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ECOLOGICAL TASK ANALYSIS:
A METHOD FOR DISPLAY ENHANCEMENT

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ECOLOGICAL TASK ANALYSIS:

A METHOD FOR DISPLAY ENHANCEMENTS

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SUMMARY

Previous use of various task analysis processes for the purpose of display interface design or enhancement has run the risk of failing to improve user performance due to the analysis resulting in only a sequential listing of user tasks. Adopting an ecological approach to performing the task analysis, however, may result in the necessary modeling of an unpredictable and variable task domain required to improve user performance. Kirlik (in press) has proposed an Ecological Task Analysis framework which is designed for this purpose. It is the purpose of this research to measure this framework's effectiveness at enhancing display interfaces in order to improve user performance.

Following the proposed framework, an ecological task analysis of experienced users of a complex and dynamic laboratory task, **Star Cruiser**, was performed. Based on this analysis, display enhancements were proposed and implemented. An experiment was then conducted to compare this new version of **Star Cruiser** to the original. By measuring user performance at different tasks, it was determined that during early sessions, use of the enhanced display contributed to better user performance compared to that achieved using the original display. Furthermore, the results indicate that the enhancements proposed as a result of the ecological task analysis affected user performance differently depending on whether they are enhancements which aid in the selection of a possible action or in the performance of an action. Generalizations of these findings to larger, more complex systems were avoided since the analysis was only performed on this one particular system.

CHAPTER I

TASK ANALYSIS AND DISPLAY ENHANCEMENT

System and display designers have often used the method of task analysis to assist them in the design or enhancement of displays. The task analysis provides the designer with information concerning the activities required of the people who will interact with the system at hand. By understanding what tasks these users will be faced with, the designer can attempt to develop a display, or enhance an existing one, which will assist, and not hinder, the user in performing the tasks. The exact steps in performing such a process may differ from designer to designer, but the goals are always the same. The designer hopes to create a human-machine system which will operate in a safe and efficient manner.

In order to accomplish this goal, the system designer will generally begin the task analysis process by listing all functions in the system that involve, to some degree, human interaction. These functions are analyzed to determine what tasks must be performed by the human in order to fulfill the purpose of the function. Once these tasks have been identified, they are further broken down into the steps necessary to perform them. Steps are then usually analyzed further to determine other factors which may influence the human's performance in working with the system. Such factors include the stimuli which signal the onset and completion of the step; physical actions required to perform the step; decisions that must be made while performing the step; information required to complete the task; feedback information resulting from completion of the step; potential sources of error; and criterion for successful performance. The task criticality and difficulty, as well as the number and skill level of the people required to operate the system, are often also estimated (Sanders and McCormick, 1987).

This information can be especially helpful to the designer of human-computer interfaces. By analyzing the tasks required of the human in this manner, the designer is able to better determine what information the interface should provide to the user as well as what information, and actions, the user should provide to the system via the interface. In other words, the designer can decide what information will be inputted into the system and outputted by the system and how this transfer of information will be accomplished.

Trying to simplify this process of performing a task analysis, attempts have been made to develop taxonomies of generic functions and actions performed through display interfaces. Williges, Williges, and Elkerton (1987) describe several such efforts including taxonomies which list common communication interfaces or user-system interface actions. The benefit of these listings is that they provide the designer with information concerning what information or actions should be accounted for in the display interface. How the information should be manipulated is usually left for the designer to decide. In order to develop useful, performance-enhancing displays though, designers need to be aware of how the presentation of information will affect user performance.

The designer may receive help in making this determination if an ecological perspective towards the task analysis is adopted. Vicente (1990) describes such an approach as one which defines the system goals in terms of "the constraints in the environment that are relevant to the operator." Vicente then proceeds to explain how traditional task analysis cannot account for variability in system behavior. This fault is due to the nature of the analysis being a "single, temporal sequence of overt behaviors." The variability typically found in system behavior can result in the degradation of system performance when its design has been based on such a sequence. Such variability results from changes in initial system conditions, unpredictable external disturbances, and differences in users' methods for operating the system. This variability is often not described by traditional task analysis well enough to ensure satisfactory system performance.

Vicente (1990) states that separate descriptions of three classes of constraints are necessary in order to account for these sources of system variability. The first description is of the problem space in which the behavior occurs. The second is of the generic tasks that the operator is to accomplish. The final description is of the set of factors used in selecting possible actions that may be employed by different system operators in order to perform those tasks. By developing a complete set of descriptions, the designer is generally better able to predict the operator's behavior for any given combination of constraints. As a result, the designer is more knowledgeable about the system environment and therefore can more closely accommodate the complex and dynamic world in which the system operates.

Such an ecological approach to task analysis was taken by Kirlik (in press). It is his approach which was investigated in this research. Of concern is how effective such an approach to task analysis is at enhancing the display interface of a complex dynamic system in order to improve operator performance. A laboratory task known as **Star Cruiser** served as the system. Experienced users of this simulation were created to provide a basis for defining the functional problem space of **Star Cruiser**, the tasks performed during operation of the simulation, and the different methods, constraints, and rules that such users may employ during operation. This analysis follows Kirlik's framework for ecological task analysis. Once the analysis was completed, areas of the current **Star Cruiser** interface which were possible causes of poor operator performance were highlighted. Based on these findings, enhancements to the display interface were proposed and implemented. An experiment was then conducted to compare the enhanced display interface to the original interface by measuring at various levels user performance on the task.

Upon completion of this research, it should be apparent as to whether or not this particular framework for ecological task analysis is beneficial and effective. If it is, then the degree to which it aids in enhancing display interfaces should be able to be determined. Possible results, therefore, would reveal that this framework is effective at enhancing the display for particular characteristics of the simulation. What those characteristics are can only be determined at the conclusion of this investigation. In addition, the framework may effect instances where training is occurring rather than normal operation. It should be constantly remembered, though, that this research is solely concerned with one particular ecological task analysis framework and its effectiveness on one particular system. Therefore, any conclusions made as a result of this research are context-specific. Though the findings may seem to be able to be applied to other frameworks or systems, any general theories concerning ecological task analysis may only be constructed once other frameworks and systems are investigated.

CHAPTER II

ECOLOGICAL PSYCHOLOGY IN HUMAN-MACHINE SYSTEMS

Some work has already been done in the field of ecological psychology in the context of human-machine systems. The two disciplines of ecological psychology and human-machine systems are considered well related since they both rely on analyzing and modeling the human-environment system as a unit (Kirlik, Miller, Jagacinski, in press). It is the goal of the ecological approach to human-machine systems to reduce the cognitive demands and errors attributed to human control in complex systems. This goal is generally accomplished in two ways. The first method is to enhance the information presented to the user. The second is to improve the user's abilities at utilizing the presented information to determine control actions. The former is achieved by presenting the user with a more effective representation of the environment, generally through the use of computer information displays. The latter is the result of providing the user with assistance, possibly computer-generated, in determining what control actions to perform. As stated, some work along these lines has already been performed. As will be seen, even though different research efforts share the name "Ecological," their approaches to improving the human-environment relation may be different. Their goal, to improve human performance while reducing the cognitive demands of the user, is always the same.

Throughout these discussions, it is important to bear in mind exactly what is of concern. A major focus of this research is to determine what properties of the environment, usually information displays, will cause different cognitive activities, usually resulting in some decision or action. Hammond summed up his attempt at answering this question in the following way:

> If (a) the displayed data present many redundant cues, (b) the cue values are continuous, (c) the cues are displayed simultaneously, (d) the cues are measured properly, and (e) the subject has available no explicit... method for organizing this information into a judgement, then intuitive cognition will be employed. Analytical cognition will be induced by the opposite set of conditions. (p. 310, Hammond, 1990)

Based on this theory, a relationship between the task and the required cognitive activity can be predicted. By understanding the above criteria and the type of relationship that exists between the two, the system designer can modify the information displays in whatever way is necessary to satisfy the criteria in order to achieve a desired effect. Two such procedures which incorporate these ideas, and more, are discussed here. The Ecological Interface Design and the Ecological Task Analysis frameworks are both designed with the intent to improve information displays and, thus, user performance. The former is concerned with identifying causes and solutions to rare-event occurrences in complex systems while the latter, the focus of the present research, is geared towards the specification of actions during system operation..

Ecological Interface Design

Vicente and Rasmussen (1988) have developed a theoretical framework known as Ecological Interface Design (EID). Its foundation is based on the skills, rules, knowledge (SRK) framework as proposed by Rasmussen (Rasmussen, 1983). The purpose behind this framework is to design interfaces so that cognitive processes are not required at a higher level than the task necessitates. At the lowest level of the framework is skill-based behavior which involves highly automated sensory-motor and cognitive performances and occurs with little, if any, conscious control. The next level of the framework is rule-based behavior. This level is behavior activated by a hierarchy of rules stored in working memory. Knowledge-based behavior comprises the highest level of the framework. It consists of behavior that is evoked when new, complex problems are encountered. These problems are tied to meaningful concepts through similar functional or physical properties. The SRK framework is used to ensure that users rely on lower levels of cognitive control (i.e., skill-based behavior). In addition, the framework also attempts to ensure that information presented via the display is of similar form to the method with which it is manipulated. The EID framework consists of three principles, one for each level of the SRK framework, in order to satisfy these goals.

The first principle in the Rasmussen and Vicente (1988) framework is to permit the user to act directly on the display so that interaction with the system occurs "via time-space signals." This principle supports the skill-based behavior portion of the model. Its purpose is to allow the user to manipulate what is displayed in the interface and is an attempt to develop a high-degree of manual skill within the user.

The second principle is in support of the framework's rule-based behavior component. It states that a unique and "consistent one-to-one mapping" should exist between the underlying processes of the system and the perceptual information displayed on the interface. This information, in the forms of cues and symbols, is used to determine which actions are proper to perform. By developing a unique and consistent mapping, it is possible for the user to merely rely on perceptual cues in order to control the system. This reliance on cues occurs instead of depending on knowledge-based behavior. By relying on such rule-based behavior, cognitive control of the system is reduced and thus mental effort is as well. In addition, because of the one-to-one mapping between the symbols and cues, the user can exhibit knowledge-based behavior while only having to rely on the cognitive loads typical of rule-based behavior. As a result, while experiencing such reduced cognitive load due to the rule-based behavior, the user may continue to take advantage of the general applicability that is characteristic of knowledge-based behavior.

Finally, the third principle involves presenting an "externalized mental model" to the user via the display interface. This principle is geared to facilitating knowledge-based behavior. By providing a model of the complex system to the user, the user no longer needs to keep track of the "complex casual network" they are reasoning about. Instead, the external model provides the support necessary for deductive reasoning about system states and planning actions. Vicente and Rasmussen (1988) also suggest that this model may additionally aid the user by providing the depth of understanding of system functionality required in order for error recovery.

According to Flach and Vicente (1989), such an interface which accommodates all three levels of behavior in the SRK framework allows the user to deal with the entire range of task demands that are encountered during interactions with a complex system (Flach and Vicente, 1989). By representing the display information to be in accordance with the cognitive processes of the user, the meaningful characteristics of the system become visible (Vicente, 1988). Therefore, the user can concentrate on the system and the situation at hand without relying on unnecessary and wasted cognitive effort. These claims of EID have recently been empirically supported through research conducted by Vicente (Vicente, 1991). In the end, the EID framework provides an interface which takes advantage of the user's stronger skills and supports those that are not as good.

Ecological Task Analysis

The ecological approach has also motivated the development of a task analysis method to guide display design. A task analysis method predicts the cognitive activity required of the user in performing complex tasks. This model of cognitive activity is created by analyzing how the structure of the task environment influences cognitive activity. By developing such models of the user and the environment, the design of various system components, such as the display interface, can be geared towards alleviating some of the cognitive burden demanded by the task, as well as improving overall user performance.

The Ecological Task Analysis framework, as proposed by Kirlik (in press), begins by describing the structure of the task environment. Two different descriptions are necessary for this task. The first details the environmental *surface* structure. This structure is a description of the perception and action interface that exists between the user and the task at hand. The second examines the environmental *depth* structure. This structure is a description of the covert relationships that link the surface perception and action structures.

