easier just to look at this and then look on the screen because if you hit the on-line definitions, the whole program kind of paused, so it was kind of easier just to look between this and that.

I: Because you could go through each step while you're seeing it?

R: Right, right.

I: Okay. Was it pretty clear what the different buttons and switches did?

R: Yeah, I mean everything made sense and I didn't really have…I mean the first couple times, a little…..I had to learn it, but after that it was really pretty clear.

I: Did you understand what they did in relation to each other?

R: Most of the time, yeah. Some of the stuff was kind of confusing, but I got the general idea.

I: Did you find yourself, like, building some kind of model, about how the system really worked?

R: Yeah, sort of. I mean, I could figure out that you had to turn on the switch, like turn the power on, and then select the, you know, the accumulator you want to use and then if the lights came on, and then you got to choose the two buttons and see if they worked.

I: Did you find the indicators quite helpful?

R: Yeah, those are really helpful.

I: Okay. I already asked you if you understood what each button did.

R: Right.

I: Okay. Do you think there's any more you want to add?

R: I thought it was a pretty good program and was easy to use and I think it made a lot of sense. It sounded kind of confusing before I started, but once I got started, it was easy to use.

I: That is a common experience. You don't really recognize it in text.

R: Until you started doing it, yeah. The first time was kind of confusing, but after that it was…the program was really helpful. It was easy to use.

I: Okay. Did you get the impression that it was an actual hardware system that this could have been controlling?

R: Yeah, I thought it was a good simulation of something that could possibly happen.

I: Okay. That's all I have to say.

R: Okay, sounds good.

I: Thank you very much.

R: You're welcome.

PARTICIPANT NINE

I: First of all, in general, do you find operating the thing easy or difficult?

R: It was medium. I had to sit there and look at where it said, for instance, ES selector, and I had to sit there….what is ES selector? It may have been an obvious energy source but I had to kind of hunt down that on the screen.

I: so translating the labels was rough.

R: Yes. If you had said "energy source selector," I would have okay, there it is, there.

I: Okay. Well, that answers the next question, "What was easy or difficult?" What additional information, like the full labels?

R: They were on the short hand of the screen and they helped also. I think if I remember right, you had SP for shift power over here, but then you said Energy Source over here. written out instead of ES, so it is some consistency issue.

I: I noticed that you spent time with looking at the definitions on paper. Why do you think you didn't bother with the ones on the screen?

R: Oh, it never crossed my mind. I was just so used to flipping through the pages , it didn't occur to me just to click the procedure on the screen.

I: Was it pretty clear what the different buttons and switches did in relation to each other?

R: No, I never really paid attention to that; I was just sort of kind of busy making that light blink.

I: Goal-oriented. Given that idea, did you ever think there was an actual kind of a hardware system, or at least some system along the way things worked?

R: Kind of random to me, because…the first four procedures, if I remember right, one and three and two and four are the exact same, if I remember right. So, the way I thought about it was I thought if one worked, or if one didn't work, three wouldn't work, but there were times when one didn't work and three would work and they were the same thing to me. So, I don't think there was any real order to it. It was just random to me because of that fact.

I: Did you conceptualize anything about what the system was doing in terms of, in general, the system was directing energy flow. Do you think that was built up underneath the display??

<u>R</u>: I think much in terms of the engineering aspect, no. Programmatically I was thinking, how was it working, but I couldn't really get much, so…

<u>I</u>: So you were thinking more about the program?

<u>R</u>: Yeah, more or less an engineering mind.

<u>I</u>: You're a CS guy, right?

<u>R</u>: Exactly. Go CS!

<u>I</u>: Well, that's about all I have to ask. Do you have anything you want to add?

<u>R</u>: No, that's fine, ____.

<u>I</u>: Alright, well, thank you very much.

<u>R</u>: Thank you.

<u>PARTICIPANT TEN</u>

<u>I</u>: These are just a couple of general things about the experience that I'm going to ask about. In general, do you find operating this device difficult or easy?

<u>R</u>: I guess I would say it was easy.

<u>I</u>: Okay. What in particular did you find made it easy?

<u>R</u>: Well, it wasn't in particular a demanding task; it was just repetitive. Yeah, it was repetitive. So how fast can you click these buttons?

<u>I</u>: Okay. Do you think there could have been any extra information that would make it easier for you?

<u>R</u>: Well, considering the nature of your machine, since it kept making mistakes and never really did the same thing each time, I guess what you gave me was good enough because at least I didn't really have to think about what I was doing; I could just follow the arrows every time.

I: So following the arrows was very helpful?

R: Yeah, I just basically started following the arrows instead of … All of the tasks were very similar anyway, so the only arrows I really followed were whether it should go to secondary or primary.

I: You also never looked at the on-screen definitions.

R: No, I read through these and then I just started following the arrows. Was there something special in there?

I: Not really. Actually, no one is. I'm just wondering why no one is.

R: Well, it's already here, so I guess that's reason to look at it again.

I: Yeah, I guess so.

R: Three different places.

I: I think it's…well I don't know, I have a lot of theories, I'm not quite sure… Was it pretty apparent to you what the different buttons and switches did?

R: Sure, they were well labeled to each other. They were labeled well enough.

I: Did you conceptualize a model of the system underlying this display…what you were actually doing?

R: A faulty one, but yes, I got the idea of how it works.

I: Did you develop a model of the general process was controlling the energy flow…

R Right

I … and did you follow the way they went to the different accumulators and buttons and so on?

R: I never really actually looked at it. The on/off switch and the things as part of the stream… And the what was it called….master and secondary accumulator the main and secondary accumulator switch between those two.

I: The Energy Selector? MA, SA, and Neutral.

R: Neutral , yeah. I only looked at the on switch dot and the…

I: Di0d you look at the indicator lights at all?

R: Well, once you turn the power on, those two right there, the two on the top left, were always on so they were just another bump in the road. But the one that actually showed you that was firing was how to determine whether it worked or not. If that one didn't go when I switched it to the right accumulator, then I just went to the next procedure.

I: Did you go through the procedures kind of sequentially or did you have any kind .of order?

R: Well, I blindly believed you telling me one and two are pretty common, so after I…

I: They actually are.

R: That's good.

I: Not as common as they would be if it worked right, but…..

R: First I took the one you gave me because it has the same odds as one through six; at least it seemed to at least. So I did that, and if that didn't work I did…it was always one or two that gave you at the beginning. And if that didn't work, then I did the one that wasn't done, one or two, and then I did seven because that was real easy because… and if that didn't work, then I just creatively went through the rest of them, like sometimes I would go top-down; some I would go bottom-ups and…

I: It is interesting to see different strategies …..

R: …tried to make the task interesting since it really wasn't doing what it was supposed to do, so I said "Well, okay, just play around."

I: Did you understand what the buttons did? You said that you have the right concept of what the process was. Did you see what the buttons…what their function was in relation to that system?

R: How so?

I: For example, what different settings of the energy selector did.

R: As far as…the concept I had, the main power comes on, gets routed to two things that I never read the names of and then to the main and secondary accumulators and then you decide which one you want to pull the power from and send it to the phaser banks.

I: Do you think seeing the device like this the way it was drawn with that kind of a map helped?

R: How else would you draw it?

I: Well, you could draw the individual features separately.

R: Just like radio buttons and then…

I: Yeah, like radio buttons, some with the energy selector….

R: I think this one is better because it actually gave you like a flow diagram where the energy was going and then you could conceptually explain it.

I: Were the arrows pretty helpful?

R: Yeah, I just stopped looking at anything else and just click…click…click…click…click…click…click.

I: I think that's all I need to get.

R: Alright.

PARTICIPANT ELEVEN

I: In general, did you find operating it easy or difficult?

R: Easy.

I: What in particular do you think you found so easy about it?

R: The fact that I had instructions prior to me operating it and the fact that I couldn't do anything wrong. If something was not going to work, it wouldn't be clickable. It wouldn't work. So, I could not make a mistake because the system won't let me.

I: And you found it easy because you could always go to a different procedure?

R: Really I could always go to a different procedure and they are all laid out in an easy-to-read manner and it is really easy to use.

I: Okay. Do you think the addition of any extra information would make it easier?

R: I think that I had to look up the sheet again and again to look for what a procedure meant. Instead of that if as soon as I click on a procedure if there would be a small textbox or whatever on the left-hand side rather than me having to go click on that, so while I'm doing it, I can just halfway do it on that side of the screen, as where I'm looking here, and that does save so much more time.

I: Okay. Was it pretty apparent what the different buttons did in relation to each other?

R: No, it wasn't. It wasn't really apparent what they did in relation to each other, I mean…

I: Did you have any impression of an actual hardware system this can relate to?

R: No, I couldn't, using this I couldn't really figure out what that hardware was trying to do.

I: So you were just going through the procedures as they were written?

R: Yes. I mean, maybe after a couple of times maybe doing it a couple of times you tend to understand but in the beginning or the first five or six times, it doesn't make much sense.

I: Did you rely on the indicators at all?

R: Oh yes, a lot. The indicators are very helpful.

I: Did you use some kind of strategy for which procedure to use next?

R: Uh-huh, I went and, let's see, if the procedure went one, I went in odd numbers order so that I knew it was MA, MA, MA for all three and then if it was procedure two, I went two, five, seven; for one I went one, three and that two, four, six, I'm sorry, and one, three, five and seven.

I: Okay, so even and odd.

R: Yeah, even and odd. Because those procedures are related; they pretty much had the same kind of steps to go through.

I: How do you think it would been good to express what the underlying system was; what things were actually doing?

R: More graphics, I guess. You could have bars which showed energy levels going all the way up and once they're all the way up, instead of having a blinking light, you could have a bar showing that energy level is reaching maximum and then coming down or something as such. I mean if you could make it more graphical I guess it would be much more easy to understand.

I: Do you think not having a concept or image of what was going on affected your performance?

R: In the beginning, yes, I would think it did. Because in the beginning, I had to follow the step procedure and to follow the step procedure I had to look at the paper again and again. If it was something graphical I wouldn't have to look it up. Once you get the hang of it, no, I don't think it affected that much.

I: Alright. I think that's all I have to say.

R: Alright. Thank you.

PARTICIPANT TWELVE

I: Okay, this is the last part to go through. I have some questions here to discuss your overall experience with it. In general, did you find the task pretty easy or difficult?

R: Pretty easy.

I: Pretty easy? What kinds of things did you find easy about it?

R: It was easy to click through and since the procedures weren't very difficult to remember, it was easy to keep going through and just…it was well ordered; you could just start at the beginning and go straight through the procedures and it was easy to keep in memory which procedure went with what things so I was able to just click across.

I: Okay, so did you find yourself going sequentially or …

R: Yes.

I: Okay. What kind of information do you think I could have added to make it even easier?

R: It really, I don't know, it seemed about as basic as it could be. I actually didn't even use the bottom panel, to be honest. I didn't even, I mean, things were lighting up but I wasn't really looking down there.

I: Okay. You also chose to get the paper definition rather than look on the screen.

R: Uh-huh.

I: Why do you think that was?

R: Because it was right there and I already knew where everything was when I looked at the paper, so, and there were only two things I had to refresh myself on. So, really, it wasn't a matter of, it was just a matter of I'd already read over the paper so that I was able to reference it easier.

I: Okay. Was it pretty clear what the different buttons and things did?

R: Yeah.

I: Was it clear what their functions were in relation to each other?

R: Yeah.

I: Did you have an overall concept of the system?

R: Well, because I had read the paper you know, and so I knew what everything did, yeah, it made a lot of sense what was what.

I: So, did you originally have a concept of the system routing the energy flow?

R: Yeah, you could, you know, because you were flipping the switch to start it up, and then you had to decide, you had to indicate where it would go, so it was like, almost like a, almost like a…open and closing a circuit, you know, so it was like completing a circuit by doing that and then I just hit the button at the end, kind of like hitting a light switch.

I: Do you think it helps your performance or hindered it to have an idea of what the roles were of each of the units?

R: Oh, yeah.

I: Okay. Well I guess that's it. You've done really quickly..

R: No, that's okay. Yeah, for that last question, knowing what it all meant helped keep in track in your mind..you know, you had to turn on the power before you could switch the indicator and before you could fire but really, I mean, you could have done this same thing…it was just the fact that you knew what the procedure was, you knew which one you had to do in what order and for which procedure, which thing, but, so, it kind of helped, you know, like it wasn't the major thing that made it easy. It was just that helped keep in mind…..

I: So it helped order each procedure but it didn't really do too much helping you decided which procedure to use?

R: Right.

I: Yes, that makes sense, each procedure does follow very similar pattern; pretty much opens out choosing the accumulator to fire.

R: Yeah, so you always knew that that had to be done and then you had to close it back and then turn it off and then it finished.

I: __________, is that it?

R: Yeah, yeah, it's done now.

PARTICIPANT THIRTEEN

I: First of all, did you find operating that thing pretty easy or pretty difficult?

R: Pretty easy, thanks to the arrows that were on the screen.

I: So you found the arrows made it easier. What about the arrows made it easier?

R: I just like how it helped indicate which light should be on at which point in the process.

I: So the arrows pointed to which light was going on…or should go on?

R: Which light should go on with each activation so you knew if a light didn't turn on, and it had an arrow to it, you can skip and go to the next procedure.

I: Okay. Do you think there should have been anything else on the display?

R: Some sort of indicator that showed that the process wasn't going as planned might have been helpful…just to alleviate the fact that you have to follow those lines.

I: Like something letting you know as soon as it failed that it failed.

R: Um-hum.

I: I noticed that you never looked at the instructions on the screen on definitions…instead you looked at the paper. Why do you think you preferred the paper?

R: One side I read through the paper once or twice pretty much all the procedures followed a general pattern that was pretty easy to recognize once you've gone through with it.

I: And the arrows might have reminded you of specifics?

R: Yes.

I: Actually nobody has looked at the on-screen ones. Just wonder why. Was it pretty clear what all the buttons did in relation to each other?

R: I don't think it was entirely clear at the beginning….just like actual concept of primary and secondary, whether or not they were actually independent of each other or not wasn't entirely clear but as it went on and I became more comfortable with the controls I think it was fine; you don't really have to memorize which buttons to push or with each specific energy bank I guess you would say.

I: Did you find yourself thinking about what the overall system or process looked like?

R: Initially, yes. After a while I became hopefully more fluid with the controls; I was thinking less about the actual process going on behind it.

I: That's kind of interesting. I would think it would be the other way around.

R: Yeah. I think once I just became comfortable with the basic procedure and what was happening, I could just think about it less and became more of just pattern recognition at that point.

I: Yeah, well that makes sense. Did it seem to you like it was an actual process to be controlled?

R: It seemed like it could be an actual process. I really can't think of anything off-hand that would be comparable right now, but as far as the Star Trek universe concern there, I think it was believable in that aspect.

I: Did it seem like, regardless of content, seem like there was an actual hardware system underneath that this could have been describing?

R: Beside the universe, I'm not really positive at that point. That would be something I would have to think more about. I just can't draw any real comparisons right now to something I can think of that it might control.

I: Okay. Well, do you have anything more to add?

R: I think I did pretty well except for one large error which probably would have gotten everyone on the ship killed. Other than that, I thought it was fine.

I: Well, thank you very much.

PARTICIPANT FOURTEEN

I: …your experience with this thing. First of all, did you find operating this task in general easy or difficult?

R: I found it was very easy to operate it.

I: What did you find was easy about it?

R: There's like few buttons to press to like operate it so it wasn't too difficult to understand.

I: Do you think I could have put any additional information on there?

R: Maybe like the procedures, instead of having like a menu or dropdown menu or whatever, you just like have them like listed right there, instead of…because it took more time to check the procedures.

I: You also seem to prefer looking at the paper rather than the screen.

R: Yeah.

I: Why do you think that was?

R: I don't know….I guess 'cause clicking, more clicking would take more time than just looking at the paper and using the mouse at the same time to click.

I: Was it pretty clear to you what the different buttons and things did?

R: Yeah, they're all pretty clear to me.

I: Do you think you had any kind of an idea of what the actual process was that this controlled?

R: Sort of, I don't know. I don't know, really, what exactly the whole process was, but sort of; I had an idea.

I: Did it come across to you that you were controlling the energy flow from the ship to the accumulator?

R: Yeah, yeah

I: Okay. That's the process I'm pretty much talking about.

R: What's that?

I: That's the process…

R: Yeah, yeah, I had an idea that I was controlling it.

I: Okay. Do you think the layout as it was was helpful or do you think….

R: Yeah, it was a nice flowing layout of it, so it was helpful.

I: Do you think knowing what the process or whatever it was underneath looked like affected the way you dealt with it?

R: Like what process?

I: The idea of the energy flow that you were controlling.

R: Yeah, I think so.

I: Do you think that improved your performance __________?

R: Improved it.

I: Improved it?

R: Yeah.

I: Did you find yourself using the indicators to help you decide what procedures to use?

R: No, I just went sequentially through them.

I: Okay. Well, do you have anything you want to add?

R: No, nice and easy.

PARTICIPANT FIFTEEN

I: In general, did you find the task easy or difficult?

R: Pretty easy.

I: What kinds of things do you think made it seem easy?

R: The arrows; the fact that it was pretty much pick and pull and then follow directions.

I: And the arrows, how did they work?

R: It was easier as soon as they lit up to see where your mouse needed to go to, and then go ahead and clicking on that spot.

I: Okay. They can mark the steps as you went along?

R: Um-hum.

I: Do you think there could have been any additional information to make it easier?

R: Yes. While going through the procedure figuring out I guess a better process of the lights when it malfunctions, like either green or red or red or something like that, so they could seen not the same, that it supposedly working but saying whether it's working and working right, so you could follow the flow process better to choose the procedure that would best fit.

I: Okay. So different colors…

R: Or different warning signs also the same thing with the second accumulator didn't have an indicator light on it, so you weren't, so that didn't help out to see if it was properly flowing in that direction either.

I: Okay. I noticed that you didn't look at the on-screen definitions of the procedures; just the paper and the arrows. Why do you think that was?

R: Because it was a time-demand task and the time would have continued flowing had I done that plus I still had the procedures in front of me had I wanted to look at them.

I: Okay. So basically it was easier on the paper?

R: It was also easier to just kind of point and click, and trial and error because it wasn't really, although you could find some pattern, the pattern wasn't necessarily the same for certain procedures.

I: So did you find that what made it easy was that you had a concept of what the system was?

R: Yeah and no. Not really, I mean, because it was just kind of a point and click and follow the arrows, but it was nice at least to know what I'm supposed to be doing like what the goal of was.

I: Did you think about the roles of the switches and buttons in relation to that at all?

R: At the beginning, but after you started off it wasn't, it wasn't a point that was moot, really.

I: And did you have any concept of what the underlying system was that you were dealing with?

R: You mean as in I'm supposed to be firing my phasers?

I: I mean things like the routing energy and the energy flow.

R: I had but I didn't want to take time to stop and actually think about it, because like you're thinking in the time that it's going to take you so you just want to kind of get it done.

I: Okay. Do you think it…well, you seem to think it would have slowed you down to think about it. Do you think it really did that?

R: Had I stopped to think about it?

I: If you give it the chance to formulate it.

R: Uh, probably not in the future, but it wouldn't have necessarily, I mean it would have maybe increased each process just a little bit depending on whether or not it malfunctioned or not; otherwise, it wasn't that big of a difference.

I: So knowing what the underlying system was really didn't matter too much to you?

R: Not really, just how I needed to make it work, I mean which I guess what, the knowledge of knowing what the system is and what each of those functions did, but mainly because part of the indicator lights really didn't mean too much, you know, you just really cared about that final, the final output or whatever, make sure that last little thing was blinking.

I: Okay. Alright. Well, that's all I have to say.

PARTICIPANT SIXTEEN

I: I have a few questions that we can talk about while we're going through this. In general, did you find operating this thing easy or difficult?

R: Easy.

I: Pretty easy. What did you think was so easy about it?

R: Because all of the steps are pretty easy. Yeah.

I: Did you find it hard to choose which procedure would work?

R: No, you just keep choosing it, so I don't think it was hard.

I: So you would just choose it…did you find yourself using the indicators to help you decide which to go to?

R: The indicators?

I: The lights, the red

R: Oh, sometimes.

I: What additional kind of information do you think would help?

R: Would help? I say, it's like I can practice more before I should have started, like it would be much easier because like on the first few times, I have to look at the procedures to make sure I am doing it right, and then like afterwards you just know which one is which.

I: Okay. Did you find yourself thinking about how the system worked like making some sort of impression of the accumulators and the energy flowYou were just going through it through the steps?

R: Yeah.

I: Okay. Was it pretty clear to you what the different buttons and all did in relation to each other?

R: Would you say that again?

I: Did you get a pretty good idea of what the different buttons did in relation to each other?

R: Sometimes, yeah.

I: Well if you were just stepping through the steps then you probably didn't think about what they did in relation to each other. Okay. I noticed that you only looked at the paper; you didn't look at all on-line at the procedure definitions. Why do you think that was?

R: Why? Because I think if I do look at them on-line, like I just don't like to have another screen show up and it's easier just to have it on hand. So, I just look at it.

I: I've got to say that you've also been the first one actually so far actually separate the two sheets and it seems to be a pretty good thing. I don't know why other people aren't doing that.

R: Oh really?

I: But, why do you think you did that?

R: Well, because it’s on two separate pages.

I: To put all the procedures together so you can see them all in one shot?

R: Um-hum. That will actually help too. Or if, because there’s so much words to read; you know, if it just tells you like procedure one and three are the same, procedure two and four are the same … the only difference between five and six is like you click on the bottom. That would be easier. Yeah.

I: Well, you said before that after going through it a few times, you saw that they were all similar so you weren’t really paying attention to each of them so much anyway.

R: Yeah, like after I read it a few times, like when I do a procedure like maybe the first few times I have to look at it, but then like either you just know okay because it’s just the same steps, so I don’t have to look at it anymore.

I: Okay. Well, do you have anything more to add?

R: No.

I: So, thank you very much.

PARTICIPANT SEVENTEEN

I: In general, did you find operating this device easy or difficult?

R: In general, it was easy.

I: What do you think was easy about it?

R: The linear sequence of the operations was easy. But, One thing I have to comment, like the tasks operating procedure as they were set down on the paper, I found browsing through them difficult. Two or three times it confused me.

I: Okay. What do you think was confusing?

R: They were arranged on the paper, like….

I: Because they were on different pages?

R: Different pages and they were arranged without any gaps in between, like they were sequentially arranged. There should have been a proper gap of white gap spacing between maybe some other kind of human friendly way,

I: Okay. So, well you seemed to have preferred the paper definitions rather than the online.

R: Yeah.

I: Do you have any ideas why that was?

R: I didn't actually look at the screen, so, maybe, I don't know. I should have looked online, I don't know, like…..

I: Do you have any idea why you automatically looked at the paper didn't even bother to look at the screen?

R: It didn't actually occur to me that the screen is providing the information. Probably, maybe you didn't tell me about, like, you can look on the screen or I might have looked, I don't know.

I: Did you have some kind of an idea or concept of what this system looked like that you were working with?

R: Yeah. You…as told by the instructor the ship's weapon system. So, I thought like I'm interested in measuring greater efficiency or something like that. So I had some vague idea.

I: Did you have an impression of the overall energy flow that this device was to controlling?

R: Yeah, it might be involving a lot of energy because bombs are being fired and, so a lot of energy is being thrown there.

I: Okay. Was it pretty clear what the buttons and switches did in relation to each other?

R: The sequence of the system sir?

I: Yeah. Was it like when you activated one, it required that you activate something else or shut this one off, disable this.

R: Yeah, I had some idea like it was some kind of a binary switch or like some kind of switch which went from the proper logical sequence, so I got some hang of it..

I: Okay. Do you think knowing more about the context was of help to you? About the context?

R: Yeah, it may have helped me, like a technical person or something like, it might have helped me.

I: Okay. Is there anything else you ask?

R: No, it's okay.

I: Okay. Well, thank you very much.

PARTICIPANT EIGHTEEN

I: First of all, did you feel operating the device was easy or difficult, in general?

R: Easy.

I: What do you think was so easy about it?

R: I think the procedure, the markings, it was well-designed, and very user friendly. So we really knew what we had to do.

I: What made it clear what you had to do? The green arrows?

R: Yeah, the green arrows. The bright green arrows.

I: Do you think there should have been anything additional on there…any additional information?

R: Yeah. (Could not understand much of this response at all….sorry).

I: Okay. Well, you didn't use the online definitions of the procedures.. Do you know why? Do you have any impression of why you preferred the paper rather than the screen?

R: Yeah, initially when you introduced me to the thing through the paper, I didn't. But later on, after the first two or three I came to know the bright green arrows actually indicative of what I had to do, so I followed that out pretty easily.

I: Actually nobody has followed the online ones…just wondered why people prefer the paper.

R: Probably a little easier…if you tell the people that okay "that's the procedures online" and I start reading it and then you go to the paper to read. Then I continue to read it on the computer.

I: So you saying the first way you see…

R: The first I start reading filings, then I continue like that. Because we don't like change.

I: Okay, that makes sense. Do you find that you had an impression or model or concept of what the system looked like that you were controlling?

R: Yeah. most of the time it wasn't one; it is to be two, so I did one or two procedure and it usuall worked out..

I: So that was your strategy for choosing procedures?

R: Yeah, one or two, then if one or two don't work usually try three or four then five; One, two, seven, and then five and six. The last would be three and four.

I: That makes sense. Do you have an impression of what the buttons and switches did in relation to each other, like what kind of system did they work on? Like when you change from MA to SA and then you press the MA or SA button. did you understand, like you were talking earlier about how the FM button seemed linked to the MA power source.

R: (I could hardly understand anything in this response due to the accent)

I: So you had an idea of where the energy was in the system?

R: Kind of, I don't know whether I'm right or wrong, but I would like to know.

I: Well, I don't know how to find out if you are right or wrong; that's not what I'm measuring. Do you have anything more you'd like to add?

R: Hum?

I: Do you have anything you would like to add?

R: Yeah. One thing which I had mentioned, a year or two and I think that should be the key. If this thing is taking place on a time-constraint, it would be better to do another thing such as _________. I think of the _______ and the __________ of the operations ________________ acting behind the operations _______________.

I: So you're saying it would help if people had some kind of model of what the system was?

R: Yeah.

I: Okay. That makes sense. Alright. Well, thank you very much.

PARTICIPANT TWENTY

I: First of all I want to know if you felt the task was overall easy or difficult.

R: Very easy.

I: It was very easy, and what do you think made it so easy?