The surface structure is described in terms of its perceptual structure and its action structure. The surface perceptual structure is comprised of that information within the environment which is readily perceivable by the user. This information includes, for example, information which is displayed in human-machine systems to inform an operator of system states. Information which is present but not easily detected by the user is part of the depth structure. The surface action structure can best be thought of as those actions made readily available by interface controls. Actions which must be performed but cannot be performed readily with interface controls are part of the environmental depth structure.

Performing an ecological task analysis involves determining how the surface perceptual structure specifies the surface action structure. When the surface perceptual structure specifies the surface action structure, the perceptual guidance of action is possible. Two separate models are constructed during this type of analysis. The first details the surface perceptual structure by describing what perceptual cues are available to the user. The second model provides a description of the user's action capabilities. An ecological task analysis then simply involves creating these two models and identifying where mismatches occur between the environmental representations. Mismatches between the surface perceptual structure and the surface action structure are indicative of demands for post-perceptual cognitive activity to effectively guide action. This process is demonstrated in the following research by performing such a task analysis on a particular system.

Kirlik (in press) emphasizes that in order to perform this type of analysis properly, the modeling of the environmental depth structure must occur after that of the surface structure to ensure that incorrect assumptions are not made concerning what cognitive activities are guiding the user's behavior. This constraint in a sense is what makes the ecological task analysis unique. It considers how perception and action abilities determine necessary cognitive processes rather than assuming certain cognitive processes first and then determining how those processes define the functionality of perception and actions.

There are four possible results of an ecological task analysis process. These results have been indicated in Table 2-1. Each type of result indicates a different kind of mapping between the surface perceptual structure and the surface action structure of the interface.

The first possible result is *perceptual overspecification of action*. This result occurs when many distinct perceptual cues and situations point the user towards performing one particular action. This situation poses a problem by forcing the user to undergo unnecessary categorical or instance-based learning in order to identify the relations between perception and action. By arranging the cues so that perceptually salient features are distinguishable in a like manner as the actions they reflect, perceptual overspecification can be avoided.

Table 2-1. Possible Results Of An Ecological Task Analysis

Perceptual Overspecification	Many distinct cues point towards performing one particular action
Perceptual Underspecification	Not enough perceptual information exists to identify the proper action to perform
Perceptual Specification	Ideal situation: direct relationships exist between perceptual cues and specified actions
Perceptual Misspecification	Perceptual information does not map to any specific action

Perceptual underspecification of action is the second level of agreement that may exist between the models. In this case, not enough perceptual information exists to identify to the user the proper action to perform. This situation often occurs when the user must decide between actions based on what is remembered, not what is presented on the display interface. In addition, beside information concerning the past system states, the display may not provide cues indicating future states. When these situations exist, the user must formulate models of the system in order to successfully interact with it. These often take time and much effort to construct. As a result, the skill acquired from them only surfaces after considerable learning. Incorporating memory aids and/ or predictor displays are possible means of remedying such underspecification.

The third type of agreement is *perceptual specification of action*. This agreement is the ideal situation. Here, direct relationships are fostered between the presence of perceptual cues and the specification of actions. As a result, skilled performance arises without the user requiring significant learning or other cognitive demands.

The final situation that may occur is *perceptual misspecification of action*. This situation is characteristic of when perceptual information does not map to any specific action. In these circumstances, skilled performance is not solely guided by perceptual information. Effective performance requires the user to possess some other knowledge which allows him/her to overcome perceptual misspecification. To remedy this situation, the perceptual information must be altered or replaced with action specific information, if possible.

Simply stated, the goal of the ecological task analysis is to identify what perceptual information exists to guide action. Once the levels of agreement existing between the perceptual and action environmental models have been determined and any existing problems diagnosed, possible remedies can be suggested and implemented to alleviate them and any associated cognitive burden. It is the purpose of this research to determine how effectively this goal is accomplished. Does the ecological task analysis framework allow the researcher to determine where problems exist in the display interface? Will it aid in the modification of the display if necessary? Will these modifications actually improve user performance and reduce cognitive burden? These questions are examined in the following chapters in an attempt to determine if ecological task analysis can indeed serve to improve display interfaces and, thus, user performance.

CHAPTER III

THE STAR CRUISER TASK

The effectiveness of Ecological Task Analysis as a display design framework was assessed in the context of a laboratory task known as **Star Cruiser**. This simulation was designed by Alex Kirlik of the Georgia Institute of Technology and Robert J. Shively of the NASA - Ames Research Center and operates on the Macintosh computer. Simply stated, the task involves a user controlling a spaceship through the use of a standard Macintosh mouse. The ship, or Star Cruiser, travels to various solar systems collecting precious commodities. The user is awarded points for each bit of the commodities that are returned to the home port. In a sense, especially from the user's viewpoint, **Star Cruiser** is very much like a video game. From the researcher's perspective, however, this interactive simulation may be used to explore issues involving decision making, skill acquisition, and display design. In this particular case, the research question being investigated is how effective the ETA framework is in display enhancement aiding. What follows is a description of **Star Cruiser** including the various components of the task and the rules which govern the playing of the "game." Also included throughout will be a detailed look at how these elements are displayed to the user while performing the task. Photographs of the Star Cruiser interfaces have been included in Appendix A.

Beginning The Task

To start the simulation once it is ready, the user simply needs to press and release the mouse button. The user will then be able to interact with the task until the session is over. The session will end if either Star Cruiser explodes (discussed below) or if the time allowed expires. The time remaining in the session is displayed in the upper right hand corner of the screen.

Star Cruiser

Star Cruiser Movements

Star Cruiser, a yellow and blue object with "NASA" written on its side, is the ship which the user manipulates during the task (see Figure A-1). The user directly controls the cruiser's flight speed and direction. This manipulation is accomplished when the mouse is used to first place the cursor (an arrow) on the cruiser icon and the mouse button is depressed. Without releasing the button, the user may draw a thrust string, a straight white line, away from the cruiser by moving the mouse. The further the arrow is moved away from the cruiser, the longer the string becomes. The length of the string indicates the amount of thrust applied to Star Cruiser. This length is, however, limited. Therefore, there is a maximum amount of thrust that may be applied to the cruiser. If the string length exceeds this limit, it will disappear from the display. If the user moves the mouse back towards the cruiser, in a sense shortening the thrust string, the white line reappears. The direction the string is drawn is the direction in which thrust will be applied. One may think of this action as the string pointing in the direction that the user wishes the cruiser to travel in. The thrust magnitude and direction as dictated by the thrust string act upon the cruiser when the mouse button is released by the user. If the button is released before a thrust string is drawn or when the string has been drawn too long and has disappeared from view, then the cruiser will not be affected and the user will have to restart the thrusting process.

At the beginning of the task, Star Cruiser has a full load of fuel. This fuel is depleted a certain amount whenever a thrust is applied to the cruiser. The amount of fuel used is proportional to the magnitude of the applied thrust - the greater the thrust, the more fuel that is used. If the application of thrust uses all the remaining fuel, the cruiser will explode and the task session will be over. The cruiser's current amount of fuel is monitored via a "Fuel" gauge. This gauge is located on the upper left side of the display. Initially, the gauge is colored blue. As the fuel level on board the cruiser begins to decrease, the level of the blue bars in the gauge also decreases. Fuel is fully replenished each time Star Cruiser returns to the home port.

The thrust string, it should be noted, is not the only force which will affect Star Cruiser's speed and direction. The gravitational pull exerted by the suns of the solar systems in the galaxy also have an effect. This effect will be explained in greater detail further on in this chapter. Another important point to note is that if Star Cruiser crashes into a sun, the ship will explode and, as with running out of fuel, the session will be over.

Commodities

In order to be successful at this task, the user must be able to load the cruiser with commodities from the different planets and return them to the home port. There are two types of commodities (see Figure A-2). The first is "Data." Data is considered to be any information or non-physical item that a planet may provide. It is represented on the display by a light pink color. The other commodity, "Resources," is represented by a magenta color and may be thought of as minerals, plant life, or any other physical object. Star Cruiser can only transport a limited amount of data and resources. This capacity may be monitored by two bar graphs labeled "Star Cruiser" on the left side of the display. Each graph, one representing the amount of data on board the cruiser, the other resources, is filled as more of each kind of commodity is brought aboard. The data graph filler is colored light pink and that of the resources is magenta. If the user tries to load some amount of data or resources that would exceed the cruiser's capacity, then that amount is lost. Once the user returns the cruiser to the home port, it is unloaded and the bar graphs are reset.

Star Base

The Purpose Of Star Base

Star Base is the Star Cruiser's home port (see Figure A-1). Returning the cruiser to Star Base results in two significant events. Upon docking at Star Base, the cruiser unloads any data and resources it may be carrying. Two gauges, one for each type of commodity, display the total amount of data and resources which have been unloaded from the cruiser during the entire session. Similar to Star Cruiser's capacity gauges, these are also bar graphs which are filled with the commodity's corresponding color. Labeled "Star Base," these graphs are located below "Star Cruiser" on the left side of the screen. It should be noted that the scale for the "Star Cruiser" gauges is such that the gauges are totally full when the cruiser's storage capacity is exhausted whereas the scale for the "Star Base" gauges is such that they are completely full when all data and resources in the galaxy have been collected and transferred to Star Base. The transfer of commodities is indicated on the display by the cruiser's capacity gauges being cleared and the increase in Star Base's gauges. Points are awarded for each unit of data and resources returned to the base. The total score for the session is displayed in the upper right hand corner of the display.

The other event which occurs upon Star Cruiser's docking at Star Base is that the cruiser's fuel is fully replenished. This event is indicated by the fuel bar graph becoming fully blue. Once the cruiser leaves Star Base, the fuel will be consumed with each thrust as described previously.

Docking At Star Base

For the cruiser to dock at Star Base, two important conditions must be satisfied. The first is that Star Cruiser must be located near enough to the base for it to dock. This condition generally implies that the cruiser must be passing over Star Base, or at least crossing over the edge of it. The second requirement which must be met is that the cruiser must be traveling at a slow enough speed. If Star Cruiser is traveling at the proper speed while it passes over Star Base, then it will automatically dock, unload its haul and refuel. Star Cruiser will depart from Star Base only when the user has applied to it a thrust string of sufficient magnitude. This action is the only one which involves the cruiser that the user may perform while it is docked.

Map Views

During the task, the user is presented one of two different displays. The first display, or view, is of the entire galaxy. This view is the same as at the start of the simulation and is referred to as the "global" map. The other view displays the contents of a particular solar system and can be thought of as a "local" map.

Global Maps

The global map shows the entire galaxy including the locations of Star Cruiser, Star Base, and the solar systems (see Figure A-1). The Star Base appears as a green pentagon with a large white star on it. Its position never changes. The solar systems are identified by their "suns." Similar to Star Base, the suns' positions within the galaxy are fixed. Each sun conveys two pieces of information. The size of the sun indicates the amount of gravitational pull it exerts. The larger sizes exert greater force. As previously mentioned, this force will act upon Star Cruiser, thus affecting its speed and direction of flight. The sun's color informs the user of the amount of commodities contained within that solar system. Based on the number of planets in each system, those systems which contain the highest percentage of possible commodities are assigned the brightest suns. There are five different colors which may be used. They range from yellow, the brightest, and increase in redness until the final color of dark red.

Global maps also present the user with one other piece of information. At the start of the task, the only clue as to the contents of the solar systems is the color of their respective suns. Once a solar system has been visited, though, the amount of data and resources contained within it are displayed on the sun in the global map in the form of pie graphs. Each "full pie" is divided into halves, one for each type of commodity. The left half corresponds to the data content and is colored light pink accordingly. The right side is assigned to the resources and is magenta in color. Each half is divided into discrete fourths to represent the possible amount of data or resources that the solar system may possess. For example, if the system contains anywhere from 51% to 75% of the possible total amount of data, then three-fourths of the left side pie half will be filled in. If on the other hand, if it contains greater than 75% of the total amount, then the full half would be colored. If no pie pieces of a particular color are present, then that solar system does not contain any of that particular commodity.

Local Maps

A local map (see Figure A-2) of a solar system is displayed automatically whenever Star Cruiser travels near its respective sun in the global map. (Therefore, the ship will only crash into a sun in the local view). The global map automatically returns when the cruiser travels beyond the screen boundaries of the local map. When the local map appears, the display shows the system's sun located in the center of the screen.