R: I mean, it was it really was just a clicking back, right, so…and there were these arrows to guide you through the process…the lights really help you. I know I followed the lights except for…

I: Lights didn't do much?

R: No, except for the final blinking thing, I was expecting to do because I just wanted to do it fast. But it did not happen, so…but the arrows were like the most helpful things.

I: So it was the final blinking that was there now that was helpful?

R: Yeah. That was good; that was really good. But the regular lights are not helpful according to me

I : Okay, but the arrows….

R: Yeah, the blinking arrows were really helpful.

I: The changing of colors …

R: Yeah, yeah.

I: Do you think there could have been any additional information on the display?

R: You mean I wish there was some?

I: Yeah, would you have liked to have seen any additional to make it easier?

R: Oh, I really don't think I could have expected anything more. I don't think so…

I: Why do you think that you used the paper definitions rather than looking on the screen?

R: Initially I had to, but then I could not get a grasp of the task but once I got in there and never looked back. I did not know, you had to tell me that I was, I mean any one of the seven of the tasks might fail for a particular performance of my tasks, so I never knew that that thing was the case, so I just picked out randomly before you told me that you have to try out all of them to make one of them work. I never knew about that before that, so, I never looked at the paper after that because I knew that, you know, I just had to try all of them to get one of them working, so it's no big deal.

I: Okay. Did you find that you had an idea or a concept of what the machine was?

R: Yeah, I think I do. It was…I think it was like a ship power system then the power was actually temporarily stored in one of the two subsystems. And then the power was like triggered, you accumulated the power, then triggered it whatever to a cannon..

I: Did you understand what the role of the buttons was in relation to each other?

R: I did, yeah. One was to like switch on the power, one was a trigger kind of thing.

I: Okay. So you think you had a pretty good model of how it worked?

R: I think so, but then I could not really follow the blinking of lights and how they worked, because according to the document given over here, there were just two paths that led to the firing of the trigger, you know. But here actually I found that it did not make logical sense because even though the (family??) thing was blinking, I had to select the secondary trigger to make the whole thing fire, so, I could not relate to that really, though I could understand the two alternative flows of power.

I: So you found lights and your model of the system conflicted somewhat?

R: Yeah, really.

I: Okay. Well, do you have anything more that you would like to add?

R: Pardon me?

I: Do you have anything that you would like to add?

R: I could not relate to the blinking of the lights and that's it. That's about it.

I: Okay.

R: And I could not really understand that only one of the seven tasks was going to work for each run of the experiment. You had to tell me that. I would have gone on and on and on randomly selecting tasks because I thought like only one of them would work, so.

I: Okay. So.

R: Yeah.

I: Okay. Well, I suppose that's all I need.

R: Okay.

PARTICIPANT TWENTY-ONE

I: I have some discussion questions to go over. You seem to have a lot of interesting comments, so these may seem ridiculous. The first question, which you have answered already is, did you find operating the device pretty easy or difficult?

R: It's pretty easy.

I: Yeah, you're pretty sure it was easy?

R: Yeah.

I: What do you think was so easy about it?

R: First of all, all the steps were laid down, what I was supposed to do. I knew the problem definition. I knew the steps that were supposed to be followed in order to answer the problem, the definition, and not only the steps were laid out but the steps were simple. They do not demand in a sense. I do not have to think much on them as to how I am supposed to go about doing them or whatever. They were laid out simply. The language used was pretty clear, so…

I: Did you find yourself using the indicator light to figure what procedure to use?

R: ______ ________ indicator light? Uh-huh; I found that procedure one was not almost always working, but working more often than the others. I don't know why, but…

I: That is true.

R: Yeah.

I: Did you find the strategy for choosing procedures?

R: Yeah, right, I found the strategy. After a couple of operations, I was almost always trying procedure one because the probability of it giving me a positive result was higher than the others – is what I came to know after a couple of operations. But I also tried this technique that, say suppose for operation N, I would get procedure five. Procedure five would do the job for me, so I would try for operation N plus find out whether procedure five would do the job for me or not.

I: You looked only at the procedures on the paper. Why do you think you didn't look on the screen?

R: Because I memorized them. I did not even need to memorize them. It was, I mean, it's so simple that, see, I have been using a lot of techniques in order to memorize things right from my childhood and a technique like this, technique in the sense the flow of events such as this like, say, turn on the switch first and then Neutral to MA, so MA was corresponding to FM. So number one MA/FM; number two SA/FS. Number three MA/FM. Number four SA/FS. And then number five was just like, you know, MA/FS and number six was SA/FM, so it wasn't tough for me at all to memorize this flow of events.

I: So did you find yourself using some kind of concept or model of what the system looked like?

R: Uh-huh. Yes, yes, exactly. I knew, after reading through it I was just visualizing the same and since I was pretty much visualizing it in the context of Star Trek. While I was visualizing this I'd look at accumulator, the main storing energy so for procedure one I'm supposed to click on FM. I mean I was just having this model - accumulator, main accumulator, FM …

I: So you understood the role and function of different buttons?

R: Uh-huh, pretty much.

I: And their relations to each other?

R: Right.

I: Okay, Well, do you have anything more you want to add?

R: It was a nice experience.

I: I'm glad to hear that. I'm hoping to make it less painful as possible.

R: It's not at all painful, sir, Mr. Staderman. Not at all painful and let me assure you of that.

I: Okay. Well I suppose our time is……

PARTICIPANT TWENTY-TWO

I: Yeah, they get pretty easy after a while, pretty simple. The first question I want to talk about is, in general, did you find operating this easy or difficult?

R: At first it was very, very frustrating and very, very difficult because like I read it but I just didn't know how it would work exactly, but after a while I think it became a little bit easier because I was able to memorize the first two procedures and the last procedure and in the beginning I was reading like what each procedure involved and I was getting caught up in the language so I was just looking for the ….

I: Uh-huh, especially putting the text into actual actions was difficult?

R: Yeah, like I think if I took the time and re-wrote, you know, one equals ES or MA/FS, I would be able to do this incredibly fast because I was trying to read it and I was always getting caught off on the select ES selector. For some reason that slowed me down and then I had to get over to the SA …

I: What do you think would make it easier to do, aside from rewriting the procedures?

R: Maybe for me if I saw like an example of what needed to be done, like I understood the buttons and I don't know, I guess toward the end I kind of got frustrated because I was clicking finished like it was indicating, you know, this isn't working series or whatever. I was clicking finished and it wouldn't stop – it was still blinking. So I was like come on! I'm trying to do it as quickly as I can.

I: Do you have any idea why you looked at the definitions on the paper rather than looking at them on the screen?

R: I don't know, I just, I didn't try what it looked like on the screen, like I don't know if the screen had like a flow chart. It might've – I just don't know because I didn't look. I don't know, I guess I just did it by habit looking down for the…

I: The screen actually had the same text.

R: Oh it did?

I: And it would have been just as problematic if not more. Did you find yourself developing any concept or model of what the system might be like…

R: Like the pattern of it?

I: Yeah, the system you were controlling, what that looked like?

R: Not really, like I was able to understand, you know, for most of them when it's FM or when it's MA it's FM, but not for all of them. Like I understood some of the patterns but for some of them, like I knew the first one and the second one and the seventh one, because that one's pretty easy. And then I started to learn the three and four but then by the time I was learning it, it was already like 27/28.

I: So you were thinking more about the interaction of the buttons rather than the overall system?

R: Right. I wasn't able to figure out the pattern, if it would be like one one two seven one one two seven three. I didn't quite get that. I know sometimes there were a lot of ones and twos but those are the ones I tried first, and if it wasn't one of them, then I tried seven, just kind of process of elimination. Sometimes I tried to work numerically progressively but that didn't always work.

I: So did you find that was your strategy most of the time?

R: To work progressively?

I: To go sequentially?

R: Yeah, most of the time it was sequentially. I think in the beginning I was just like "Oh it's going to work" And sometimes I just started at seven, like it was either – I started with the ones that I knew and then I'd go to the ones that I didn't memorize the codes for.

I: And the ones you knew were one, two and seven?

R: One, two and seven.

I: Which actually works out pretty well because it's not determined what procedures will work but the probabilities are and one has the highest probability and two has the second highest probability.

R: Oh wow.

I: And all the rest of them are the same probabilities that are left over, so one will work more often than the rest. So starting out with one, two is a pretty good procedure, pretty good technique. Were you clear about the role or function of each of the buttons?

R: Not really, like I knew like the goal was to get it to fire or whatever, to get energy where the energy needed to be, but I don't know what it means, just like I don't know what it means when it selected MA. I just kind of, I mean I'm sure it says in here, I just don't remember exactly what it means, but I just knew that when it's MA for one then it needs to be clicked on FM, like I just picked up the associations but not necessarily the definitions.

I: Do you think it affected your performance of how you did this, knowing or not knowing Star Trek?

R: It might've. I think if I had watched Star Trek I would have understood a little bit, a little bit, but I was able to learn pretty quickly about what needs to happen. Like the SA has something to do with the FS, but I don't know what the relationship is just for two. That's just what you click. I think it's for another one as well, I just don't remember which one. But it might've.

I: In actuality, in the FM and the MA the M is the same thing, meaning the main, so in that case, number one relates to the main. Number two they have the FS and the SA. The S is secondary. So the two is secondary.

R: So it's fire secondary?

I: So that's kind of how they relate. Perhaps I should have said that somewhere.

R: I mean, you might've. I just don't remember. Oh it does say, it does say secondary.

I: I think I said something somewhere like that

R: Yeah, I just didn't remember exactly what I read.

I: I don't think many people do. Do you have anything more you'd like to add?

R: It was a little bit hard because at first I didn't know. I hadn't memorized all the associations. For the first two I had to flip back and forth and then some of the language, maybe it was just my brain, but some of the language was just…I got stuck on the ES and then I couldn't get past to the MA, like for some reason it always stops at the ES because they're all capital and they're all two letters. I don't know, I mean, I think after a while I caught onto it, but…

I: I can see what you're saying. Textually, they all look similar and they're all two letters and capitals but they do entirely different things. The MA and SA are totally different from ES, so I can see how it looked. Okay. That is all I have to say.

R: Okay.

I: Thank you very much.

PARTICIPANT TWENTY-THREE

I: First of all I'm interested in whether you found operating the device, in general, easy or difficult.

R: Yeah, the device was easy. You start using it some three or four times I think you get used to it very much.

I: What did you find was so easy about it?

R: The reason I was sure what is the next step, I think because pretty …the next step so you could easily follow through it.

I: Okay. Do you think there could have been anything additional on the screen?

R: No, I think it was pretty good. It was sufficing enough to, for the user to know.

I: Okay. Did you find yourself using any kind of strategy for choosing what procedure worked?

R: Yeah, actually, first few times when I saw that performance one was working, so for the next two or three times whenever I see that that other wasn't working, I went back to one. But after that I knew that it's going to be, it was in a random manner, so I just followed things like one, three, five and two, four, six, something like that I was

I: Okay, just kind of a random?

R: Yeah, just kind of random.

I: Okay. Was it pretty clear to you what the different buttons and switches did in relation to each other?

R: Yeah, it was kind of, yeah, kind of decently clear.

I: Do you seem to have used some kind of model or concept of what the system looked like?

R: This system, you mean?

I: Yeah.

R: I could see …of how it was done, but…

I: The system that it represented.

R: No, I couldn't relate it to any model.

I: Did you picture it kind of a like a flow of the energy that you were routing?

R: Yeah, the flow of information there, you mean?

I: Energy.

R: Oh, the flow of energy…I kind of understood that, but I couldn't get the whole concept behind that.

I: Okay, so you really didn't have a picture of that?

R: Right.

I: Did you find yourself using the indicators to help you figure out which procedure worked?

R: Yeah, yeah…

I: As you were going along…not just the final indicator?

R: No, as I was going along, I could see that the PF indicator, that doesn't glow, then it means I've failed in that one.

I: So the PF indicator was where you were paying attention, not the others?

R: Yeah, right, right, not the others.

I: Okay. Do you think there is a reason why you looked at the procedure definitions only on paper for a while and then you didn't look at them at all, and you never look at them on the screen?

R: No

I: Why do you think that was?

R: First I thought that I had to follow all these, then slowly I was like thinking why this green thing is coming up exchanging colors, arrows in different places; then I got to know okay that's indicating the flow of what I should do next. So from that on, I thought okay so it will let me not wait for that, I need to follow that. If the PF indicator is glowing, then I'm done. Otherwise, I need to go to another procedure and do it.

I: Okay. So you just followed the arrows.

R: Yeah, I could easily follow.

I: Okay. Well, do you have anything more to add?

R: No. I mean, it was a pretty good one. The way it was done, it looks really good.

I: Okay. Well, thank you very much.

R: Thank you.

PARTICIPANT TWENTY-FOUR

I: First of all, did you find operating the device typically easy or difficult?

R: Yeah, it was easy.

I: What do you think was so easy about it?

R: I think is, one and three follow the same procedure; two and four follow the procedure and five was like a variation of these two things, five and six. Just the MA and SA is changed, and seven is then like just the on and off. Once you get that right, then it is just…

I: All of the procedures were very similar so you can keep them all in mind.

R: Yeah.

I: Okay. Do you think any additional information would have helped?

R: The main thing is I didn't know the connection between the power coming and what does it got to do with the thing which we, which I operated, like, did it follow some logic or was it just a random thing you just click on the outcomes.

I: Well the procedure that worked was, they were random with different probabilities for each trial. Each number operation was independent from the others. So, within those there was very…

R: But then what connection does it have with the power thing? I couldn't follow that.

I: Uh-huh. Well, but that leads to another question. Did you find yourself using some kind of a model or a concept of the system that you were operating?

R: Yeah, just like, the thing is - once you follow the procedures, get the procedure, you tend to work more on that rather than thinking how it works together.

I: So you were focusing more on the steps than…

R: Yeah, I understood like how it flowed and this thing. But I felt everything has the same probability. Three, four, five, six, I couldn't find any difference between all those things. And one and three also had the same procedure so what difference did it exactly make…..

I: Well, this device basically routes energy from ship to phasers. Did you find yourself thinking about a model and how it worked and how the buttons and switches related to that model?

R: What's that?

I: Were you thinking about how the buttons and switches related to the model?

R: That was okay. I understood the first thing, the one, two, three, four kind of thing….. But exactly if the model had performed according to, say, a proper routing, it performs properly, then we can get an idea of the ship…it's just like basically, you may think once the model starts, once you know the operation is performing, you may no think again. like it is nothing concerned with the routing of information, just clicking and if this glows or not, and what activity. It was like not an educational sort of thing but just a play to look at.

I: Did you find yourself looking at the indicators through red lights to help you figure out which procedures to choose?

R: Yeah, I really did.

I: So you used that a lot. Do you know why you looked at the definitions on the paper and you didn't look at them online?

R: Paper – you can just look at it.

I: Okay. No one has looked at them online; that's why I'm asking here….

R: Yeah, because you have to go there, click it and then once you read it, you have to just close the screen, come back to the … You just do this, see it on the paper, click it on.

I: So when you are looking at the paper, you can see it all at one time?

R: Yeah, that is also there.

I: Well, I suppose that is all I have to say. Do you have anything that you want to add?

R: No thanks, that's it.

I: That's it?

R: Yeah.

I: Well, thank you very much.

R: Thank you.

PARTICIPANT TWENTY-FIVE

I: First of all, was operating this device, in general, easy or difficult?

R: In the beginning you had to understand how; I could not actually get the flow of things. I thought it was like a perfect system. I was thinking I just go to the arrows and then identify which process. But then I realized it's just an experimentation. Once I got the hang of it, yeah, it was easy.

I: So at first you thought that it always operated according to the arrows that were in the model rather than the black arrows.

R: Yeah, uh-huh, yeah. So I thought the arrows showed the pattern of how it flows and that thing, but once again, it's a random thing, that was easy enough.

I: Yeah, there's a difference between the black arrows and the green arrows.

R: Yeah.

I: What do you think would have made this more easy?

R: Visually it could be better, I think. You could use some animation over there like showing the flow where here you're just using arrows and saying this is the flow, and I actually have to follow the lines and see how it's going You could have some sort of visualization sort of like something going around that shows flow…

I: Like dynamic movement…

R: Yeah, that would be good actually. You don't actually have to, say, check out the flow, like the focal there, one person's going up, one line is going down, so okay this is going like this rather than press something, then show something moving around which shows the flow, a long line, so that would be interesting, I think and you wouldn't have to think too much. It would be very helpful.

I: Do you think that you had any concept or model of what the system was like in your own head?

R: Yeah, I had a description and yeah, that more or less represented the same thing.

I: Did the one in your head and the model on the screen match?

R: Yeah, it matched more or less. It's the same thing.

I: More or less?

R: Yeah.

I: Did you change the one in your head when in malfunction situations?

R: You mean looking at the diagram?

I: Yeah.

R: Yeah.

I: How so?

R: I mean, each of like the models was like here's this sort of thing, or that, but then when once I saw this model, actually it became more clear and so it just lapped onto this, so…

I: Did your model change at all when things did not work perfectly when you would send things to the main accumulator and fire the secondary accumulator?

R: Depending on the scenario right, procedure wise, so I guess it did change, yeah.

I: Just a little bit for procedures?

R: Yeah.

I: In general it was pretty consistent??

R: Yeah.

I: Did you understand what all the buttons and switches did in relation to each other according to the model?

R: Yeah, yeah, yeah, yeah, yeah. That was pretty easy.

I: Okay. Do you have any idea why you looked at the definitions on the paper and did not look at them on the screen?

R: The procedures? I think it's much easier looking on the paper than on the screen, yeah. I understood the procedures they're all things on the same thing, so it's much easier. Comparison wise, it's much better.

I: Actually everybody is looking at the paper instead so far. Well, that's all I have to say. Do you have anything to add?

R: Yeah, ___________________ better. I thought it was very good.

PARTICIPANT TWENTY-SIX

I: First of all, did you generally find this task easy or difficult?

R: Generally, pretty easy.

I: What do you think was easy about it?

R: It was a very simple task to do. You just had to follow the procedures; follow, just had to make sure that you were following procedures, and make sure you that you were doing exactly what it told you to do, but it wasn't extremely complicated the task itself.

I: Okay. So the procedures were broken up enough so that they were just specific steps?

R: Yeah.

I: Okay. Do you think any additional information would have made what you were doing easier?

R: If there'd been like some way to tell before the last indicator light, like if there had been some middle indicator light that had said "This process won't work, " because that was would have been easier.

I: So, did you find yourself using any kind of strategy to choose procedures?

R: The list said one or two would be most often used, but then after that, like if it wasn't one or two, it's kind of a crapshoot, so I was just going numerically, I was just going in order like…..

I: Did you find yourself developing some kind of concept or model of what the system looked like?

R: Kind of…not…I don't have a great visual scene in my head, but, like, I kind of have a vague idea of what it might look like.

I: Okay. Did you understand the role of each one of the buttons and switches, what they were doing?

R: Yeah.

I: Do you think that if I did the way you operated it, that you knew what they did?

R: No, not really. I feel that, even though I understood the task of each button there, what each button did, in fact, it was such a set procedure it didn't really matter, like the application of the buttons themselves really did not matter because of the fact that there was a set procedure, so…. didn't really matter.

I: Okay. Well, I think that's all I have. Do you have anything you want to add?

R: It was really a little frustrating because there was no real clear way to determine anything until the very end, but other than that….

I: Okay. Well, thank you very much.

R: Um-huh.

PARTICIPANT TWENTY-SEVEN

I: First of all, in general, did you find operating this device easy or difficult?

R: Easy; more towards easy.

I: What do you think made it easy?

R: I think because you had visual cues, like you can see that the light is blinking/not blinking, what is on, if it is working/not working.

I: So you paid more attention to that last indicator than the list?

R: Yes, I did.

I: Did you find yourself using the list at all to figure out which procedure to choose?

R: No, most of the time I did not, no.

I: Okay. Do you think any additional information would have helped?

R: Yeah, I think if I had paid attention, probably it would have helped me, but I didn't use it, so probably, I'm not sure if it's the placement of that indicators….I think I should have used it but I did not.

I: Did you consider the model on the bottom part of the screen?

R: No, I did not. Once I started working on that I completely based my judgment on the top. I did not use the bottom one.

I: Do you think you had your own model in your head of what the entire system was?

R: Yeah, I think, like, from the old model, I understood what was happening on the top screen but after that, while operating it, I did not think of the old model.

I: The old model being…what was the old model?

R: I'm sorry.

I: The old model you said?

R: The bottom model.

I: The bottom one.

R: The bottom one.

I: Did you find yourself relating the functions of buttons and switches to each other?

R: I didn't get you.

I: Like, did you find any relation of the buttons and switches to each other in your head? Things like the accumulators….

R: I was actually trying to I didn't figure out. I did try to.

I: Do you think you developed a strategy to choose which procedures would work?

R: I think I was making an effort to, but like in the start of the task, I was kind of just going through the motions and trying to see when it's working/not working. It's after I had been doing a few that I really started thinking is there a sequence…is there something happening, you know, trying to figure out the logic, so I think by the end of it I did not have it.

I: Well, I guess that's all I have. Do you have anything that you want to add?

R: No.

I: Okay. Well, thank you very much.

PARTICIPANT TWENTY-EIGHT

I: In general, did you find operating the device easy or difficult?

R: Easy.

I: What do you think was easy about it?

R: The thing I think was easy about it was, it was very uniform. Each set of procedures was the same; each sequence was the same. One was one throughout. They all didn't work the same, obviously, but once I saw what was going on…didn't quite see what was going on at first, but once I picked it up, I picked it up very quickly and I wrote doing, I just kind of went through the procedures…the procedures made sense, you know, first procedure the main accumulator, then you fire main to see if that works. And you do the secondary, you fire secondary and see if that works. Then you mix it up; you do the main accumulator, then the secondary fire and secondary fire, and so on. So it made sense when I knew it was a pattern to it. And once I got the hang of that pattern, it was very simple for me to just go through..bang…bang…bang…until I found one that worked and just carry on to the next one. So, once I got the hang of it, to me it was very easy. The thing that made it easy was the pattern involved.

I: Did you find the green arrows very helpful?

R: Yeah, at first when I was first getting the hang of the pattern, but after a while I knew conceptually what was going to be next, so I didn't…after a while I ignored the arrows.

I: So you didn't even look at those…

R: At the end, yeah.

I: Did you find yourself developing some kind of a strategy of what procedures to choose?

R: No, because where I was noting….I spent a little bit of time, as you saw, noting which procedures were working. I could not discern a pattern to that, so my strategy was just go from one to seven till I got one that worked. And it averaged out to about three or four, which I guess is what you would expect if you've got seven procedures and they work…each one of them works randomly, then you'd expect the average to be about three or four, so I guess I could have done some sort of analysis of the numbers I'd gotten, you know, but that probably wouldn't have been worth the time.

I: Yeah, I guess that would be too much.

R: And so I just kind of went from one to seven until I got one that worked.

R: Yeah, so I just worked from one to seven until I got one that worked and it averaged out. You know, sometimes I'd get one and sometimes I'd get six, but it averaged out to about three or four, so I think the time I spent would have been about the equivalent of had I tried any kind of trick, you know, so….

I: Did you find yourself developing any kind of model or image of what the system looked like of what you were doing?

R: I'm not sure what you mean. Of what it looked like?

I: Like how all the buttons were related to each other and what they were doing.

R: Yeah, yeah, The buttons on the display, to me, I guess to sound corny, became like real buttons, like I was actually operating, you know, like Mr. Worff I was actually at the controls of the phaser fire, and, that's why I say, once I got the hang of the pattern and I saw that the lights once I saw that, were lighting up when I did certain things, when I hit the switch, etcedra - once I saw that, the arrows lost their significance for me and instead I just went through as though I were actually doing it, you know, on board the Enterprise. Okay, turn the switch on….set the main accumulator……fire, you know, and so on. And so, I guess to answer your question did it become real to me? Yeah, it did…they became like real buttons, like I was actually doing something for a purpose.

I: Well, in general, things followed in an operational flow, energy flow. Did you think of some kind of model of what that energy flow looked like?

R: I'm not quite sure what you mean but…

I: Well, how different buttons directed that energy flow?

R: Oh, sure, yeah, I had, I guess you could say I had a picture in my mind, maybe this is what you're asking, I had a picture in my mind when I was hitting the buttons of the phaser apparatus of the ship actually doing something, actually drawing energy from an energy source, filling up with the energy. I mean I've seen enough episodes of Star Trek, I should know how this works, and, so yeah, I did feel that there was some sort of quasi-reality. I was hitting a button, you know, turning the switch on, for example, and I was actually activating the flow of energy. I was selecting an accumulator. That was actually activating an accumulator somewhere, you know, several decks below me. So, I guess, yeah, did I draw up a model? Yeah, I had a picture in my mind as I was doing it of what I was doing. I was hitting a button and something was happening. So…

I: That is just what I mean. I probably should have used the term "picture in your mind."

R: Okay. When you said model, yeah, so, but yeah, if in fact that's what you're asking, yeah, I did feel that.

I: Yeah, I think it's a terminology problem. Well, that's about all I have to say. Do you have anything you want to add?

R: No, it…well, yeah, real quick. This is not really anything crucial, but I didn't fully understand what I was doing at first…of course you can't tell me too much because otherwise it would give it away and kind of, you know, destroy the sanctity of the experiment, but…

I: Well, at this point I am allowed to tell you whatever you want to know.

R: Right, right, but I mean, what I'm saying is when I first got started I wasn't quite sure…the procedures were all the same; I could see that from the paper, but was one of them going to work all the time, or what….I wasn't quite sure what the goal was, and, but however, once I got into it and started working I feel that I picked it up very quickly and as you saw, I just kind of went and cruised through it after that until I got to thirty and so, I just, there was a slowness, and it could be due to me or it could be due to the experiment, who knows? Probably due to me…of picking up what was going on. But I think by about trial ten, I think I had it down, and after that for the next twenty trials, it was quite simple actually for me.

I: That is not entirely particular to you. A lot of times it takes people about ten trials until you get used to it but once they get used to it, it comes pretty naturally. Just reading it, people start wondering, yeah, what does this mean, what do I do? You come up with a lot of questions, but when you're actually doing it, it fits together better.

R: Well, I think it makes sense, like you know, like driving a car. How do you describe to someone how to drive a car? Well, they have to actually drive the car to know what it's like to drive the car, see, so, yeah, I think, you know, I really wasn't understanding it very well at all at first. But then, over the course, said, ah yeah, I see now. So then it went on from there. That's the only comment I really have to make. Other than that, it was pretty, pretty, pretty fun actually, being the Star Trek fan that I am.