Orbiting around the sun are anywhere from zero to six planets. There are eight possible orbits where Orbit #1 is closest to the sun. Each orbit can only have one planet.

There are two types of planets which may be present. A solar system may contain any number (up to a total of six) of each. The two types are identified by their colors - blue and green. Blue planets cannot "support life" whereas green planets can. The significance of this distinction will be explained later. As with the suns in the global map (once a solar system has been visited), the planets also show pie pieces. These, however, show the amount of data or resources contained on the one planet. The pie charts work the same way for both the color of the pieces and the amount of the pieces displayed.

Similarities Between Maps

Regardless of whether the user is viewing a global or local map, there are some items which are always displayed. The gauges depicting Star Cruiser capacity, Star Base contents, and fuel are always present in both maps. Additionally, the user's score and the time remaining in the session are also visible in either map. The tools (these probes, satellites, etc. will be discussed later) available to the user during the task are constantly present as well.

Tools

To assist the user in performing the task required in **Star Cruiser**, tools are provided. These instruments are displayed at the top of the screen in both local map and global map modes (see Figure A-1 and A-2). There are five tools with which the user can perform several different functions. The tools are, in the order that the are displayed on the screen from left to right: probes, satellites, science ships, robot miners, and miner ships. All but the first are instrumental in the collection of data and resources.

Collection Tools

To use any of the collection tools (all the tools except for the probes), the user must first place Star Cruiser in orbit around a solar system's sun (see Figure A-3). In order to accomplish this task, the cruiser must be present in a local view of some solar system. Like the docking process mentioned earlier, two conditions, speed and location, must be satisfied for the cruiser to orbit the sun. First, the cruiser must be traveling at a slow enough speed so that the "pull of the sun" will automatically place it in orbit. Of course, the cruiser will only enter orbit if the second condition, proper location, is met. Star Cruiser will orbit around the sun in the ninth orbit. Therefore, if it is traveling at the proper speed as it intersects the ninth orbit, the cruiser will go into orbit. Once Star Cruiser is in orbit, it will continually revolve around the sun without any assistance from the user. The cruiser will also become highlighted with a green outline indicating to the user that it is, in fact, in orbit.

Once Star Cruiser is in orbit, the user may deploy any of the collection tools. The tools are used to gather the data and resources from the planets and transfer these commodities to the cruiser. To deploy a tool, the user must first select it from the top of the screen by placing a mouse controlled arrow over the desired icon and clicking the mouse button. The tool will change color indicating that it has been selected. The next step in deploying the tool is to place the arrow over the orbiting cruiser and press down on the mouse button. While still holding the button down, the user can now deploy a tool by drawing a deployment string from the cruiser to one of the planets. Unlike a thrust string which has limited length, the deployment string has the capability of reaching any planet within the solar system. When the arrow is over the intended planet, the user must release the button. If the user is successful at "hitting the target," the icon will be seen traveling from the cruiser to the planet where it will be displayed next to the lower right-hand corner of the planet. The associated tool icon will also disappear from the selection bar at the top of the screen. The user is provided with a limited number of tools. If the planet is missed, then the user must simply click on the cruiser once more and try hitting the planet again. If, however, the user is unsuccessful at clicking on the cruiser, the tool must be selected again in order to deploy it. When the cruiser is missed, the tool icon will revert back to its original color to indicate to the user that it is no longer selected.

There are rules which govern the deployment of the collection tools. Each tool collects a certain type of commodity, has restrictions on which planets it may be deployed to, and behaves differently once it is deployed.

Satellites. Satellites collect data (light pink) from planets. They may be deployed to either the life-supporting (green) planets or those that do not (blue). Once a satellite is deployed, it will remain at the planet collecting all possible data until the user returns it to the cruiser.

Science Ships. Like satellites, science ships collect data. Whereas the satellites are strictly mechanical in nature, the science ships may be thought of as being manned ships. Therefore, they may only be deployed to the life-supporting green planets. Another difference between the satellites and the science ships is that after the science ship is finished collecting data from one green planet, it will seek out another which also contains data. If one is found, the ship will automatically "jump" to that planet and begin adding its data to what was already collected. If no other data-rich planets are present, the tool will remain at the last planet it collected data from until the user returns it to the cruiser.

Robot Miners. Robot miners collect resources (magenta) from the planets. With this exception, they behave similarly to the satellites: they may be deployed to either type of planet and they will only collect from one planet.

Miner Ships. Miner ships are manned ships which collect resources. Since they are manned, they, like the science ships, may only be deployed to the green planets. A miner ship will jump, in the same fashion as a science ship, from green planet to green planet continually collecting resources until no others exist or until the user returns it to Star Cruiser.

The user is not limited in the number of tools deployed in any one solar system. In addition, more than one tool can be deployed to the same planet. For example, two satellites can be deployed to the same planet, a satellite and a science ship can both be sent to a green planet, or a robot miner and a satellite can both collect commodities from the same planet. If multiple tools are deployed to the same planet, they will all be displayed in the same position next to the planet, thus overlapping one another. The displayed icons flicker, however, letting the user know that more than one tool is located there. In addition, if multiple tools of the same type have been deployed to the same planet, they all will collect the appropriate commodity. Once a tool has been deployed to a planet, it will automatically start the collection process. The user can watch as the pie pieces representing the data or resources on that planet begin to disappear. This disappearance indicates to the user that the tools located at that planet are indeed collecting the data and/or resources. The same holds true for the pie pieces displayed on the suns in the global map. The absence of a pie piece indicates that all of that type of commodity has been collected.

The collection tools will continue to collect as much data or resources as possible unless the user intercedes first. At any time, right after deployment, in the middle of the collection process, or once all possible data or resources have been collected, the user may retrieve the tool back to Star Cruiser. Retrieving a collection tool transfers any data or resources that it may have collected from the planet(s) to the cruiser. In order to retrieve a collection tool, Star Cruiser must again be in orbit. If it is in orbit in a solar system where tools have been deployed, the user needs only to click on the collection tool desired for retrieval without releasing the mouse button. A retrieval string can then be dragged to the cruiser where the button is then released. (Note that this process is merely the deployment process in reverse.) If done properly, the user will witness the tool returning to the cruiser. It will then take its original place back at the top of the screen and, if anything has been collected, the appropriate Star Cruiser gauge will increase. The tool may then be deployed once again. If multiple tools have been deployed to a single planet, their order of retrieval will be the same as their displayed order at the top of the screen from left to right (satellites, science ships, robot miners, miner ships). As mentioned previously, Star Cruiser has a limited storage capacity. If a retrieved tool contains more data or resources than the cruiser can hold, all of that gathered commodity is lost. In addition, the user loses the service of that tool for the remainder of the session. This loss is indicated by the appearance of the tool icon at the top of the screen with a yellow 'X' over it.

The user is not required to wait for the collection tools to finish gathering the data and/or resources before doing anything else. If so desired, the user may visit other solar systems to either begin collecting commodities or to gather what has already been collected. If Star Cruiser's capacity is near full, then the user may want to dock the cruiser at Star Base in order that more data and resources may be collected. What the user decides to do is dependent upon his or her particular method for performing the task. It is important to remember, however, that it is permissible for the user to leave the solar system after deploying tools. Star Cruiser, though, must first be taken out of orbit. This task is accomplished by applying thrust to the cruiser. If its magnitude is great enough, Star Cruiser will break out of orbit and head in whatever direction the string was drawn. The thrust string may only be drawn if none of the tools have been selected for deployment. Otherwise, a deployment string will be drawn. Similarly, if a tool is not selected, any strings drawn from the cruiser will function as a thrust. The user always has the option of having Star Cruiser return to a previously visited solar system since the deploying and retrieving of collection tools can only occur if the cruiser is in orbit in the system of concern.

Probes

Probes are the rocket-like icons displayed first in the tool selection bar at the top of the screen. Unlike the other tools, they are not used for gathering data or resources. Instead, their function is to transmit information about the solar systems back to Star Cruiser. The probes' method of deployment is slightly different as well. The key variation is that the cruiser does not need to be in orbit for a probe deployment to occur. The user may perform the action in either the global or local maps. Like the collection tools, the user must first select a probe for deployment from the top of the screen. Then, after clicking on the cruiser, a deployment string is dragged to the sun of the solar system in which the probe is to be sent, rather than to a planet. If the current display is the global map, the user will see the probe icon move to the selected sun where it will be displayed next to it the lower right-hand corner. This indicates that a probe has been deployed to that solar system. If the local map is displayed, the probe will be seen orbiting the solar system's sun in the ninth orbit ring. (Note: The users are not informed of this fact since this orbit is the same as Star Cruiser's orbit. If told, the users would be more likely to use the probe to locate the ninth orbit for the purpose of placing the cruiser into orbit. This "trick" was left to the user to discover.) The process of retrieving a probe is the same as for the other tools: the cruiser must be in orbit in the proper solar system.

Deploying a probe to a solar system has the same effect as visiting it with the cruiser. Upon arriving at a system, the probe reveals the amount of data and resources contained within it by displaying the pie pieces on the sun in the global map. In addition, the user now has the means to "look into" the system without having to actually visit it with the cruiser. When viewing the global map, if the user clicks on the sun of a solar system where a probe has been deployed, the local map of that system will be displayed. The user, however, will not be able to perform any actions within that view since the cruiser is not present. Clicking on the sun in the local map will return the display to the galaxy view. This process will also work for those solar systems that were previously visited by the cruiser, even if a probe has not been deployed to them. Basically, this "looking into the solar system" may be performed on any suns which have been visited or probed at any time.

Switching Between Maps

The user has the ability to switch to a local map from the global as Star Cruiser travels through the galaxy. The user at times may also switch from a local to a global map. In order to do so, the cruiser must be in orbit in some solar system. By clicking on the sun in a local map, the display will switch to the global map. The Star Cruiser icon will be displayed next to the sun of the solar system where it is currently in orbit. Again, since the cruiser is not actually located in the global map, no other actions, with the exception of switching between maps, can be performed. After switching to the global map, the user has two options. One is that the user may switch back to the local map of the solar system which contains Star Cruiser by clicking on the appropriate sun in the galaxy view. The other choice is that, if other solar systems have been previously visited or probed, the user can view one of them by clicking on their corresponding sun. Clicking on the sun in the local view will return the display to the global map. This ability to switch between maps is useful in identifying the contents of various solar systems without having to direct Star Cruiser to actually visit them. The user must remember though, that other actions may only be performed when operating in the same view as Star Cruiser.

Scenario Files

Scenario files act as an initialization file which creates the galaxy. The number of solar systems in the galaxy, the number and types of planets in each system, the amount of data and resources on each planet, the amount of each tool initially available to the user, and the locations of the solar systems and Star Base can all be manipulated by the researcher through the scenario files. The files also allow certain task parameters to be varied. Examples of these include the number of points awarded for the data and resources, the fuel consumption rate, and the time given to perform the session. Appendix B lists all parameters that may be adjusted in the scenario files.

CHAPTER IV

AN ECOLOGICAL TASK ANALYSIS OF THE STAR CRUISER TASK

An ecological task analysis was performed on the **Star Cruiser** simulation. Three experienced users were created by having them continually practice the game until no further improvements in their overall score were detected and, thus, had reached a maximum plateau (this occurred after approximately 20 sessions). These users were then videotaped while playing Star Cruiser. Verbal protocols and written questionnaires were also given to the subjects. Reviewing these three items for each subject revealed the methods for performing the task that the experienced operators employed. As a result, the **Star Cruiser** simulation was broken down into the following tasks:

1. Deploy Collection Tool
2. Retrieve Collection Tool
3. Deploy Probe
4. Retrieve Probe
5. Place Star Cruiser Into Orbit
6. Remove Star Cruiser From Orbit
7. Dock Star Cruiser At Star Base
8. Release Star Cruiser From Star Base
9. Change View To Galaxy/Solar System Map

Each task was analyzed and described in terms of whether or not perceptual cues existed to indicate the availability of the actions comprising the task.

Deploy Collection Tool

Only under certain conditions may a user deploy one of the four collection tools: satellites, robot miners, science ships, and miner ships. Star Cruiser must be in orbit around a sun which also has orbiting planets. In addition, the user must be viewing the local map of that system. If the user wishes to deploy either a science ship or a miner ship, then planets which support life, green planets, must also be present in the solar system.