PARTICIPANT TWENTY-NINE

I: First of all, in general, did you find operating the device easy or difficult?

R: Easy.

I: What do you think was so easy?

R: After you did it a couple of times, it was just a repetitive process and you didn't even have to think much about it.

I: So it was pretty easy to follow along with what you were doing?

R: Um-hum.

I: Do you think that model of it helped you follow along or did you just follow along with your own thoughts about how it worked?

R: The model probably helped.

I: Did you find that you had your own idea about things were related to each other?

R: Not really. I wasn't really thinking about it other than what the screen showed.

I: Do you think anything else could have been displayed to make it easier?

R: I don't think so. The visual is good the way it was.

I: Did you understand the role of each of the buttons and switches in relation to each other?

R: Yeah.

I: Like what they did to each other and so on?

R: Um-hum. Yeah.

I: Okay. Do you think you used any particular strategy to choose the procedures that worked?

R: No, I didn't at all. I just randomly picked them each time.

I: You just pretty much guessed.

R: Yeah.

I: Okay. It seemed to work from what I saw you seemed to be doing okay. Do you think it would have affected your performance either improved or decreased if you had a different model of the way it all worked?

R: I don't think so. I think I still would have randomly chose them.

I: Well, you are one of the people that looked at the online definitions briefly. Why do you think you looked at that and chose not to look not to?

R: I just thought it was quicker since it was timed and you couldn't do anything while you were looking at it; I just thought it was easier to look at the paper and then work at the same time instead of going back and forth.

I: Okay. Well I suppose that's all I have. Do you have anything more?

R: No.

I: No? Well, thank you very much.

R: Okay. You're welcome.

PARTICIPANT THIRTY

I: In general, did you find operating the device easy or difficult?

R: One of the two, easy or difficult? I would say difficult.

I: What do you think was so difficult?

R: Well, at first there looked like there were so many things on the screen and I didn't know like where to look and I realized that like there are a lot of arrows that show what you do next and I kept clicking on them and tells you the exact same thing, so I don't know, I kind of felt like there was a lot on there, like a lot of writing I guess.

I: A lot of visual clutter?

R: Yeah, yeah. There was a lot of that.

I: Okay. My next question is do you think anymore additional information would have helped?

R: Probably not. I mean, I guess it was helpful to have the descriptions on the side because at first I didn't even under…like I completely ignored the arrows. I didn't even know what they were for. And then, it simplified it, you know, by having seen them and then finally understanding what they were. So, I don't think so. I think it was just fine.

I: Okay. Several people have looked at the procedure definitions on the paper before. Why did you opt to look at them on the screen?

R: On the screen?

I: Or why do you think that you….?

R: Well, I think this is on working with the computer and like I'm operating it myself. If it's that available, like right next to what I'm doing, it makes it, for me I would think it would make it easier since it's right there instead of having to look at a paper … You kind of get distracted from it.

I: So you could like do, keep the visual medium consistent?

R: Yeah, yeah, definitely. I thought that was pretty helpful.

I: Okay, that makes sense. Did you find that you had any picture in your mind about what the system looked like?

R: Semi, but not really, like I was mostly going through what I was just seeing on here, but, like in my head I was thinking okay, well, this has to work in order for that to work, and if that works, then that will happen. So I kind of had this like three-box image in my head.

I: Um-hum. Do you think the way the device was on the screen it gave you a good image of the way the device worked?

R: Yeah, yeah, I think so.

I: Do you think you had any strategy for choosing what procedures worked?

R: If I had a strategy?

I: Um-hum.

R: Somewhat, like I thought I did. But then it didn't work out. Like I thought I did and then I didn't check like the sides like that told you what to do, but that didn't work. So then I had to go back and make sure I was clicking on the right …

I: Okay. Did you refer to the indicators to suggest any procedures?

R: The side descriptions you mean?

I: No, the indicator lights, the red lights.

R: Oh, yeah, yeah. Yeah, it was like an elimination. I was like okay that works, this works, let's see if the final one works.

I: Well, do you think you understood the relation of buttons and switches to each other?

R: Probably not, no. I can't say like I fully understood it, but like I got a concept of it.

I: Yeah, well, you had the model that if this is active then this goes.

R: Right. But that, that I understood as far as knowing which ones and why.

I: Well that's pretty much what I'm asking about. And you did. That's all I have to ask. Do you have anything you want to add?

R: It was interesting; it was a good experiment.

I: Okay. Well, thank you very much.

R: You're welcome.

PARTICIPANT THIRTY-ONE

I: In general, did you find operating this device easy or difficult?

R: Easy.

I: What did you find so easy about it?

R: It just, it seems pretty straight forward. There's only a couple of controls; switches seem logical; just felt like I could make sense of it.

I: Things kind of flowed along?

R: Yeah.

I: Did you find that you had some kind of a concept or a picture in your mind about the way things should flow?

R: Um-hum. The way they went from left to right. First you turn it on and you decide where the power's coming from and then finally over on the right you carry out what you have to do fire the phasers.

I: So do you think you kind of saw the relationships between the different buttons to each other?

R: Yeah, it seemed to flow temporally like the left-most thing is what you do first and the right-most thing is what you do the very last.

I: Do you think there could have been any extra information there?

R: There was a, there was a main. I'm trying to think of the name, the main power source had a light, but the secondary power source didn't have a light. I thought that was kind of lacking, I guess.

I: Okay.

R: … a little on the NCC1701, I guess.

I: You didn't look at the definitions online. Do you have any idea why?

R: I looked at them on the paper and I felt like, okay, I thought that the online one was going to be similar if not exactly the same and I figured I've them here on paper in front of me, I'll keep the screen free for the controls.

I: And pretty soon you didn't even look at the paper.

R: Yeah, I usually try to see if I can get the what I have, the procedure in my head and move from there I guess.

I: Do you think you had any strategies about choosing which procedures would work?

R: I tried to. I tried sticking with the same array for the main one. If main was lighting up, I tried to stay with main, but it seemed from my results it wasn't too closely interrelated. I didn't really find the working procedure any quicker when I tried to. So by the last cue I was pretty much just going with the first one and then if that didn't work, I'd start at one and move right down.

I: Well, that turns out to eventually get to it.

R: Yeah.

I: Well, actually, that's all I have to ask. Do you have anything more that you want to add?

R: One thing that I kept missing, I probably did it four or five times, I'd go to finish before I shut everything down and I guess, I think it is I just got used to going left to right and I think of like a finish button as like the shut down thing itself I guess, so I wasn't always going back and putting it back to end……

I: Yeah, that makes sense.

R: and turning it off and then I'd have to go and do that.

I: The finish button, if it were more usable thing, the finish button should really…

R: It would probably take care of that itself.

I: Take care of the finish.

R: And then clicking on the procedure would probably take care of all that other stuff for you.

I: Um-hum. Then you wouldn't have anything to do.

R: That's true. So it seemed pretty well put together throughout. The one thing that I noticed was that that secondary light was missing from the secondary power source.

I: Okay. Admittedly, this is a…usability has some problems with this, but I'm not really looking so much at usability. I'm looking more at people's ways of choosing procedures and people's development of some kind of model of what's going on. You seemed to have a pretty good model going in a directional model.

R: Um-hum, I felt like for the first fifteen I was trying to find a way to trouble shoot and I felt like I just ran into walls, like sometimes I would try, if two didn't work, I'd go to five and six and see if maybe if I kept the same power source and fired a different one..or if I went to a different power source and fired the same one, but I never really found myself getting anywhere any quicker so I just went for literally stepping through the procedures by the end of it.

I: Two has the next probability and four through seven all have the same probability.

R: Okay. I guess I was doing the right thing to start over at one then.

I: Yeah. Yeah, if you go through it sequentially that tends to, you can distinguish that from what would be a motivated choice.

R: Yeah.

I: Well, thank you very much.

PARTICIPANT THIRTY-TWO

I: In general, did you find operating this device easy or difficult?

R: I found it operating it easy.

I: What did you think made it pretty easy?

R: The procedures were pretty clear and probably after about ten trials or so I was able to pretty much memorize them, and I mean, there are only basically, you know, three aspects of the control panels, so it was quick to memorize.

I: Do you think any additional information might have helped?

R: I didn't look at all at the model below. I just went through the control panel and tried to accomplish the procedures as fast as possible and memorize them. I didn't make like a direct correlation between the model and the control panel.

I: Do you have any ideas why you didn't?

R: I think in the instructions when you said that I was supposed to have operated the top part of the diagram, I mean the top part of the panel, at that point I just focused on that. I didn't, I mean when you told me not to, like when you said that the bottom part wasn't even operating to me like it meant that I didn't really have to pay attention to it.

I: Okay. Did you find yourself developing any kind of mental model or picture in your mind of what the system looked like?

R: Not of the system – just a mental model of how to memorize the procedures.

I: Okay. Did you make any estimate as to how the buttons were related to each other?

R: I didn't understand when I had to put the dial to the main to the MA, and then I had to fire the secondary. That didn't make sense to me. But, you know, setting the dial to the main and then firing the main and sending it out to the secondary and firing the secondary….that all made sense.

I: So you got some kind of model for the sensible procedures?

R: Yeah, it was, yeah, I mean the model was power, main, fire main, power, secondary, fire secondary, so, that's how I lined it up.

I: So the other ones stuck out because they contrasted?

R: Umm-hum.

I: Okay. Do you think you used the indicators to help you figure out what procedure to choose?

R: No. I pretty much went down in sequential order. Whenever I would hit start, whatever procedure one or two was there is what I would start with and I would immediately do those two first and if they didn't work, I would just go three through seven as fast as I could.

I: So your strategy was the default and then one or two and then the rest of them sequentially?

R: Right.

I: Okay. Well, that's all I have to say. Do you have anything you want to add?

R: No, that's it. Did you purposely not tell me to focus on the model below?

I: No, I'm thinking perhaps I shouldn't have said that, actually. But, regardless, you went through it very quickly. You've been one of the quickest people to get through that part. Well, thank you very much.

PARTICIPANT THIRTY-THREE

I: In general, did you find operating this device easy or difficult?

R: Easy.

I: Why do you think it was so easy?

R: Well, after I did it a couple of times, then it was easy. But first, the first probably two times were a little confusing, but after that, with the arrows…..it helped not looking, at first I thought looking at the paper was going to be easier, but just following the arrows on the screen made it a lot easier.

I: So the green arrows were very helpful to remind you each of the steps?

R: Um-hum.

I: Okay. Was it pretty clear to you what the different buttons and all did?

R: Not really.

I: Did you see them as an overall system, like did you picture a system in your mind?

R: Not really.

I: You just followed the procedures and steps?

R: Yes.

I: Okay. Do you think you had any strategy as to which procedure you would choose?

R: Well, I started with, I always started at the top since you said they would mostly work with procedures one and two. And then I just went straight down the line so I wouldn't forget. I tried to go straight down the line so I wouldn't forget which one I had already done.

I: Okay. Do you think you had any concept of the energy flow overall that the device controlled?

R: No.

I: Like where it was routed to and all?

R: Not really.

I: Okay. Do you think it would have helped you if you did or do you think it would have had any effect if you did?

R: I don't think it would've had any effect.

I: Because you were more concerned with just going through the procedures?

R: Right.

I: Do you think that it was a time concern?

R: Not really. I mean I didn't pay attention to the clock at all; I never really compared times.

I: Um-hum. So, in your case, I think maybe it worked because you went through it very quick. You did it very fast. Well, that's all I really have left. Do you have anything you want to add?

R: No.

I: Okay. Well, thank you very much.

R: Sure.

PARTICIPANT THIRTY-FOUR

I: First of all, did you find operating the device easy or difficult?

R: It was difficult at first, but then after a while it got easier…getting used to it.

I: What do you think made it easy?

R: Just repeating it over and over again.

I: Repeating a small number of steps?

R: Yeah.

I: Okay. Do you think there could have been anything extra to make it easier?

R: No, I, once you got the habit of it, it was pretty easy.

I: Did you have any picture in my mind about the overall system and how things were related to each other beyond what you saw on the screen?

R: No.

I: Did you think in terms of the way it was drawn on the screen?

R: Yeah, just by looking…

I: like this goes to this and so on…?

R: Right. Yeah.

I: Okay. Did you find the indicators at all helpful in determining what procedures to choose?

R: What's the indicators?…

I: The red lights.

R: The red lights….ah, yeah, like once the light turned on it helped and then you, I repeated that same one for the next one just to see maybe if it was the same .

I: Okay. So was that part of your strategy for choosing procedures….or do you have more of a strategy?

R: Yeah, it was the one that was successful before; just repeat that one for the next one and see if it's the same.

I: Um-hum…And if it wasn't?

R: Just went down to the next one.

I: Just sequentially after that.

R: Yeah.

I: Okay. Well, I believe that's all I have to ask about. Do you have anything else you want to add?

R: No, that's it I think.

I: Okay. Well, thank you very much.

PARTICIPANT THIRTY-SIX

I: First of all, did you find operating this device easy or difficult?

R: It was easy…yeah.

I: What do you think was particularly easy about it?

R: It was easy like just click the buttons….it wasn't too hard to remember some of the procedures and just, the others I could click and look at. It was pretty easy.

I: Yeah, the procedures work very similarly.

R: Yeah.

I: Do you think there could have been any extra information on there?