Each subject possessed a different method for determining where and when to deploy collection tools. One subject, for instance, would first send out science ships and miner ships whenever possible before satellites and robot miners. Her method was to collect as many commodities as possible as quickly as possible. She viewed the collection of data and resources using the science ships and miner ships to be quicker since she would not be required to make as many deployments. She, more than any other subject, appeared to have the greatest difficulty with performing the necessary tracking task required to deploy the collection tools.

Another subject would normally deploy only satellites and robot miners since these did not move from planet to planet and she was thus better able to remember how much data or resources each tool had collected. Only if one green planet was present would she then send out a science ship or miner ship. This means of operating the task was developed in order to reduce the risk of a science ship or miner ship collecting to much data or resources and thus overloading the cruiser when it is retrieved. The subject would also deploy as many tools as she had available, even if the cruiser would not be able to carry all of the gathered data and/or resources. It was her reasoning that she could always return to the system after unloading Star Cruiser at Star Base and retrieve the remaining tools.

A third subject had yet a different method for deploying collection tools. He, like the first subject, would deploy science ships and miner ships first. Unlike the first subject though, this subject would send out multiple science ships and miner ships to speed up the collection process even more. This subject differed from the other two in that, after retrieving the other tools, he would deploy satellites and robot miners to other planets to collect a fraction of their data and/or resources. His method for this task focused on returning to Star Base with Star Cruiser as fully loaded as possible whereas the other subjects were content with the cruiser not being as full. He usually did not leave tools in the solar system once he had the cruiser leave. There did seem to be one bit of methodology that all subjects had in common though. In deciding where to send a collection tool, the subjects generally did not send more than one data collecting tool (satellite or science ship) or resource collecting tool (robot miner or miner ship) to the same planet.

The fact that all subjects had differing methods for performing this task serves as evidence to the lack of perceptual cues that exist for aiding the users in deciding when and where to deploy the collection tools. If these cues were present to indicate when to perform the action, then there would most likely be more similarities between each subject's method. This theory is illustrated by the subjects' common attitude that if a tool is already collecting one type of commodity from the planet, then no other tool which collects a similar commodity should be deployed to that planet. A cue does exist for this situation even though it is informing the subjects not to perform the action rather then to do so. When a collection tool is deployed to a planet, it is displayed next to it. Therefore, the user can see which tools have been sent to which planets. As a result, the user knows that the deployment of any other tool to that planet (which collects similar commodities) is essentially pointless since the tool presently there will collect all the data or resources that the planet contains. The only benefit that deploying another tool which collects the same type of commodity to that planet would possibly serve is that the tools would gather equal amounts of the available commodity. As a result, one tool will be less likely to transport too much of the commodity back to the cruiser, and thus overload it, once it is retrieved. This benefit never seemed apparent to the subjects since they were not observed performing an action of this type. The absence of this type of action is mostly likely due to the lack of cues that would inform them of how much each tool has collected, let alone whether this action was even possible.

None of the subjects appeared to have difficulty determining when the deployment of tools could be performed. The subjects were instructed during their training about the conditions that must be met to perform this action. With this knowledge, they were able to recognize easily when the conditions were satisfied. Perceptual cues, such as Star Cruiser being highlighted upon reaching orbit, the absence of the cruiser and/or the planets when the subjects were looking at a view of the galaxy or another solar system, and whether any planets were present in that solar system at all, also provided the necessary support in determining when the action could or could not be performed. The fact that the tools were always present at the top of the screen, thus appearing as if they could be selected even when they could not, did not cause the subjects any difficulties. If, for some reason, they tried to select one of the tools when that action could not be performed, they would soon discover that their attempt was not allowed due to their failure to do so. Overall, the cues were successful at specifying the availability of the action.

There was, however, one area of underspecification. Though they knew they could perform some type of deployment, the subjects had problems determining which tools should be used to collect which commodity and which type of planets they could be sent to. Most of the subjects apparently were successful at memorizing the differences between the tools. There was one subject though, that had difficulty throughout the sessions. The tools themselves provide no cues as to what they do. They are not coded in any fashion whether it be, for example, color, size, or location (at the top of the screen where they may be selected). Some form of cue should be incorporated into the display to assist the user. Successful implementation of such cues should result in the user's reduced confusion concerning each type of tool's functions and constraints as well as reducing their need to rely on memory to determine them.

Deploying collection tools was consistently regarded as one of the more difficult actions to perform. Though much of this difficulty was attributed to the tracking task involved, some of the blame can also be placed on the amount of mental effort the subjects had to use to accomplish the action. This reasoning is suggested by the subjects considering this action to be slightly more difficult than that of retrieving a tool which essentially incorporates the same type of tracking task. The subjects had to remember to which type of planet each tool could be sent as well as what each collected. Even more difficult though, they had to determine exactly to which planet to send a tool. This decision often required the subject to consider the amount of data or resources available on that planet (indicated by the "pie pieces" displayed on each), the amount currently on board Star Cruiser, the amount of data or resources being currently collected by other tools, whether the deployed tool would move from planet to planet, and how much time was left in the mission. Though much, but not all, of this information was presented to the subjects in one form or another, they were required to interpret each bit and relate each piece of information to the others in order to make a decision. This process was often quite complex and thus it is understandable why this action was considered to be so difficult. Ensuring the proper presentation of information by the current perceptual cues, along with the introduction of new cues, should help to make this action an easier one for the users to perform.

Retrieve Collection Tool

In order to retrieve collection tools, similar criteria to that for deploying the tools must be satisfied. This criteria includes viewing a solar system where Star Cruiser is in orbit. The only difference in the criteria is that, in that solar system, tools deployed earlier must still be located at the planets.

Subjects generally used criteria similar to each other in determining when it was, and was not, appropriate to retrieve a collection tool. The subjects would retrieve a tool if two conditions were satisfied. The first is that the tool had finished collecting all of the data or resources that were available. The other was that there was room aboard the cruiser to carry the collected commodities. The remaining time left in the mission also played a role in determining if a tool should be retrieved or abandoned so that the cruiser could return to Star Base with what was already on board.

The subjects had very little difficulty in determining when they could perform this action. Cues were present and noticeable to indicate when a tool could be retrieved. As in deployment, the highlighting of Star Cruiser once it is in orbit informs the user that that portion of the criteria has been satisfied. In addition, the subjects knew which tools could be retrieved due to them being displayed next to a planet in the solar system. Confusion does exist, however, in determining which tool will be retrieved first when multiple tools are present at the same planet. Since their displayed icons overlap, there is no apparent cue to indicate which tool will be retrieved first when the user selects one. In order to overcome this lack of information, the subjects were instructed that the order of retrieval was identical to the order, from left to right, of collection tools displayed at the top of the screen. It was observed though, that even with this knowledge, the subjects would attempt to retrieve one tool from a planet containing multiples, and inadvertently retrieve the wrong one. As a result, they would usually retrieve the correct tool and then deploy the one that was incorrectly brought back in order to finish collecting the available commodity at that planet. This problem could be avoided by simply locating each type of tool in a different position around the planets. With this exception, the availability of this action was generally well perceived by the subjects from the existing perceptual cues.

The ease in deciding whether or not to perform this action was variable throughout the mission. It greatly depended on the second of the two criteria mentioned earlier - how much data or resources Star Cruiser currently had on board. If the cruiser was empty, then sufficient perceptual cues existed to suggest to the user that a tool should be retrieved. The fact that the tool had completed collecting all possible commodities would be indicated by the disappearance of the "pie pieces" which show how much data or resources is present on the planet. Since the gauges which convey how much collected commodities Star Cruiser contains would be empty, the user would know that retrieving a tool was more than likely an appropriate action to perform. As Star Cruiser contained more and more commodities though, the decision to retrieve a tool became more and more difficult. Even though the user could still readily determine if the tool had completed its collection task, insufficient cues existed to inform the user whether or not the commodities collected could be safely loaded onto the cruiser. The problem is that no direct relationship exists between how much of the commodities, represented by the pie pieces, is collected and how much the gauges indicating the cruiser's load will increase once those tools are retrieved.

Unless it was learned exactly how many pie pieces completely loaded the cruiser (which two subjects did learn over twenty sessions according to discussions with them), the user would never be quite sure how much additional data or resources can be brought onto the cruiser before it exceeded capacity. Even when it was learned that, for example, three full planets completely loaded the cruiser, difficulties still arose when the subjects were forced to deal with planets which contain only a fraction of their total capacity of commodities. This problem was compounded further by the pie pieces for two reasons. One is that the same size pie piece represented a range of amount of data or resources. For example, a half of a pie piece (one full pie piece equals one half the size of the planet) of data could represent between one-fourth and one-half of the planets capacity for a type of commodity. There is no way to determine the exact amount. Contributing even more to the problem is that the gauges indicating the cruiser's current load merely present qualitative information - how full is Star Cruiser. As a result, it is also difficult to determine exactly how much data or resources the cruiser already contains as well as how much the gauges will increase by collecting a certain size pie piece. The second reason is that the pieces will disappear as the commodity is collected. Though this disappearance serves as a good cue indicating when the collection process is complete, unless the user remembers how big of a pie piece was present before the tool was deployed to the planet, there is no way for the user to know how much data or resources the tool has collected. This fact is especially true for science ships and miner ships which can visit multiple planets before being retrieved. This situation is an even greater problem when the user has done something (i.e., returned the cruiser to Star Base) which results in the viewing of the galaxy or another solar system.

The goal of the user is to collect as many commodities as possible and return them to Star Base. As a result, this action of retrieving collection tools is one of the most crucial. The users' success at completing their mission ultimately depends on their ability to make good decisions concerning when to retrieve a collection tool. The display should be designed to aid the decision-making process, not hinder it. Therefore, enhancements should be made to the current display in order to improve the users' chances of success. Creating gauges and pie pieces which have direct relationships to each other is one such improvement. Others may include memory aids which will help the users remember exactly how many commodities have been collected by a tool. Warnings can also be incorporated indicating when Star Cruiser has reached near capacity or even when the retrieval of a particular tool will overload it. These are just some of the possible enhancements which can assist the users in deciding when to retrieve a tool. As a result, not only should the users' performance of this action improve, but so should that of their overall mission as well.

Deploy Probe

A probe may be deployed at any time except for when Star Cruiser is docked at Star Base. Deploying probes has no effect on points or fuel consumption and can therefore be done without great effect on the system states. Subjects used the probes to obtain information concerning ninth orbits and solar systems' supply of commodities.

When determining to which solar system to send the cruiser, subjects would dispatch probes to the systems, usually those with the brightest suns, under consideration. They would then be allowed to view the planets in those systems and ascertain the amount of commodities available for collection in each. The only benefit this feature served was to help choose which system to go to amongst those with the brightest suns. However, other factors often contributed to this decision as well. Proximity to Star Cruiser, the closeness of neighboring solar systems (subjects' methods sometimes involve collecting data from a grouping of solar systems), and the remaining time in the session often served as determinants in deciding which solar system to enter first.

As mentioned, probes were also used to locate the ninth orbit around a sun. Subjects used their knowledge of the probe's orbit path to help locate the proper orbit for Star Cruiser. This use of the probe was not necessary at all times since other cues exist to help find the proper orbit (refer to <u>Move Star Cruiser into Orbit</u>).

These reasons for deploying probes are driven by the subjects' desire to obtain additional information about the galaxy. There are no cues that the subjects perceive which cause them to perform this action. In other words, the need to perform this action is only inferred by the subjects, no information is given instructing them to do so. Perceptual cues, however, currently exist to provide all the same information to the subjects (i.e., sun color, planets orbiting near the ninth orbit). As previously stated, the only time that probes may not be deployed is when Star Cruiser is docked at Star Base. There are no perceptual cues, though, that inform the subjects of this constraint. Only their inability to do so suggests to the subjects that a probe cannot be deployed at that time. Also, the only cue that exists to indicate that a probe has been selected for deployment is when the user has highlighted one at the top of the screen. This lack of cues poses a problem, however, when Star Cruiser enters a solar system while a subject is attempting to perform this action. On two separate occasions, with two different subjects, this problem resulted in Star Cruiser crashing into the sun. The subjects selected a probe to deploy while Star Cruiser was in the galaxy view. During this process, the cruiser drifted into a solar system. The subjects' initial, and only, reactions upon seeing Star Cruiser drifting towards the sun was to apply a thrust to the cruiser away from the sun. The probe, however, was still selected for deployment. Therefore, the only actions the subjects could do successfully would be either to pull a string from Star Cruiser to the sun to deploy the probe or to unselect the probe. Since the subjects were concerned solely with applying a thrust to the cruiser away from the sun, they did not realize that they had to perform one of the other actions first. As a result, the thrust was not applied to Star Cruiser and it crashed into the sun. Though their inability to perform the desired thrust action serves as a cue, it is embedded too deeply within the structure of the interface to be of use. The subjects simply feel that the applied thrust was not great enough to overcome the sun's gravitational pull and they continually try the action again. Some other form of cue is required in this situation to indicate to the subjects that they are performing an action unsuccessfully and that they should attempt another. The cue must serve to enlighten the subjects that their intended action is one that is not readily available.

Overall, there is no special need to use perceptual cues to inform the user when to deploy a probe. Most information that can be gained by doing so is present at all times. Cues that exist, though, at the depth structure level, especially those which indicate that the user needs to unselect a probe to perform a thrust, need to be brought to the surface. In addition, perceptual cues should indicate to the user when it is possible to deploy probes.

Retrieve Probe

A probe may only be retrieved when Star Cruiser is in orbit in the same solar system as the probe and the current view is of that system. If these conditions are met, then the user may select the probe and draw a line back to Star Cruiser to retrieve it. Retrieving a probe has no effect on fuel consumption or points and can be time consuming. The only benefit is that the user now has an additional probe which may be deployed. Therefore, if the user determines that enough probes are present on board Star Cruiser to complete the session, then there is no reason why a probe should be retrieved at any time. This observation agrees with the methods used by most of the experienced subjects. One subject would, however, retrieve a probe while Star Cruiser was waiting for the collection tools to finish gathering commodities from the planets.

His reasoning was that since Star Cruiser has visited the solar system, the amount of commodities present will always be displayed on the sun in the galaxy view. Therefore, depending on the availability of other probes for deployment, he may retrieve the probe while waiting for the collection tools to finish gathering commodities. His decision to retrieve the probe was also dependent on his confidence in being able to locate the ninth orbit if he ever returned to the same solar system in the future. Of course, if all commodities have been gathered from the planets in that system, then there will be no need to ever return.

Though there are no perceptual cues on the display which indicate that this action should be performed, the user may determine to select this action based on the number of probes displayed along the top of the screen. Whether or not a user will retrieve a probe will ultimately depend on whether or not it is felt that it will be used again. Currently, only the user's determination of certain criteria, the time remaining and where the cruiser should be sent in that time, will contribute to the decision to perform this action. As with the subject discussed previously, there are those who do always retrieve the probes though, if, for nothing else, to practice the task of retrieving an object. Because of this action's insignificance to the overall mission goal (collect commodities and return them to Star Base), it is probably unnecessary to incorporate cues which directly inform the user that a probe should be retrieved.

Perceptual cues which inform the user when this action can be performed are also lacking on the display. Though subjects had very little difficulty with determining when a probe could be retrieved, there does exist the potential for some confusion. Since a probe may be deployed at almost any time, the risk exists that a user may think that it can be retrieved at almost any time. This line of reasoning is further supported by the fact that in the galaxy view, the deployed probes are pictured next to their corresponding solar systems. Though this bit of information may be helpful in determining where the probes are located, it can also cause the user to elect to perform this task as a result of the misleading cue. To avoid the misspecification between the cue (displayed probes) and a possible action it may indicate (can retrieve the probes), the cue should either be altered or eliminated regardless of the fact that the user's inability to retrieve a probe may indicate the use of an improper retrieval method. The key here is not to correct the user once the mistake is made, but to prevent the mistake from being made in the first place.

A user may relate the retrieval of a probe to that of a collection tool. This reasoning would then serve as a cue to the user: since a tool may only be retrieved while Star Cruiser is in orbit, the same belief may be had for the probes. Though this belief would be correct, the users should not be subjected to the burden of learning it for themselves. This similarity between retrieving the tools and the probes should be evident from the display itself. Taking all into consideration, for the display to contain proper cues, it must not only inform the user of when the probes can be retrieved, but it must not mislead the user into thinking they can be when they truly cannot.

Place Star Cruiser Into Orbit

Star Cruiser will achieve orbit around a sun if it passes through the sun's ninth orbit at a slow enough speed. Thus, the user must place the cruiser in the solar system view which contains the sun to be orbited.

Subjects shared a similar reason for wanting Star Cruiser to obtain orbit: to deploy collection tools. Unless they had taken the cruiser out of orbit while tools were collecting commodities, the subjects generally did not try to place the cruiser into orbit for the sole purpose of retrieving collection tools or probes. If a subject made the decision to retrieve a probe, it was only while Star Cruiser was already in orbit.

Only previous instruction lets the user know that orbit must be obtained. Since it is known that Star Cruiser must be in orbit in order to perform any actions regarding the collection tools, once the decision has been made to deploy or retrieve a tool, the user knows that the cruiser must be placed in orbit. Thus, in a sense, those cues which aid the user in deciding whether or not to deploy or retrieve tools (i.e., presence of pie pieces on planets; absence of planets) also serve as cues to put the cruiser into orbit. There is, however, no direct mapping between the desired action of deploying or retrieving a tool and the necessary means for doing so such as first obtaining orbit. As a result, those users who do not receive instructions prior to attempting a mission may try to deploy a tool while the cruiser is not in orbit. Of course, their failure to complete this action will indicate to them that something is wrong, but they would most likely be unable to determine what.

Assuming that the user knows that Star Cruiser must be in orbit to perform actions on the collection tools, very few perceptual cues are required to indicate the availability of the action. Knowing that the ninth orbit must be located, the user generally realizes that only in a view of a solar system may this action be attempted. Thus, once the cruiser moves into a view of a solar system, no other requirements must be met in order to attempt this action.

The difficulty concerning this action, according to the subjects, was not in determining when to perform the action nor if the action could be performed. It was in performing the action itself that presented the most trouble. The subjects often complained about how hard it was to locate the ninth orbit, let alone get Star Cruiser moving at the proper unknown speed so it would automatically place itself into the orbit around the sun. As a result, they were often required to continually adjust the cruiser's direction and speed until the cruiser reached orbit. This process proved to be a frustrating one which often wasted valuable time. Regarding the speed, there are no cues whatsoever which would indicate to the user that the cruiser has the proper velocity for obtaining orbit. Only upon seeing the cruiser obtain orbit (Star Cruiser is highlighted) will the user learn what the proper speed is. The user, however, usually has difficulty remembering what the speed was, or duplicating it. This difficulty is because the user is required to match it to a pictorial representation of the cruiser's movements. No quantitative information is provided. There are several cues, though not intuitive, which may be utilized in locating the ninth orbit around a sun. The first is to use the planets as a guide. Eventually a subject will learn that the furthest orbit for a planet is one less then that of the cruiser. This bit of knowledge allows the user to approximate the ninth orbit's location based on the orbits of the existing planets. Another cue that may be learned over time is that the orbit is elliptical in shape. The user can then "picture" the path that the orbit takes at a certain distance from the sun and attempt to have the cruiser intercept that pictured path. A third method for finding the orbit, one consistently performed by several of the subjects, is to dispatch a probe in the solar system where the cruiser is to obtain orbit. Learned through practice, the users soon realize that the probe travels around the sun in the ninth orbit. This "trick" allows the user to deploy a probe to identify the orbit which can then be easily located while attempting to place the cruiser. Though cues do exist to show where the orbit is located, apparently they are not readily perceived by the user unless their existence has been learned.

While the number of cues indicating that this action should be performed, and that it can be performed, might be sufficient, additional cues should be added to assist the user in placing Star Cruiser into orbit. To be effective, the cues would need to alert the user to the location of the ninth orbit. This alert can simply be accomplished by highlighting the orbit in some manner. In addition, some form of a cue should be used to indicate when the cruiser is at the required speed for obtaining orbit. This cue may include, for example, the use of a "speedometer" or changing the color of the cruiser. Without these additions, users will face difficulties as they attempt to place Star Cruiser into orbit.

Remove Star Cruiser From Orbit

This action may only be performed if Star Cruiser is, obviously, in orbit in some solar system and the user is viewing that system. Subjects usually took the cruiser out of orbit only if one of two conditions was met. If all possible commodities had been collected in the system, and all tools had been retrieved, then the subjects removed the cruiser from orbit in order to send it to another solar system or to Star Base. On the other hand, if more commodities could still be collected but there was no additional storage space on board the cruiser, then Star Cruiser was taken out of orbit as well. In this case, the cruiser was returned directly to Star Base.

The number of perceptual cues which would lead the user to perform this action are minimal. When presented with a view of a solar system which is void of tools, probes, and commodities, the user should realize that there is no reason to have the cruiser in orbit. Other cues may also be present which may lead to the decision to remove Star Cruiser from orbit. These, however, do so indirectly since they actually inform the user that another action should be performed (refer to Dock Star Cruiser at Star Base). In order to perform this action, though, the user must first remove the cruiser from orbit . In this case, this cue is satisfactory since the relationship between the two actions (one must precede the other) is an easy one for the user to perceive. The action of removing the cruiser from orbit is easily triggered by the cues which currently exist and, thus, no modifications are necessarily required.

As mentioned before, the user must be viewing the solar system which contains the orbiting Star Cruiser in order to perform this action. If not, then the user's inability to successfully remove the cruiser from orbit serves as a cue that the action cannot be performed. Otherwise, there are no other cues which indicate this situation to the user, nor that the user can perform the action. It was noticed, though, that subjects very rarely, if ever, attempted to remove Star Cruiser from orbit when it was impossible to do so. In addition, whenever they decided to perform the action, they were in a situation which permitted the action. Thus, it appears that whenever the user has decided to remove the cruiser from orbit, no additional cues are required to show the availability of that action.

Problems do arise, however, when the user does not wish to remove the cruiser from orbit, but does so accidentally. Unintentionally removing the cruiser from orbit may occur as a result of the aforementioned lack of cues which indicate when this action may be performed. Several attempts made by the subjects to deploy tools resulted in their accidental removing of Star Cruiser from orbit. When deploying a tool, after selecting it from the top of the screen, the user is required to select Star Cruiser as it is traveling around the sun. If the user is unable to track and select the cruiser properly, then the tool is unselected. The subjects would not realize this occurrence and attempt to select the cruiser again. If successful at the second attempt, since the tool is no longer selected, they would actually be placing a thrust on the cruiser. This thrust more than likely pulled the cruiser out of orbit at an undesirable time. This error was often experienced during the earlier sessions. Even with more practice, the mistake was still made, though not as frequently. The subjects learned that they needed to select the tool again before selecting the cruiser. Some form of cue should be present, however, to indicate to the user when a string from the cruiser will deploy a tool or probe or when it will act as a thrust. In other words, a perceptual cue should be implemented which will inform the user of the availability of this action.

Dock Star Cruiser At Star Base

Star Cruiser can be docked at Star Base if it is moving around in the galaxy and the user is viewing it. The cruiser must be traveling at a slow enough speed as it passes over the base in order for it to dock.

Subjects shared similar lines of reasoning in deciding when to dock the cruiser at Star Base. Any one of three situations would result in the subjects abandoning their current activities and performing the necessary actions that would lead to the cruiser's docking. The main reason people docked the cruiser was when they wished to unload its contents. Some subjects attempted to fill the cruiser as full of commodities as a solar system's planets would allow, while others were satisfied with partial fillings. Another factor which often led to subjects moving the cruiser to Star Base was the time remaining in the session. If the cruiser had some commodities on board and time was nearly expired, the subjects would dock the cruiser as quickly as possible in order to increase their point total. The third factor which compelled people to perform this action was the amount of fuel the cruiser had remaining. Lack of fuel would force subjects to return the cruiser back to Star Base in order to refuel. Essentially, as long as the cruiser had enough cargo space and fuel, the subjects were content with keeping it moving through the galaxy and collecting commodities from the various solar systems.