R: Maybe that you can just click from procedure to procedure without like having to start the like reset the whole machine, just have to click and it resets itself. I don't know if that was written down here but I didn't pick it up if it was.

I: Did you find yourself developing some kind of picture in your mind of what you were doing – like a model of the entire system?

R: Some kind. Not like, as I was working like…I just did it like as it was asking. I didn't, the way it's across the screen helps, from one end to the other, like you're the middle guy.

I: The way the buttons are ordered kind of goes in that direction.

R: Yeah, what I would imagine the direction would be. There might not even be direction, but

I: Yeah, that's true….whatever the direction is. Did you find yourself using any kind of strategy to figure out what procedures to use?

R: No, I started at one and just worked my way through. If I got to seven once or twice I think I went back and checked some of the others. I was like…I'm not sure if I hit those just right.

I: You sound disappointed that you went through it that way.

R: Well, it's not a very interesting way. I knew if I skipped around I would forget the one that was, so.

I: Well, it works. Did you use the indicator lights at all?

R: If it weren't for those things…just the buttons all lit up at different times and like sometimes both would pop up and sometimes just one I noticed it but not real sure what it was for, but the blinking light was amazing. Without that, like number seven where you just can't use it….it's good to have the blinking light to know that I've done it right.

I: Well, that's pretty much all I have to say. Do you have anything you want to add?

I: Well, thank you very much.

R: You're welcome.

PARTICIPANT THIRTY-SEVEN

I: First of all, did you find operating this device easy or difficult?

R: I thought it was fairly easy, once you started getting used to the procedures.

I: What in particular did you think was easy about it?

R: Well, if you notice procedure one, two, three and four or one and three and two and four are the same. So that definitely wasn't as demanding, trying to memorize four procedures.

I: Yeah, they were all very similar.

R: Yes.

I: Did you find the definitions of the procedures on the screen helpful?

R: Yeah, I thought they were very helpful, especially since I never really scanned the bottom that much, the bottom diagrams, so I clicked on the show definition a lot to get me through them.

I: Did you look at the bottom enough to relate it to the top?

R: Oh yeah, I looked at it enough to see the correspondence between the two.

I: Did the bottom show anything more than the top?

R: Yeah when I looked a couple of times I did look down there I did see how it would relate to the top and how you would, which procedure you would choose depending on how the bottom looks. But I thought clicking on the show definition button was much easier than the…..

I: Did you find yourself developing any kind of picture in your mind about what the entire system looked like?

R: Yeah, at times I did develop of how everything would be put together rather than a simulation.

I: So was it pretty clear what each of the buttons and switches did in relation to each other?

R: Oh yeah, of course.

I: Do you think there could have been anything else that would have made it more clear?

R: Not that I can think of at the moment.

I: Okay. Did you find the indicators helpful in determining what procedures to abort or which ones to choose?

R: Well, yeah, other than being told that if the light doesn't flash, then you know it's not right. I would say yes.

I: So that blinking light to be an indicator at the end was the most important? Did you consider any of the others along the way?

R: Well, not really. looking down at the bottom for but, not quite.

I: But you considered it down at the bottom as it went along?

R: Um-huh. Yeah.

I: Okay. Did you have any kind of strategy to choose what procedures would work?

R: I pretty much just ran through them one through seven, in order.

I: Sequentially?

R: Yeah, sequentially.

I: Okay. Well that's about all I have to say. Do you have anything you want to ask?

PARTICIPANT THIRTY-EIGHT

I: first of all, in general, did you find operating this device easy or difficult?

R: Initially it was kind of difficult but subsequently it was easy.

I: What do you think was so easy?

R: The layout and the arrows – they basically guided me through the procedures.

I: The green arrows?

R: Yeah, the green arrows – they basically guided me a lot through the procedure.

I: Yeah, I noticed that you barely looked at the paper.

R: Yeah, I barely looked at the paper; I was basically going by the cue of the green arrows. That's it.

I: Okay. Do you think any additional information would have made it easier?

R: No, any additional information probably…no…I can't think of any.

I: Well you mentioned that it might be better if it displayed what procedures you had already through.

R: Yeah, maybe so, yes.

I: That might be good to show. Do you think you had some kind of a picture in your head or a model of what the entire system looked like, like what the energy flow or something was?

R: I thought it would be some graphical….something which is very graphical, something that is more horizontal rather than, you know, arrows pointing..I really thought that, you know, it would, when I thought of energy boosters, I really thought of, you know, something which is more horizontal you know, where the graphics go from the left to the right and as the energy goes, you know, it moves back – something typical of a visual display or something like that.

I: So did you have that kind of image in your mind?

R: I initially did have something but when I was reading the paper, when I was reading the paper, I thought it would be something like that written, but you know, once you hit a button I can visually see something going and coming. But here it was more than, you know, the arrows moving from left to right and right to left.

I: Were you thinking about how the buttons and all are related to each other in terms of that system?

R: No, not really, not in the of buttons, but I was more focused on the visual display, you know. If you're talking about buttons which were on the display, I wasn't at all focused on that.

I: But did you have a picture of, like which ones were stopping or branchng the flow or feeding to each other and things?

R: No, I kind of got the picture that, you know, there are two accumulators and that you would go from one to the other, so I basically thought of a more graphic representation of that, but this was more of a, you know, more of a, I guess from what I could understand, this process was more like how quickly you could complete the procedures, not on terms of what happens where. So…

I: Did you find yourself using the indicator lights to help choose procedures?

R: Yes, that helped me a lot because the moment I could, basically when I was going through a couple of procedures, a couple of indicator lights were not working at all, so, I, the moment I knew that, you know, there's no point even going through the procedure, because if the first couple indicator lights don't work, it doesn't make sense, so the indicator lights were really helpful. The moment I saw in any particular procedure, that the indicator lights were on, then I kept going on and you know, close those procedures and I got the hang of it towards the end.

I: So if they weren't lighting up when they were supposed to, you knew that procedure wasn't working?

R: Yeah, yeah, yeah, yeah, yeah.

I: Okay. Do you think you had any strategy for choosing procedures?

R: Yeah, actually I kind of figured it towards the end, probably towards the end of the procedures where you know, when none of the lights were working, I directly went on to seven and seven, you know, generally worked, so that was, I don't know whether that was more of a comfort activity or what, but I don't know, maybe that would work.

I: Well, that's about all I have to say. Do you have anything to add?

R: No.

I: Okay. Well, thank you very much.

PARTICIPANT THIRTY-NINE

I: First of all, in general, did you find operating this device easy or difficult?

R: I think it was pretty easy with the procedures in front of you.

I: What did you find made it easy?

R: I think the directions were pretty simple, like you could remember them after going through the procedure once or twice, you could remember so you didn't have to keep referencing the procedures. And then, I guess the indicator lights – like at first I didn't really pay attention to them but then, once I stopped looking at the operating procedures and using those more, that made it just as easy basically as looking at the procedures.

I: Did you find that you used the indicators to help you decide that a procedure was not working?

R: Mainly with just the power switch, yes, when the power switch, when the indicator light after than wouldn't go on, then, yeah, that, I used that a lot like the two times that it happened.

I: Did you think you had a picture in your mind or a model of what the system looked like?

R: Possibly but not really. If it wasn't in front of me, I don't think I could have pictured it.

I: Did you think of the relationships between buttons and settings, and what they did for this overall system – this energy flow?

R: Yeah, once I stopped looking at the procedures, and yeah, the switches and how they corresponded with the buttons – I considered that more.

I: Do you think the display gave you a pretty good picture of the way the system went, the way the energy flowed?

R: Um-hum…now that I think about it. At the beginning I was just going, reading off here and trying stuff but once I started watching it, then yes.

I: Okay. Do you think there could have been anything additional on the screen that would have helped?

R: Not really since the operating procedures were…you couldn't find them. They were located if you clicked up the button up in the upper left-hand corner, so, no, I think it was fine the way it was.

I: Do you think there was a reason why you didn't click that button to look at them?

R: Just because I had them right here in front of me. It was just easier I guess. I could keep the mouse on the switch meter, so, I don't, I guess just because they were in front of me. If they weren't in front of me then I would have clicked on it a lot.

I: Yeah, very few people click.

R: Yeah.

I: There must be some common reasons. Do you think you had any kind of strategy as to what procedures worked?

R: Yeah, I thought I got strategy, that's when I stopped looking at this, like I felt that procedures three and four were the exact same as one and two, I think, so I tended to go to those last. I would go through one and two and then I'd go to five and six, so yeah, I guess so.

I: Well, three and four are actually the same as one and two, but the number is different and the computer thinks they're different because the number is different.

R: Oh, okay. That's why one of them took me so long to get because I thought that, I thought one and three were the same thing and then it turned out it was three and so..

I: As far as the computer is concerned, they're different.

R: That's what, that was the one that took me longest. I didn't understand why it was three.

I: Well, your overall time was still pretty good so it must not have slowed you down too much. Well, I suppose that's all I have to say. Do you have anything you want to add?

R: Is this for a class project or something?

I: This is part of my dissertation.

PARTICIPANT FORTY

I: First of all, in general, did you find operating this device easy or difficult?

R: Pretty easy; pretty straight forward.

I: What did you think was so easy about it?

R: All you had to do was push a button, I guess, to do the job.

I: Okay. Do you think any extra information would have helped you along the way?

R: Probably not, I mean, as long as it does what it says it does, then that's all that I really should need.

I: So did you find yourself putting together some kind of mental image of what the system did?

R: A little bit, but kind of, from what the chart showed, it kind of showed…I'd get enough image of the flow, so that was good enough for me.

I: So you followed along with the display pretty well?

R: Yes.

I: Okay. Well, I don't think you even looked at the procedures on the paper rather than the screen. Why do you think you didn't feel the need to?

R: Because it was quicker to look at the arrows and go to where they were pointing rather than to keep referring back to the paper.

I: So the green arrows were pretty helpful?

R: Yeah.

I: Okay. Did you find yourself developing some kind of strategy about what procedures to choose?

R: Yeah, I think so. I don't know; I was kind of confused because sometimes when it worked, I didn't understand why it worked.

I: What kind of strategy do you think you were using?

R: Like I kind of looked ahead to the other arrows so once I knew something, if I didn't see the power then I would usually skip to the next one and try that, so, the power indicator lights were probably the main thing that I would look at.

I: The power indicator lights…the first light? The ship power?

R: Yeah, or the first….yeah, the ship and then the other too.

I: Okay. So did you use the indicators a lot to help you figure out which procedures?

R: Yeah, I think so.

I: Well, I think that's all I have to say. Do you have anything you want to add?

R: Okay. No.

I: Alright.

PARTICIPANT FORTY-ONE

I: First of all, in general, did you find operating this device easy or difficult?

R: It was pretty easy once you figured out the procedure.

I: You mean each procedure or the general procedure?

R: The general procedure.

I: They were all very similar so figuring out what they were all doing was probably important. Do you think you had any kind of picture in your mind about what the overall system looked like?

R: Should look like? Somewhat, but, well, operating it was something more with the bar rather than just having dots because the dot indicator was not very clear sometimes. And, after you got used to the procedure, you kind of ignored it except for the two indicators on the far right and the far left.

I: Do you think you pictured the flow of energy or the system that you were controlling?

R: I couldn't visualize it. I could only visualize it using just the two dots. The SP and the PF.

I: Did you try and imagine what kind of model in the background would be?

R: Like what the actual physical model was?

I: Yeah, like, or conceptual?

R: I didn't visualize that.

I: Okay. Do you think you developed any kind of strategy for what procedures to use?

R: Ahhhh, yes. If SP did not light up, I'd automatically go to seven. If it did, then I'd go to one through six.

I: Like sequentially?

R: Didn't have to be sequentially because sometimes when you started a new operation it would go to two automatically so it wasn't exactly sequentially.

I: Well, before you started you seemed to trace out the procedures. Did that help at all?

R: Somewhat because before I started I figured out, okay, well, for odd ones you'd switch ES to MA; even procedures you'd switch EF to SA, but from there it's pretty much the same for all four except for five and six where you flipped the FS and FM.

I: So you kind of put together a framework of the procedures?

R: Right.

I: And how they worked. Okay. Well, actually, that's about all I have to say. Do you have anything you want to add?

R: The interface itself was fairly easy to understand. Just felt that it could have been a lot faster if it was simplified a little bit more and just be concentrated on this, not necessary to concentrate on two buttons, or two indicators would have made it a little bit easier so I'd know when the power was going.

I: So knowing when the power was going would have been important?

R: Right.

I: Okay. Do you think a graphic more related to showing the actual flow of the power would have helped?

R: Probably. From where the ship was, or…power from the main power?

I: Yeah, from the main power.

R: I guess, but so long as you kept it simple. If it was too much, then…

I: Yeah, that's the hard part.

R: Yeah.

I: Okay. Well, thank you very much.

PARTICIPANT FORTY-TWO

I: First of all, in general, did you find operating this device easy or difficult?

R: I found it difficult to get the light to blink. It was easy following the directions; those were…they were easy directions, but just in terms of getting a strategy to get the light to blink, I thought it was hard.

I: So finding the one that worked was hard?

R: Umm-hmmm.

I: Did you find yourself using any kind of strategy?

R: I noticed that number one worked a higher percentage than the other ones usually, so I tried using that one more than the other ones, but besides that, I didn't have too much of a strategy. Sometimes I would look at the lights up top and then I did sometimes make a judgment, but otherwise it was pretty random.