The availability of this action was usually not questioned by the subjects. Though not often attempted, an inability to maneuver Star Cruiser while it is located somewhere other than the current view provides the necessary cue to the user that the action cannot be performed. Due to the nature of this action though, this cue is not often enough. In order to dock the cruiser at the base, the user may have to, or wish to, perform other actions first. For instance, if Star Cruiser is in orbit, the user must take it out of orbit before the cruiser can be docked at Star Base. Therefore, in some cases, the availability of this action depends on that of others and thus the cues which signify the availability of those other actions become significant. The subjects did not seem to have trouble with this aspect of the docking action. They took into account such relationships between actions and performed them accordingly.

From subjects' performance, there appeared to be several perceptual cues which led them to perform this action, especially when considering the cargo space and time factors. The gauges depicting the amount of cargo space aboard Star Cruiser were often referred to during the collection of commodities. As a result, the status of the cruiser's cargo space was often known. Thus, if the user deemed it necessary, Star Cruiser would be returned to Star Base. The presence of the timer during the mission provided the subjects with the necessary information concerning the time remaining. It too was often checked to determine if Star Cruiser should be returned to Star Base, or if any other actions should even be attempted.

The subjects often ran into difficulty when it came to the third factor. Star Cruiser's fuel level was very rarely monitored by the subjects. As a result, the cruiser would explode, thus ending the mission, much to the surprise of the user. This sequence of events happens even though there exists a fuel gauge monitoring the amount remaining in the cruiser. A possible explanation for the subject not monitoring the fuel level is that while the cruiser is in orbit, the subject is solely concentrating on the collection of commodities. Thus, the only gauges of concern are the cruiser's storage capacity gauges. In addition, since no thrusts are being applied to Star Cruiser, no fuel is consumed and therefore there is no need to monitor the fuel gauge. If the cruiser is not in orbit, then the subjects appeared to be more concerned with steering the cruiser through the solar systems and galaxy in order to avoid from crashing into any suns and/or to make sure it is heading back to Star Base. Very little attention was given to the fuel consumption gauge. Thus, if only a small amount of fuel was present, the subjects were likely not to notice, and after performing several thrusts the cruiser would explode. This behavior occurred frequently whenever the subjects had difficulty controlling the speed of the cruiser. Since no cues exist which convey this speed to the user (refer to Place Star Cruiser Into Orbit), it sometimes took several attempts to get the cruiser traveling at the proper docking speed. Docking the cruiser, of course, may only involve small thrusts, but they can be numerous. As a result again, the cruiser would run out of fuel and explode.

This problem results from the perceptual cues' overspecification of action. Too many cues exist independent of one another. The user is unable to efficiently monitor, identify, or notice all cues. Therefore, the information that is available to the user should somehow be restructured. In doing so though, no additional effort, mentally or physically, should have to be exerted by the user in order to successfully determine when to dock Star Cruiser at Star Base. One possible method for accomplishing this restructuring of information is to reduce the number of independent cues. For example, combining the information presented by multiple cues into one cue should help the user in determining when to perform this action. Whatever the method, though, care must be taken that the modification does not result in the action becoming underspecified, mismatched, or even more overspecified than before.

Release Star Cruiser From Star Base

The subjects considered this action to be the easiest which involves movement of Star Cruiser. Not only is it easy to perform the action, applying a thrust to a stationary object, but determining when to perform the action is simple as well. Unless the amount of time remaining in the mission is so low that nothing can be accomplished or all commodities within the galaxy have been collected, the subjects would remove Star Cruiser from Star Base immediately after it had docked.

Since the users cannot perform any other actions that affect the status of the galaxy while the cruiser is docked at Star Base, they understand that in order to continue achieving their goal of collecting commodities, they need to pull the cruiser away from the base and have it travel towards one of the solar systems. This constraint serves as a forcing function (Norman, 1988) which guarantees the users will perform the action if they are going to better their performance. In a sense then, the requirement to remove the cruiser from the base in order to affect the status of the galaxy is enough to inform the users that they should perform this action. Therefore, no additional perceptual cues are required.

The only time this action would not be available to the user is if the current view is of a solar system. Only when viewing the galaxy is the user capable of removing Star Cruiser from Star Base. In a view of a solar system, though, the cruiser would not even be displayed. Thus, the absence of a displayed Star Cruiser signifies to the user that a thrust cannot be applied to the cruiser to move it away from the dock. Whenever viewing the galaxy, however, the user may easily apply the thrust and pull Star Cruiser away from the base. Since it was apparent that the subjects consistently knew about the availability of this action, no further perceptual cues are warranted.

Change View To Galaxy/Solar System Map

Whenever subjects performed this action, it was to gather information which would help determine Star Cruiser's next movement. With the cruiser in the galaxy view, subjects would select a view of a solar system to assess the amount of commodities available on its planets. Different solar systems would be selected until the subjects determined that one contained enough commodities to justify sending the cruiser there. The cruiser's next movement would then be towards that particular solar system. If the cruiser was present in the solar system, most always in orbit, the subjects often selected the galaxy view in order to determine which side of the system the cruiser should exit from. The subjects who performed this action for this reason found it necessary to do so since the thrusts they applied to the cruiser to break it out of its orbit often sent it flying out of the solar system uncontrollably. Information obtained from viewing the galaxy, such as the location of neighboring solar systems or the location of Star Base, often helped the subjects to either prevent the cruiser from sailing into another solar system and crashing into it's sun or find the shortest route for the cruiser to return to Star Base or to travel to another solar system. Often these alternate views are selected while the subject is waiting for the completion of another action (i.e., tools collecting commodities, cruiser traveling through galaxy, cruiser docked at Star Base).

Though some subjects took advantage of this task in this fashion, some do not. Even though they were told about the option of different views and how to access them, some subjects would not use this feature. This lack of use may be because no perceptual cues are present to inform the user of the action's availability. There is nothing about the display which lets the user know that by selecting a sun in the galaxy map, or the sun in a local map, a different map can be observed. Though there are cues which indicate which solar systems may be viewed (the presence of the pie pieces on the suns), these still do not inform the user that the action can be performed.

Additionally, cues which assist the user in determining when to perform this action are lacking. Only as a result of practice and habit does the user perform this action. And then again, the multiple views are only employed if the user fails to remember the various states of the system. As a result, this action currently does little to help relieve the memory burden placed on the user.

There are essentially no perceptual cues which specify this action. The subjects who did perform it though, generally had an easier time determining where to send Star Cruiser. Therefore, the action has merit and the display should support it. In order to support the action, perceptual cues need to be introduced which will aid the user in determining if and when to perform this action, as well as whether or not the action can be performed.

Summary

The movement of Star Cruiser, as controlled by the users, is determined by a number of factors. These factors include the distance the cruiser has to travel, the configuration of solar systems within the galaxy, the cruiser's amount of fuel, and the time remaining in the mission. All these factors play a vital role in the determination of where Star Cruiser needs to go and how it is going to get there. All of this information is readily available to the user via the display interface. In addition, this information serves as cues which contribute to the decision to perform other actions. Quite often, the user elects to perform an action but cannot, or will not, do so until another is performed. Many of the actions are related through such precedence constraints. For example, a subject may elect to remove Star Cruiser from orbit. As a result, the user might first perform the action of viewing the galaxy to determine the cruiser's destination and exit path and then actual remove the cruiser from orbit. Such relations can be this simple, or they may be more complex. The action of returning commodities to Star Base may involve the user first deploying a probe, viewing the solar system containing that probe, steering the cruiser into that system, obtaining orbit, deploying collection tools, retrieving the tools, removing the cruiser from its orbit (which itself may require multiple steps), steering it through the galaxy, and finally docking it at Star Base.

The user must clearly understand these relations for acceptable performance to be obtained. The perceptual cues within the environment play a significant role in supporting this process. The cues should accomplish two goals. The first is that they should always let the user know when a certain action may be performed. Secondly, if an action is unavailable, then cues should specify to the user what actions need to be performed in order to make the unavailable one possible. This process should repeat until the user is presented with an available action that will help achieve the availability of the original action. Whenever breakdowns in this process occur, then the existing perceptual cues should be investigated and the determination made about whether new cues should be used, current cues should be eliminated, or multiple cues should be combined.

The preceding discussion concerning **Star Cruiser**'s possible actions attempted to accomplish this type of investigation. Experienced subjects were examined to determine when a particular action was likely to be performed. The subjects' abilities to perform these actions were then evaluated. Possible explanations for the ease or difficulty of selecting each action, based on the perceptual support available within the **Star Cruiser** environment, were also offered. As a result, areas of improvement can now be suggested. These improvements should concentrate on improving Star Cruiser's perceptual environment so that, where it failed before, the perceptual guidance available will specify what actions the users should do as well as whether those actions can be performed.

CHAPTER V

PERCEPTUAL ENHANCEMENT OF THE STAR CRUISER DISPLAY

Upon review of the ecological task analysis for the **Star Cruiser** task, two pieces of information concerning perceptual cues become apparent for each task. The first concerns what cues are available to support a user's particular method for performing a task. The second concerns what cues exist to indicate to the user the availability of each task. With this knowledge, one may examine the existing display interface and propose certain changes to it which will help improve overall task performance. Proposed changes to the **Star Cruiser**'s interface are presented below. Possible improvements concerning the nine originally analyzed tasks and other actions which may have surfaced during the task analysis are suggested. After each section is a brief description of the actual change, if any, made to the display interface.

Deploy Collection Tools

Proposed Display Enhancement

An ideal display for **Star Cruiser** would be a display which indicates to the user which tools to deploy as well as when they should be deployed and where they should be sent. This support, however, would most likely require aiding that is beyond the scope of perceptual enhancements (as defined in the context of Ecological Task Analysis). Some problems, however, may be eliminated. One problem was the confusion experienced by the users in trying to remember which tools collect what commodities and which types of planets they may be sent to. Simple modifications can be made to the display interface to help alleviate this problem. This assistance may be accomplished by incorporating color coding into the part of the display where the various tools are located for selection. An example of such coding would include outlining the tools with the same color as the type of information that they collect. The background behind the tools can also be changed to match the color of the type of planets the tools can visit. These changes should help to reduce the confusion that users, especially novices, may experience. An additional enhancement that may be made to the display is to dim the tools available for selection whenever it is impossible for the user to do so. Though whether or not a tool could be deployed was very rarely an issue for the users, the possibility of confusion does exist and this change should help prevent such a problem from arising. Display enhancements concerning this task are also discussed in <u>Determining Star Cruiser Mode</u> which occurs later in this chapter.

<u>Actual Display Enhancements</u>

Several enhancements were made to the display interface to support this task. The first involved drawing some of the collection tool icons on a colored field (see Figure A-4). The science ships and miner ships, the two collection tools which can only be deployed to life-supporting planets, were placed on a green field, the same color as the life-supporting planets. This change was done to indicate to the user that the science ships and miner ships could only be deployed to the green planets. The other collection tools were left unchanged in this regard since there are no restrictions on where they may be sent.

Background colors were added to the collection tools in order to indicate which type of commodity, data or resources, each tool gathered (see Figure A-4). The satellites and science ships each possess a light pink (to represent data) background while the robot miners and miner ships both have magenta (to represent resources) backgrounds. These colors are the same as those used to identify the presence of data and resources on the planets. This similarity should then aid the user in determining which collection tools should be deployed in order to gather a particular type of commodity present on the planets.

A third enhancement involved crossing out the collection tools whenever they could not be deployed, such as when the cruiser was not in orbit. A yellow 'X' was placed over the tool icons when they could not be deployed (see Figure A-4). The tools were still visible, however, underneath the 'X'. Since the original **Star Cruiser** display also used a yellow 'X' to show when a tool was out of commission (due to an overloaded Star Cruiser), the enhanced display incorporated a red 'X' to let the user know when this situation had happened and the services of a tool for the remainder of the session had been lost.

Another enhancement to the display was that the string drawn by the user during a tool deployment would change color when a possible target was acquired. When the user first selects a tool for deployment, clicks the mouse on the cruiser, and then drags a deployment string out from it, the string is colored white. As soon as the mouse arrow is over a planet to which the tool may be deployed, however, the string changes color to green. This change in color informs the user to release the mouse button in order to deploy the tool. This display alteration was done in order to reduce the amount of deployment errors that occur because the user was unable to click on a planet during this task.

Retrieve Collection Tools

Proposed Display Enhancements

Three crucial problems with retrieving the collection tools were discovered by performing the task analysis. The first was the difficulty in selecting a particular tool for retrieval whenever multiple tools were located at the same planet. This problem was due to the tools being overlapped near one corner of the planet. As a result, the tools could only be retrieved in a pre-specified order. This constraint was sometimes undesirable. Therefore, by depicting one tool in each corner, the user can select which tools to retrieve without having to retrieve any others beforehand.

The second problem was the disappearance of the perceptual cues indicating the amount of data or resources contained on a planet once the cruiser collected that information. The user would thus have to remember how much each tool had collected so as not to overload the cruiser when the tools were retrieved. In order to reduce the amount of memory demands in such a task, other cues should replace those that vanish to indicate that the information has been collected and how much had been collected. Using "ghost images," replicates of representations which are a different color than the originals, in place of the pie pieces once they have disappeared would serve such a function.

Lastly, confusion was often present due to the lack of a direct relationship between how much information was collected from planets (pie graphs) and how much Star Cruiser's load increased (bar graphs). Incorporating similar types of graphs to represent the two pieces of information would provide important perceptual cues to the user in determining whether or not to retrieve a particular tool. This goal may be accomplished by either changing the pie graphs on the planets to bars, or by changing the bars representing cruiser capacity to pie graphs.

Actual Display Enhancements

One enhancement which supports deploying collection tools also supports their retrieval. As described before, the string which is dragged from the cruiser during deployment changes color when the target is hit. This enhancement also aids in retrieving a tool. After a deployed tool has been selected, as soon as the white retrieval string lands on the cruiser it will change to green. Thus, as with deployment errors, the number of retrieval errors should be reduced due to this change.

In addition, ghost images were added to the planets in the local maps (see Figure A-3) and to the suns in the global maps (see Figure A-6) to indicate how much data or resources had just been collected. As data is collected, the light pink pie pieces on the planets or suns are replaced by white pie pieces. Black pie pieces appear in place of the magenta ones as resources are collected. As a result, the user no longer needs to remember how much data and resources were present before they were gathered by the collection tools.

The gauges representing Star Cruiser's capacity were also altered (see Figure A-4). Empty planets now represent how much Star Cruiser can carry. One planet holds the maximum amount of data and resources of an orbiting planet. The capacity of Star Cruiser is therefore represented by as many planets as would be needed to fill up the cruiser. These planets are filled with pie pieces representing the total amount of commodities brought aboard Star Cruiser just as the planets orbiting the suns are initially filled. This enhancement, along with the preceding one, was done to reduce the chance of the user overloading the cruiser by retrieving a tool which had collected to much data or resources. For example, when the user retrieves a collection tool, it is known how much the tool has gathered by the appropriate ghost image of the pie pieces on the planet. The user also is able to see if that pie piece will "fit" into the cruiser by noticing if there is enough room in the planet gauges. If so, the user knows that the tool may be retrieved without overloading the cruiser. As a result, a more direct relationship exists between the pictorial representation of commodities on the planets and the amount on board Star Cruiser as depicted in the capacity gauges.

Deploy Probe

Proposed Display Enhancements

The deployment of a probe is very similar to that of a collection tool. Essentially, the only difference is that a probe's deployment string is dragged to a sun whereas a collection tool's string is dragged to a planet. As a result, several of the possible enhancements which were directed at the deployment of a collection tool may also be applied to that of a probe. These include indicating when a probe cannot be deployed and the changing of the deployment string's color. Other possible enhancements made to the interface which involve this task are discussed in Determining Star Cruiser Mode.

Actual Display Enhancements

Some of the enhancements used to assist the user in deploying collection tools may also be used in deploying probes for similar reasons. These include changing the deployment string color to green when the target, in this case a sun, has been hit and crossing out the probes when they cannot be deployed (Star Cruiser is docked at Star Base).

Retrieve Probe

Proposed Display Enhancements

As discussed in the task analysis, the current display interface presents possible confusing perceptual cues with respect to retrieving probes. The displaying of a probe next to a sun in the global map may lead a user to try to retrieve it even though Star Cruiser is not in orbit in that particular solar system. In order to avoid such confusion, the cue should be altered. One such remedy is to reduce the brightness of the picture of the deployed probe in the galaxy view. This modification should still present the same information as before, that a probe has been deployed to a system, but it should also reduce any tendencies that the users may have to try to retrieve it when the proper conditions have not been satisfied.

Actual Display Enhancements

Just as deploying collection tools and probes shared similar display changes, so too do retrieving collection tools and probes. The retrieval string also changes to green to indicate to the user when to release the mouse button in order to retrieve a probe.

Place Star Cruiser Into Orbit

Proposed Display Enhancements

Some of the problems involving placing Star Cruiser into orbit that became apparent from the task analysis were associated with trying to identify the location of the ninth orbit and when the cruiser was at the proper speed for obtaining orbit. Even though various perceptual cues already exist to aid the user in locating the ninth orbit, they are not direct and thus an additional cue should be added. One such possible cue involves highlighting the orbit in some fashion. Using a dotted line to trace the ninth orbit, for example, would allow the user to easily locate it. A different form of highlighting can be employed to indicate when the cruiser is traveling at the proper speed for obtaining orbit. When the speed is slow enough in the solar system view, the ship may either change color or, similar to when the ship is in orbit, become outlined using some color. Not only will such an addition of perceptual cues allow the user to identify when the cruiser is likely to obtain orbit, but it will also allow the user to notice when Star Cruiser may be captured by the orbit even though it is undesirable. The cruiser's speed or direction may then be changed to ensure that it does not enter the orbit.

Actual Display Enhancements

In order to assist the use in determining when the cruiser was crossing over the ninth orbit, a white 'X' indicating the orbit's position was added to the display (see Figure A-5). This 'X' follows the path of the ninth orbit, always placing itself in a direct line with the sun and the cruiser. This way, as the cruiser moves closer to the orbit, it is also getting closer to the marker. Therefore, when Star Cruiser is crossing the 'X,' it is also intersecting the orbit. Therefore, if the cruiser is going at the proper speed, Star Cruiser will go into orbit as soon as it passes over the 'X.'

A second enhancement was also added to the display to assist the user in this task. Star Cruiser, when it is traveling at the proper speed for obtaining orbit, will be outlined in purple, much like it is outlined in green when it is in orbit. From this change in color, the user will know if the cruiser will enter orbit as it crosses the ninth orbit or if it will not because it is traveling too fast.

Remove Star Cruiser From Orbit

Proposed Display Enhancements

One problem that often occurred when users attempted to remove Star Cruiser from orbit was that it was done so accidentally. This occurrence resulted because they did not realize that a thrust was being applied to the ship. This problem, along with possible solutions, are further discussed in Determining Star Cruiser Mode. Users also experienced difficulty with this task whenever they applied too big of a thrust to the cruiser. As a result, the cruiser would leave orbit at an uncontrollable speed, leave the solar system, and sometimes enter other systems. This sequence of events increased the chance of Star Cruiser colliding with a sun and exploding. Even though this may be the case, it is not apparent whether or not adding any additional perceptual cues to reduce this risk would have any benefit on performance since this sequence of events only occurred infrequently. Such cues, though, may include changing the color of the cruiser or causing the cruiser to blink on and off whenever a thrust string applied to it is large enough to remove it from orbit. Also, an auditory tone may be used to indicate if the cruiser's direction of travel will send it into a neighboring solar system.

Actual Display Enhancements

With the exception of those enhancements discussed in Determining Star Cruiser Mode, none were added to the display interface to support this task since the ecological task analysis failed to indicate their possible benefit on user performance.

Dock Star Cruiser At Star Base

Proposed Display Enhancements

When to perform this action is sometimes not clear. Of the three factors which may cause a user to return the cruiser to Star Base (loaded cruiser, no fuel, session time expiring), the only one which seemed to go unnoticed repeatedly was the amount of fuel Star Cruiser had remaining. In order to make the fuel gauge more noticeable, several changes to this perceptual cue should be made. One is to change it's color. Currently, it is difficult to discriminate between the fuel gauge and the display's background due to their colors. As a result, the user must look carefully at the gauge to determine the fuel level. Changing the color, and even using multiple colors to represent different fuel levels, should help to make the fuel gauge more discriminable from the rest of the display. In addition, the information provided by the gauge should be more interpretable (i.e., given how much fuel is remaining implies how big of a thrust can be applied). One other enhancement to the display concerning the docking of the cruiser at Star Base is to change its color when it is traveling at the proper docking speed. This display change is essentially the same as the enhancement suggested for obtaining orbit with Star Cruiser.

Actual Display Enhancements

Star Cruiser becomes outlined in purple so that the user can determine when the cruiser is traveling at the proper docking speed. This display enhancement is similar to the one described in Place Star Cruiser Into Orbit. Since the cruiser can never dock at Star Base in the local map, and since it can never go into orbit in the global map, there should be very little confusion in determining the meaning of this cue at a given time.

Release Star Cruiser From Star Base

No significant problems resulting from a lack or misuse of perceptual cues concerning this task were noticed during the task analysis performed on Star Cruiser. Therefore, there is no need to make any changes to the display interface in order to better support the releasing of the cruiser from Star Base.

Change View To Galaxy / Solar System

Perceptual cues which informed the user of the availability of this task or assisted the user in determining when to perform this task were discovered to be lacking. This task could be eased by presenting a smaller view of the global map to the user whenever the cruiser is in a solar system. Similar "radar views" of solar systems could also be used when Star Cruiser is traveling through the galaxy. These changes, however, are not in accordance with the perceptual enhancement approach used in this study. Therefore, without the addition of any perceptual cues, this task should be thoroughly discussed with users during training sessions in order to familiarize them with it.

Choose Star Cruiser's Destination

Proposed Display Enhancements

This task involves the user determining to which solar system to send Star Cruiser. It does not include determining when to send Star Cruiser to Star Base as that is covered by another task. Since the user's primary goal is to collect as many commodities as possible from the solar systems and return them to Star Base, any display enhancements aimed at assisting the user with this task may result in a significant increase in performance. In attempting to aid the user in making this determination, the display offers as a perceptual cue the color of the suns. As the scenarios are currently programmed, the color of the suns indicate the amount of commodities contained in the solar system given the possible amount that may be contained there. This calculation is based on the number of planets present within the solar system. As a result, one solar system may actually possess more data and resources than another even though the color of its sun indicates otherwise. An improvement would be to program the scenarios so that the color of the sun indicates the amount of commodities available in the solar system relative to the amount available in the galaxy. This simple change should facilitate the user's determination of which solar systems contain the most data and resources and are worthy of attention.

Actual Display Enhancements

Two changes were made to the display interface to help better support the user in determining to which solar system to send the cruiser. The first involved a change in an existing perceptual cue. As mentioned previously, the suns' colors could be programmed to better indicate the systems which contained the most commodities. This use of color was done by assigning a brighter colored sun to those solar systems which contained a higher percentage of the total amount of data and resources in the entire galaxy. Those systems which did not contain many commodities were therefore given darker colored suns.

Another change to the interface resulted in the addition of a new cue. A blue 'X' was placed over the sun of any solar system in the global map to indicate that it was completely empty (see Figure A-6). A solar system was considered empty if it did not contain any commodities, collection tools, or probes. Planets were not considered. This enhancement would inform the user of which solar systems could be avoided. The 'X' was blue to avoid any confusion that may arise due to other colors used in the display, especially the colors of the suns.

Determining Star Cruiser Mode

Proposed Display Enhancements

Users often had difficulty determining when an action performed on Star Cruiser would result in a thrust being applied or whether the action would result in the deployment of a tool. Such problems arose, for example, when subjects were unsuccessful at selecting the cruiser once a collection tool had been chosen for deployment. Other times this problem was due to a probe being selected and the user not realizing it. Except for the highlighted tool at the top of the screen, no cues ever existed to indicate to the user whether a string pull from the cruiser was for a collection tool, probe deployment, or for a thrust. Incorporating auditory tones whenever the user performs an unsuccessful action (i.e., missing selecting the cruiser after choosing a tool to deploy) and/or altering the color of the cruiser to indicate the type of action mode the cruiser is in (i.e., a string pull will deploy a tool) should provide the user with beneficial perceptual cues that will help to eliminate these problems.