I: So the lights helped sometimes?

R: Umm-hmmm.

I: Not very often?

R: Right.

I: Okay. What do you think would have made it easier to find the right procedure?

R: If there was a sure sign that it was going to work that time, like I noticed that on one of the things it mentioned looking at the bottom and I didn't even look at the bottom at all, so maybe that would have helped me more if I had paid more attention to that, but I looked down there a couple times, but I didn't really…I wasn't correlating what was going on at the bottom to what was going on up top, so I didn't really…I didn't make a connection at all. So if I had done that, it probably would have helped more. Or if ah…it was..yeah, I think that would have helped.

I: Do you think it would have helped if the device thing you were interacting with looked like the one on the bottom?

R: Yes, and if I understood what the bottom was, because, like I said, I looked at it and maybe if I'd looked at it longer and studied it more I would have been able to understand what it was doing and how it was relating to the top, but I didn't, so, yeah, maybe if it was the same then it would be easier to make connections between the two.

I: Okay. Did you have any picture in your mind or anything of what the system might look like that you were actually dealing with…..what the…how the energy flow was going to the phasers to fire them?

R: Not really.

I: What kind of things were you…?

R: The main thing I was thinking of was just getting that light to blink red and then just following these directions, I mean, most of them, when you pressed one on the one panel, you always clicked the other button, so mainly for me I was just trying to get through it as fast as I could. I wasn't really thinking of much else than just clicking start and then switch button and going through with it.

I: Okay. Alright. Do you think you had any idea or concept of what the buttons did in relation to each other?

R: No. I don't, not really. I mean I knew that when you pressed SA, you usually pressed FS, and when you pressed the one on, MA, you usually pressed FM. I correlated those together but besides that, no. And then end you clicked, before, like ones that worked and then you clicked end and then you clicked the switch off. So I guess in that sense, I had a little idea of what they were doing, but not much else than that.

I: Okay. Well, I suppose that's about all I have. Do you have anything you want to add?

R: What…how did you know if it was going to flash…or can you tell me that?

I: For different lines, well procedure seven is the easiest. If the initial ship arrow indicator doesn't go on then procedure seven will work. If it does come on it will not work. Ones that used the main accumulator, there was a light there for the main accumulator. So if that indicator did not go on, then the procedures that used the main indicator would not work, the main accumulator would not work. And there are a couple that are really ambiguous, so you really can't discriminate..

R: Okay.

PARTICIPANT FORTY-THREE

I: First of all, in general, did you find operating this device easy or difficult?

R: Easy.

I: What do you think made it so easy?

R: The arrows pointed out and you got kind of used to what you were…

I: The green arrows?

R: Um-hmm.

I: How about the overall flow, the order that things went.

R: Yeah, I guess every procedure was about the same so you got used to going in the same direction.

I: Did you find yourself developing a picture in your mind or something of what the system would look like in terms of the energy flow that you were directing?

R: No I really didn't. I was just trying to get the light to blink. I really didn't worry about what it was doing.

I: So you paid more attention just to what the steps were? Just what to do?

R: Umm-hmmm.

I: Okay. Did you have any concept of what the buttons did in relation to each other?

R: Somewhat. Yeah, it was kind of a logical flow it seemed like but then sometimes it would just kind of throw some different ones at you where it didn't do anything.

I: What kind of flow do you mean there was?

R: You'd see one or two of the lights light up and you'd feel like you were getting everything accomplished and then you either would or you wouldn't.

I: Do you think you had any kind of strategy for choosing which procedure worked?

R: I started with whatever was given to me to begin with and then just went from one through seven in order, so…

I: Okay. Did you find the indicator lights helpful at all?

R: Yes and no. Now that I think back about it, it probably wasn't really that important but I thought it was when I was doing it.

I: Well, that's pretty much all I have to say. Do you have anything you want to add?

R: I don't believe so.

PARTICIPANT FORTY-FOUR

I: First of all, in general, did you find operating this device easy or difficult?

R: Easy.

I: What do you think made it so easy?

R: There are only a certain number of different combinations of tasks that you need to do.

I: Do you think any additional information would have made it easier?

R: There was one section where none of them worked and so you clicked finished when nothing was on and that took a while to figure out.

I: It was procedure seven?

R: Yeah.

I: Yeah, that one's kind of different from the rest. That one didn't come up while I was here. It would have said something if it did. Do you think you had any kind of strategy for choosing the correct procedure?

R: Excuse me?

I: Do you think you had any strategy or any way of figuring out which procedure would work?

R: Well, I just tried the one that was there and if the light didn't light up on the first one, I went ahead to the next one. If it was successive lights lighting up, I would continue and if not, then I would go to the next one.

I: So you just through it sequentially?

R: Umm-hmmm.

I: A couple of times it looked to me like you were sticking with one and three and correlating those into a four, so on. They did go together but in fact they were the same in a lot of contexts and steps but different procedure number so it was different as far as the computer was concerned. Do you think you had any kind of picture or image of what the system looked like in terms of the energy flow or whatever the flow procedure was?

R: I was kind of imagining pipes.

I: Like pipes of the energy going through?

R: Yeah.

I: So were you imagining the roles of the different buttons in terms of rerouting those pipes?

R: Umm-hmmm, yeah, just like closing one off, running others through.

I: Uh-huh. Okay. Well, that's about all I have to say. Do you have anything you want to add?

R: No.

I: Well, thank you very much.

R: Uh-huh.

PARTICIPANT FORTY-FIVE

I: In general, did you find operating this device easy or difficult?

R: I think it's easy, like you just need to, it's really easy as long as you know what to do at first, like it was hard to start out but after you know how to do it, it's easy.

I: Can you think of what in particular you thought was easiest, like the variations among the procedures?

R: Like I thought that the arrows were what made it easier, 'cause you just follow the arrows.

I: The green arrows?

R: Yeah.

I: So did that….you felt you didn't need to refer to your notes.

R: Right, like I just follow the arrows.

I: Okay. Do you think anything additional would have made it easier?

R: Who could make it easier? I don't know…I think it's pretty simple.

I: Okay.

R: If there was any, like…there's no relation at all between the lights and where you fire it from, like that's what I was looking at first. I thought where the lights were and which one you would fire would have to do with whether it would work or not, but I guess it doesn't..

I: Yeah, I see them on the one you were looking at. All the lights are kind of grouped together on the left side and the final is on the right side.

R: Or like for example, the lights on the top were lit…the accumulators or whatever, and then when I had to fire down here, like there's two firing, when I would have to fire the bottom, I would think that I wouldn't work but sometimes it would. I don't know, I thought the firing had to do with where the lights were on. I guess they didn't.

I: Well, do you think you used the lights to figure out what procedures were working?

R: No, I never figured that out. And, I don't know the secret to it.

I: Okay. Well, if there was a secret I'd share it with you, but there really isn't.

R: Okay. Alright.

I: Do you think you had a just some kind of strategy for choosing procedures?

R: I just tried one and two first because the paper said that they're the most probably and then I just randomly did three through six. I really didn't do seven much. I would always do seven last.

I: You noted that they are most probable on the paper is a pretty smart thing to do. A lot of people don't realize that. That is one of the keys.

R: Yeah. Uh-huh.

I: Do you think you had any kind of impression or picture in your mind of what the system looked like, the energy flow system?

R: No. I didn't even know what I was going to be doing to begin with so I didn't have anything in mind.

I: Even when you were here…

R: Huh-uh. No.

I: Did the display that you were looking at give you some feeling of the way things…the flow went together?

R: Oh, yeah, yeah, but it's just like beforehand, I guess I don't think that way. I don't know, I just really didn't think about it before; I just followed the computer.

I: Did you have an idea of what the buttons did in relation to each other, like one shunting off energy for you to direct?

R: Yeah, like turn the power on and then giving it some direction.

I: That counts. Do you think any kind of model would help ____________ idea?

R: As far as, like what do you mean? Like for what?

I: Like having a picture of the way the energy flowed through the system.

R: I just think as far as….I think the light should be more, like I was telling you before, I think the light should be more related to which one to fire…like the lights are on the top and there's a firing on the top and on the bottom, and I just think that the light should have to do with which one to be fired.

I: Do you mean like if the entire button like fire main or main secondary… if those buttons lit up…

R: No, I mean like if the lights on top light up I don't see why it doesn't fire, like the top one won't make it fire. If the lights are lit up, doesn't that mean like it's full - that's what I get from the lights being on, that they're full or it's ready. Then I would push fire and it wouldn't work.

I: Well, one light has to do with the main accumulator. If that light does not go on, the procedure that involves firing energy from the main accumulator will not work because the main accumulator is off.

R: Yeah. But, see sometimes they were on and I would fire and it still wouldn't work. Do you see what I mean?

I: Yeah. Yeah. It's all probabilities. Well, that's about all I have to say. Do you have anything you want to add?

R: No.

I: Well, thank you very much.

PARTICIPANT FORTY-SIX

I: First of all, did you find operating the device easy or difficult?

R: It was pretty easy once I figured out what I was supposed to do.

I: What did you think made it easy?

R: It was repetitive like procedure one and three were the same and procedure two and four were the same thing. Once you got the pattern down, it was, you just kept trying.

I: And there were all just slight variations between them?

R: Right.

I: Do you think there could have been any extra information to make it easier?

R: I don't think so. I think I just needed one or two times to practice to figure it out.

I: Did you find yourself developing any kind of strategy about choosing what procedure worked?

R: If you looked at the other lights, if they didn't come on then you knew that procedure wasn't going to work. And the ones where you had to go to MA, if that light didn't come on, then you knew that one wasn't going to work.

I: So you used the indicators a lot to figure out which procedures weren't going to work?

R: Yes.

I: Well, good for you. A lot of people haven't done that Did you have an impression of what the different buttons did in relation to each other?

R: No.

I: Maybe I said that wrong. Well, more generally, did you have a picture of what the entire flow looked like of the system?

R: No.

I: So you were just going by the steps in the procedure?

R: Yes.

I: Okay. Was it pretty clear at least what the different buttons did?

R: Yes.

I: And did you see what they did to the flow or what they did as where they fit in the procedure?

R: More on how they fit into the procedure.

I: So do you think that the procedures were pretty well organized for the machine, like from left to right and so on?

R: Yes, yes.

I: Okay. Well, that is all I think I have. Do you have anything you want to add?

R: No, I don't think so.

I: Okay. Well, thank you very much.

PARTICIPANT FORTY-SEVEN

I: First of all, in general, did you find operating this device easy or difficult?

R: At first I found it a little difficult but once I went through a couple of operations and cleared a couple of things up, I found it pretty simple.

I: Okay. What did you find made it easy?

R: Getting familiar with how the flow worked and where all the buttons were and getting used to all the different procedures which were required.

I: At the beginning what do you think made it difficult?

R: Just unfamiliar with the directions really. I couldn't get a clear picture as what to do about looking at the screen or as, once I got the hands-on with it and going through it a couple times made it a lot more easier for me.

I: Do you think any additional information would have made it easier?

R: No.

I: Okay. Do you think you had any kind of image or picture in your mind of what the system looked like that you were controlling, like the flow of the energy and so on?

R: The bottom part of the screen helped me visualize a little bit as to what was going on in the system.

I: Do you think it helped you find the right strategy that you could visualize it that way?

R: Eventually, yes. At first it just kind of made me confused but once I understood the flow it definitely helped.

I: Did the indicator lights help you along the way?

R: Yes. They helped me some.

I: All of them or just the final firing?

R: The final firing and also the one where you turned on…the one if the light didn't go on, we turn it on and it was operation seven. But if it turned on, it was one through six.

I: Okay. Do you think you have any kind of strategy for choosing which procedures worked?

R: Like I said, if the light turned on, I'd go one through six and then I'd try and start either from six and go to one or one through six. But I didn't go on to seven.

I: So you saw one through six as having equal chance of being right?

R: Uh-huh.

I: Okay. Well, that's about all I have to say. Do you have anything you want to add?

R: No, that should be it.

I: Okay. Well, thank you very much.

PARTICIPANT FORTY-EIGHT

I: First of all, did you find operating this device easy or difficult?

R: I wouldn't say it's difficult but I wouldn't say it's easy…somewhere in between, probably more easy than difficult.

I: What did you find made it seem kind of difficult?

R: Just trying to figure out, like when which procedure will work, like it took me a while to figure out, that like, on one of them that the switch, the light wasn't turning on and it took me a while to figure out that I needed to go to number seven to finish the operations.

Some of it was just kind of like an ambiguity type thing and I wasn't sure like when to use which procedure.

I: What do you think made it particularly easy?

R: There wasn't a whole lot of pressure on getting it done. Yeah, exactly, you know, it's not like, you know if I didn't fire the laser or whatever, it's not like I was going to blow up or be fired or whatever, so….

I: Do you think any extra information would have made it easier?

R: I think probably explaining when to use which procedure would have made it easier, like explaining like if this light turns on, it means, you know, do this, or if this light doesn't turn on, it means that that won't work or that this will, or that kind of a thing.

I: Okay. Do you think you had any kind of a picture or image in your mind about what the system looked like in terms of the energy that you were routing?

R: Yeah, I think so. I think I thought about it kind of like if you had like a railroad track type of thing, and you know, you needed to hit, you know, this one said the train went on to this track and then, you know, to get it to the different points, you know, you try and send it down this one but you find out that, you know, the bridge is out down there so you need to either back it up and send it down a different track or pick somewhere else that it needs to go.

I: So do you think you saw the function of the buttons and switches in relation to each other?

R: I think some of them I figured out by the end of it, which ones, especially the way that the lights and the different procedures matched up, you know, that if whatever the third light was, if that one wasn't one then you couldn't use the

I: The MA indicator.

R: Yeah, the MA indicator…you couldn't fire from the FM one; it wouldn't let you do that, so.

I: So you found the indicators pretty helpful?

R: Yeah, yeah.

I: Do you think you had any kind of strategy for choosing which procedures would work?

R: Can you repeat that?

I: Do you think you had any kind of strategy for choosing which procedures would work or which ones to try?

R: Yeah, I think for the most part, I'd start out with number one and number two because, you know, you told me those were the ones that worked most of the time and most of the time they did work, so I'd try those first and then if I found that one of the lights would turn on but it wouldn't fire for one or the other, you know, wouldn't fire from that switch, I'd go and try one of the other procedures that matched up different so that I'd be hitting a different button. So try and take what worked from one or two and then what didn't work and then try and match that up with one of the other procedures.

I: Well, that's pretty much all I have to say. Do you have anything you want to add?

R: No, I thought it was kind of neat though. I'm kind of curious as to how it all ties together, but…

I: Well, so far you seem to have one of the more fleshed out strategies that anybody has had. You were the first with the railroad analogy. So far I've heard plumbing and I can't remember what else….

<u>R</u>: Plumbing was one that I had in mind too.

<u>I</u>: Yeah, the same kind of flowing through a system thing….you could see how they related.

<u>R</u>: I think that just comes up because when you learn about electricity in most classes, they kind of use the analogy of ……

<u>I</u>: Yeah, that pretty much goes with a flow diagram.

<u>R</u>: Yeah, some kind of algorithm or something.

<u>I</u>: Yeah, in fact, another condition in this the way the conditions differ in the display you see. Some people see a flow diagram and not the device with the buttons. And from there I ask them similar questions…if they had any picture, and so far, although I haven't done the stats yet, it seems that most people when they are given a picture don't imagine a picture. It's kind of like, well, it's there, so why bother?

<u>R</u>: Yeah, that's interesting.

<u>I</u>: Which you can argue for being good or bad. I'm on the side that says it's further to the bad end.

<u>R</u>: Yeah. That's me.

<u>PARTICIPANT FORTY-NINE</u>

<u>I</u>: First of all, did you find operating the device easy or difficult?

<u>R</u>: It was easy.

<u>I</u>: What do you think made it so easy?

<u>R</u>: Well, once I memorized the procedure, it was easy, so I didn't have to really think about what to do…

<u>I</u>: Do you think there could have been any extra information to make it easier?

R: I don't think so, no.

I: Okay. Did you find yourself using any kind of strategy to choose which procedure would work?

R: No, I just went through one, two, three, four in order.

I: So sequentially you went through?

R: Um-hmm, Usually there's one or two, so…

I: Okay. Do you think you used the indicator lights at all to help you decide which procedures might not work?

R: Only the one that whether it was flashing or not. I didn't really look at the other ones.

I: You didn't look at them. Did you see them as related to different parts of the system?

R: Well, I guess I would look at them to make sure I turned it on and actually hit the button…didn't click somewhere else.

I: Okay. Do you think you had some kind of an image or a picture in your mind of what the system looked like, the energy flow of the system?

R: No.

I: That's fine. Do you think that what you saw as the device, do you think that represented any kind of image of what it would look like?

R: No, not really.

I: Did you see the relations of the different buttons in relation to each other like in terms of turning off something that going in other directions?

R: Yeah, I guess I did. Probably like turning the whole system on before I did anything else. That kind of relation.

I: Those are things that may go into a picture. Well, I suppose that's about all I have to say. Do you have anything you want to add?

R: No, I don't think so.

I: Okay. Well, thank you very much.

R: You're welcome.

PARTICIPANT FIFTY

(This respondent was very, very difficult to hear).

I: First of all, in general, did you find this task easy or difficult?

R: Easy.

I: What do you think was particularly easy about it?

R: The initial ________ like going through the procedures one by one when I wasn't even looking at any indications and lights flashing so it went like ______________ and because the steps were more or less the same way – you switch on and you go to another procedure.

I: Yeah, it wasn't much variation among procedures.

R: As a task, it was easy. Even as a mental task it was easy.

I: Okay. Do you think any additional information would have made it easier?

R: Easier in the sense of if you give them directions like you tell them any kind of like if you stress something like go look indications the red lights won't work. I was just doing it quick…

I: So you think at the beginning most of the time you focused mostly on the task and then afterwards or later on you realized….

R: Late, like after I saw the 25th procedure and I went okay which light is flashing – what do I need to do. It might have cut down on one of the procedures.

I: Okay. Was it apparent to you what the different buttons and switches did, how they worked in relation to each other?

R: In relation to each other? In the sense there were switches and just routing more like an electrical circuit, so… more or less…

I: Do you think you had any kind of image or picture in your mind about what the system looked like?

R: No, I think once I looked at it, I adopted it.

I: So you pretty much went with the way it was on the screen was close to what you thought it would be anyway?

R: Right.

I: Okay. Do you think you had any kind of strategy for choosing procedures?

R: It was completely random.

I: It was random?

R: For the most part.

I: And you adopted the strategies later.

R: Yeah, the strategies came towards the end.

I: Okay. Well, I believe that's all I have to say. Do you have anything to add?

R: Hmm…no.

I: Okay. Well, thank you very much.

PARTICIPANT FIFTY-ONE

I: First of all, in general, did you find the task easy or difficult?

__R__: Easy, once I got the hang of it, I guess. At first remembering everything was hard but after a while it was easy.

__I__: What did you find was easy about it?

__R__: There wasn't many procedures to remember, and the indicator lights helped out a lot so I didn't have to go through everything every time.

__I__: Did things seem to follow the way you thought they should…was it laid out like you thought?

__R__: Yeah. It was how I thought.

__I__: So it kind of went along with the way you thought the system would work?

__R__: Yeah.

__I__: Was that the kind of model or impression or theory you had in your mind?

__R__: I guess – I never really had it in my mind before, but, I mean, it seemed to flow like I thought it would.

__I__: Okay. Do you think you had any kind of strategy for choosing procedures?

__R__: A little. I mean, if the, like if the main power didn't come on I'd try to go to number seven just to see if that would work right away, stuff like that, depending on which indicator lights came on I guess which one I tried next.

__I__: Think you were mostly sequential the way you went through it?

__R__: Mostly sequential, yeah.

__I__: Do you think you used the indicators a lot to aside from seven?

__R__: Hmm?

__I__: Aside from procedure seven when the power didn't go on, did you find you used any of the indicators at all?

R: For the main power one used it for that.

I: And not too much the others?

R: Not a whole lot, I guess.

I Did you think it was pretty obvious what the different buttons did in relation to each other?

R: Yeah, after the first try, yeah.

I: Did you get the impression that you were actually following the route of energy through the system?

R: Yeah.

I: Do you think you would have had the impression without the display that you used?

R: No, not without the indicator lights at least.

I: Do you think it would have helped or hindered you to have this kind of display – do you think a display without this kind of flow would have worked just as well?

R: Probably not, not if it didn't have the connecting the flow like that wouldn't have been as good.

I: Okay. Well, that's about all I have to say. Do you have anything you want to add?

I: Well, thank you very much.

R: You're welcome.

PARTICIPANT FIFTY-TWO

I: First of all, in general, did you find this task easy or difficult?

R: It was easy.

I: What do you think made it so easy?

R: Probably the arrows that pointed the direction and the indicator lights.

I: The green arrows?

R: Yeah.

I: Did you find you used the indicator lights a lot?

R: I only used the last one, the final one.

I: The procedure seven?

R: Yeah.

I: Not the last indicator light, the phaser firing light?

R: Yeah. I ignored the other lights.

I: Okay. Do you think anything extra would have made it easier?

R: No, I don't really think so.

I: Okay. Do you think you had any kind of strategy for choosing which procedure worked?

R: I would always start with one and if that didn't work, I would try two, and then from there I would just take what…, randomly pick one.

I: Okay. Did you have a pretty good idea of what each of the individual buttons did in relation to each other?

R: Yeah.

I: Did you get the sense of controlling or adjusting the energy flow through a system?

R: Yeah.

I: There was a question in the questionnaire about how well the display matched your picture in your mind of what it would look like. Do you think they matched pretty well?

R: Yeah, for the current to flow for the phasers – it's pretty close.

I: Do you think you had a picture beforehand?

R: No, since it was right in front of me, I didn't really have to think about it.

I: Do you think that helped anything to have it already there?

R: Okay. Normally do you think you make up these kinds of pictures about things…

R: How things work, and whatnot, yeah. Just natural pictures to figure out how things work.

I: Umm-hmm. And this you felt was similar to the ones you would normally think?

R: Yes.

I: Okay. Well, that's about all I have to ask. Do you have anything to add?

R: No.

I: Okay. Well, thank you very much.

R: Thank you.

Appendix F: Glossary

Device: A generic term that refers to a physical component of a system. The device in this study was control panel that was simulated on a video screen.

Energy-flow: the device manipulated the energy flow. In order for the phasers to fir, the energy flow had to be routed properly.

Diagram: A diagram that represented the energy flow was presented as a model of the device's function.

Indicators: The device had several indicators, which became red when they indicated an active feature, and they remained white otherwise.

Procedural indicators: These were green arrows that pointed to steps in a procedure for operating the device.

Control panel: the type of device presented.

Device model: representation of a device's underlying function as well as relationships among the components of the device.

Mental model: mental representation of a device's or system's underlying function and relationships among the components of the system.

Operating Procedure: prescribed set of tasks for setting the device.

Cognitive distance: refers to the degree of separation between augmenting information and relevant features of the physical world.

Curriculum Vita

William P. Staderman
208 Turner St. Suite 101
Blacksburg, VA 24060
540-552-9079
wstade@vt.edu
http://filebox.vt.edu/users/wstaderm/

Interests: effective integration of technology and human capabilities in order to maximize personal comfort and potential

Education:

9/97 – 5/03	Industrial and Systems Engineering, PhD Human Factors Engineering Virginia Polytechnic and State University Title of dissertation: Communicating expertise in system operation and fault diagnosis to non-experts
9/95 – 5/97	**Philosophy**, **MA** Philosophy, Computers, and Cognitive Science Program Minor: Cognitive Science State University of New York at Binghamton Title of thesis: Comprehension of spontaneous speech disfluencies: Evidence from event-related brain potentials
9/93- 5/95	**Psychology, MA Program** (ABT) General/Research Option University of Massachusetts: Dartmouth
9/89 – 5/93	**Psychology, BA** Minor: Sociology State University of New York: College at Purchase

Experience:

2/01 – 5/01	**Knowledge Engineer** Psychometrix Associates; Blacksburg, VA Modeled individual differences in situation assessments by simulated, artificially intelligent agents in military scenarios
Summer 2000	**Human Factors Specialist** NASA Ames Research Center; Moffett Field, CA Developed video annotation system for research studies using air traffic control simulations (Future Flight Central)

Summer 1999 **Usability Engineer**
IBM; Poughkeepsie, New York
Applied research in usability to the development of software for e-business servers

Summer 1998 **Human Factors Specialist**
NASA Johnson Space Center; Houston, TX
Applied research of applications of virtual reality in training and long-duration missions

Research Papers:

- Communicating expertise in system operation and fault diagnosis to non-experts (Doctoral dissertation – May 2003)
- A shared augmented reality system for communication across environments and online tutoring (January 2000; Presented at Bioastronautics)
- Reallusory Viewing: A study of the applications of virtual windows in hermetic habitats (April, 1999; Presented at the International Conference on Environmental Systems)
- Comprehension of spontaneous speech disfluencies: Evidence from event-related brain potentials (Master's thesis - May, 1997)
- Confirmation-bias in jury decision-making (June, 1995; accepted for presentation by the Eastern Psychological Association)
- Cognitive processes during object-oriented computer software design (September, 1994)
- The resilience of the self-concept: Self-affirmation, self-verification, and cognitive dissonance strategies (May, 1993)

Professional Affiliations:

- American Psychological Association - Division 21: Member
- Human Factors and Ergonomics Society: Member
- Students with Differing Abilities at Virginia Tech: Member
- American Society of Safety Engineers: Member

Awards:

- NASA Graduate Student Researcher's Program (Fall 1999-Spring 2002)
- Safety Certificate for completing The Safety Engineering Program at Virginia Tech (Fall 2000)
- UPS Fellowship (Spring 1999)
- Teaching Assistantships: Spring 1993, Fall 1994, Spring 1995, Fall 1996, Spring 1997, Fall 1997, Spring 1998, Fall 1998
- Dean's List Spring 1990-Spring 1993
- Certificate in Early Childhood Development (Spring 1992)
- New York State Regents' Scholarship

Extra curricular Activities:

- Students with Differing Abilities at Virginia Tech: Vice-President; Secretary
- Speakers' Bureau of the Dean of Students Office at Virginia Tech: Speaker
- Ambassador Program of the Dean of Students Office at Virginia Tech
- Virginia Tech ADA Executive Committee: Student Representative

College courses assisted:

- General Psychology
- Experimental Psychology
- Psychology Research Methods
- Philosophical Methods of Reasoning
- Introduction to Human Factors Engineering
- Occupational Safety and Hazard Control
- Human Factors Research Design