Actual Display Enhancements

Star Cruiser was outlined in red whenever it was in a deployment mode. For example, if the user has selected a collection tool or a probe for deployment, the cruiser would become outlined. If for some reason the tool or probe is no longer selected, the red outline disappears. This enhancement to the display interface should assist the user in determining whether performing a string pull on the cruiser will deploy a tool or probe or if it will apply a thrust to it. In other words, will the cruiser be in a deployment mode or a thrust mode.

Summary

In summary, the actual enhancements made to **Star Cruiser**'s display interface were:

1. Place collection tools on a colored field to indicate any planet restrictions.
2. Add background colors to tools to indicate type of commodity collected.
3. 'X-out' tools when they cannot be deployed.
4. Change color of deployment / retrieval string when it ends on a possible target.
5. Use ghost images as a reminder of what commodities have been collected.
6. Change Star Cruiser capacity gauges so that they are similar to pie pieces on planets.
7. Add white 'X' to help locate ninth orbit.
8. Add purple outline to Star Cruiser to indicate speed.
9. Change definition of colors of suns.
10. Place blue 'X' over suns of empty solar systems in global map.
11. Add red outline to Star Cruiser to indicate action mode.

Table 5-1 lists the proposed display enhancements according to the task they are designed to aid. One should note that these are not the only enhancements that could have been made. Many other possibilities existed as detailed above. In deciding which changes to incorporate, two factors were considered. The first was the difficulty associated with making changes to the **Star Cruiser** software. The other factor was the goal to empirically evaluate the ecological task analysis framework. Only changes that were suggested by the ecological task analysis process were incorporated.

Table 5-1. Proposed Display Enhancements

<u>Deploy Collection Tool</u>
- Place Tools On A Colored Field
- Add Background Colors To Tools
- 'X'-Out Tools Which Cannot Be Deployed
- Change Color Of Deployment String

<u>Retrieve Collection Tools</u>
- Change Color Of Retrieval String
- Use "Ghost Images" For Collected Commodities
- Alter Star Cruiser Capacity Gauges

<u>Deploy Probe</u>
- 'X'-Out Tools Which Cannot Be Deployed
- Change Color Of Deployment String

<u>Retrieve Probe</u>
- Change Color Of Retrieval String

<u>Place Star Cruiser Into Orbit</u>
- Add White 'X' To Locate Ninth Orbit
- Add Purple Outline To Indicate Cruiser Speed

<u>Remove Star Cruiser From Orbit</u>
- None

<u>Dock Star Cruiser At Star Base</u>
- Add Purple Outline To Indicate Cruiser Speed

<u>Release Star Cruiser From Star Base</u>
- None

<u>Change View To Galaxy / Solar System</u>
- None

<u>Choose Star Cruiser's Destination</u>
- Change Definition Of Colors Of Suns
- Use blue 'X' To Indicate Empty Solar System

<u>Determining Star Cruiser Mode</u>
- Add Red Outline To Indicate Mode

CHAPTER VI

EMPIRICAL EVALUATION OF PERCEPTUAL ENHANCEMENTS

The Ecological Task Analysis framework has proven capable of *suggesting* possible perceptual enhancements to the display interface of **Star Cruiser**. This fact does not, however, imply that these suggestions will improve performance on the task. In order to determine how effective the proposed enhancements are at improving task performance, a new version of **Star Cruiser** was created which incorporated the suggested augmentations. As a result, it was possible to conduct an experiment which compared users' performance on the original **Star Cruiser** to that of users on the enhanced version.

Experimental Method

Star Cruiser Simulations

Two versions of the **Star Cruiser** simulation were used to test the effectiveness of the display enhancements suggested by the ecological task analysis. The first, **Star Cruiser v1.11 r4** , was the original task used to perform the initial exploratory analysis. The display enhancements were made to a copy of this version to create a second, enhanced version used during this experiment. With the exception of the enhancements, these two versions were alike in every way.

Both versions operated on Macintosh IIci computers, each with a standard Macintosh mouse. Two of these computers were used so that multiple subjects could be tested at the same time. The displays for both were 19" color monitors. The only difference between the two sets of hardware was that one operated using version 6.0.5 of its system software while the other ran with version 7.0. This difference did not, however, affect the operation of the simulation in any significant way.

<u>Subjects</u>

A total of sixteen subjects were used during this experiment. This pool consisted of ten males and six females. Two groups, one for each version of **Star Cruiser**, were created consisting of eight subjects each, five male and three female. All subjects were undergraduate students at the Georgia Institute of Technology. They were also all right-handed. The subjects were informed that for their full participation in the experiment, they would be compensated $25, $5 an hour for five hours over a two week period. They were also told that there were two $25 bonuses, one for each group, to the individuals who had the highest average score after the two weeks (not including scores from training).

<u>Sessions (Scenarios)</u>

The experiment occurred over a period of two weeks with the subjects performing the task for a total of ten days (Monday through Friday of both weeks). The first two days were used to familiarize the subjects with **Star Cruiser** and allow them to practice before the actual data gathering began. During these first two days, experts at performing the task were present to answer any questions and to coach the subjects whenever they were doing something fundamentally wrong. Only if they misunderstood some basic part of the task were they given advice. No tricks or important insights were revealed to them. The training periods lasted for one half hour each day. After the second day, the subjects were given two sessions a day for a total of eight days. No assistance of any kind was given to them at this point. Each session lasted a maximum of ten minutes.

There were four different types of sessions that the subjects experienced. No matter the type though, the subjects were instructed to try to achieve as high of a score as possible. The first type was the training sessions. These were then followed by a total of twelve (over six days) normal sessions which had them simply performing the task as best they could.

On the ninth day, the subjects were asked to perform an additional task. While performing the **Star Cruiser** simulation, for both sessions that day, the subjects were required to listen to a tape of simple math problems (i.e., 14+7, 24-10, 8*4, 42/7). It was their goal to answer, verbally, as many correct as possible. In order to ensure that they performed as best they could on both tasks, the subjects were informed that their score on **Star Cruiser** for the two sessions would be multiplied by their percentage of correctly answered math problems when determining who received the bonus money. The motivation for these sessions was to test one of the main goals of ecological task analysis. That goal is to reduce the cognitive demands placed on the user. By monitoring the performance of the subject groups at the Star Cruiser task while attempting the concurrent task of answering math problems, the effectiveness of the display enhancements, and thus the task analysis, can be determined.

On the last day of the experiment, the subjects were required only to perform the **Star Cruiser** task. It was, however, presented to them using whichever display they were not familiar with. In other words, those who had originally been using the enhanced display version were given the original and vice versa. The goal of these last two sessions was to determine how performance would be affected if the additional cues provided in the enhanced display were removed from the enhanced display or added to the original display.

Eighteen different scenarios were created for this experiment, one for each day of training and two for every day thereafter. The configuration of the galaxy was different for each scenario. Factors that were varied included the number of solar systems in the galaxy and their locations, the size of the sun in each solar system, the number and type of planets in each solar system as well as their orbits, the amount of data and resources on each planet, the location of Star Base, and the starting location of Star Cruiser. The configuration of Star Cruiser, however, remained consistent throughout all scenarios. These constants included such factors as the number of probes available, the number of each type of collection tool available, the fuel consumption rate, the data and resource storage capacity of the cruiser, and any factor within the scenario file which affected Star Cruiser's movements. In addition, the points awarded for data and resources returned to Star Base were equal and consistent throughout all scenarios. The scenarios were developed to be of approximately equal difficulty. With the exception of any differences that may arise due to the display enhancements, each subject was presented the exact same scenario during the same session number.

Hypotheses

Overall Performance

The purpose behind this experiment was to determine if the Ecological Task Analysis framework could be used to suggest possible display enhancements for a task that would improve a user's performance. For the **Star Cruiser** task, there are several different measures of performance that one could investigate to determine if the task analysis was useful in this regard. The simplest measure is the user's score on the task. High scores are typical of those users who are able to perform the task well. It is believed then, that if the suggested display enhancements did contribute to better user performance, the scores will reflect it. Therefore, higher scores would be expected from the group of subjects using the enhanced version of **Star Cruiser** as compared to those using the original.

It is also thought that the subjects on the enhanced version would reach their maximum performance level faster. In other words, they will learn the task faster than the group using the original version. This belief is because one of the goals of the ecological task analysis is to bring to the display surface more useful information about the task and the task's ever-changing system states that the user can utilize while performing the task. Since the "enhanced" user now has additional sources of information that the "original" user does not, the enhanced user should be able to learn more quickly how to perform the task as well as any tricks that may help to improve performance. It is therefore expected that the enhanced version would result in users reaching higher scores faster than the original version. Only sessions 3 through 14 were used in determining the display enhancements effects on learning and overall performance since sessions 1 and 2 involved training and sessions 15 through 18 involved slightly different tasks for the user.

Individual Performance Measures

The enhanced version of **Star Cruiser** is made up of many individual display changes. How each change affects user performance can be measured to some degree. By gathering such data, typically in the form of performance errors or time to perform an action, one may see exactly which enhancements had the biggest influence, if any, on user performance. Such results may reveal areas of the simulation where further display enhancements, or even more significant changes to the simulation as a whole, may be required. These results also may indicate those areas where efforts should no longer be placed since they appeared to have no, or negative, effects on user performance. Following is a listing of each display enhancement, how its effect on user performance was measured, and how it was expected to affect performance. It should be noted that for some of the measurements, there are limits to how well they reflect user performance.

Colored Field / Background Colors Of Collection Tools. The first performance measure actually encompasses two of the display changes. The first change was placing the science ships and miner ships on green fields to indicate that they may only be deployed to life-supporting planets. The other enhancement was providing background colors to the collection tools to indicate whether they gathered data or resources. Both of these changes were implemented to aid the user in determining the functions and limitations of the tools. One way to measure how effective these enhancements were is to check how often a user made an error by selecting the wrong tool. The only true check of this type of error is to keep track of how many times a tool is selected immediately after one has been chosen, even if it is the same tool. This procedure may, however, not account for only selection errors since other events may dictate choosing a different tool or warrant selecting the same tool over again. In addition, other occurrences of the user selecting the wrong tool may not be counted. The user of the enhanced interface should, though, have fewer selection errors than the original user because of these two display changes.

'X' - Out Tools When They Cannot Be Deployed. This display enhancement was intended to reduce occurrences of users trying to select and deploy a tool when it was not possible to do so. To measure this error, the number of times a collection tool was selected when the cruiser was not in orbit or the user was viewing the global map was counted. Each time the user attempted to deploy a probe when Star Cruiser was docked was also added to this value. This performance measure is relatively straightforward and the user working with the enhanced display should have fewer of these errors.

Change Color Of Deployment / Retrieval String. While performing the task analysis on **Star Cruiser**, it was observed that users had difficulty determining when they were able to release the mouse button over a target during a tool deployment or retrieval. This display enhancement was intended to prevent this problem. The simulation was able to count the amount of deployment / retrieval errors that occurred because the user missed the planet/sun/cruiser while performing the action. Since the enhanced subjects were being informed of when they had acquired the target, they should have had fewer deployment / retrieval errors than those subjects using the original display.

Use Ghost Images. This display enhancement was incorporated into the new version of **Star Cruiser** in order to reduce the chance of the user overloading Star Cruiser with too much data or resources. If this situation ever did occur, then the tool which the user attempted to retrieve would be labeled out of commission in the selection bar at the top of the display (red 'X' in enhanced display, yellow 'X' in original). Therefore, simply counting the number of tools that were out of commission during a session would provide a sufficient measure of the effectiveness of these enhancements. Since subjects were provided with additional and clearer information regarding the collection tools and Star Cruiser's current load of data and resources, those subjects who were given the enhanced display version would be expected to have fewer tools out of commission than those working with the original display.

Alter Star Cruiser Capacity Gauges. Remembering that the goal of the subjects is to score as many points as possible, it seems reasonable to assume that, on the average, subjects would attempt to return as much data and resources as possible each time they return to Star Base (this assumption was later determined to be reasonable by observing skilled subject behavior while performing the task). Since those subjects working with the enhanced displays should be better informed as to how much more data and resources will fit on Star Cruiser and what collection tools will accommodate that amount, they should be able to fill the cruiser to near capacity with commodities. Thus, they should be better able to unload, on average, more commodities at Star Base during each docking. Therefore, keeping track of the average percent utilization of Star Cruiser's total commodities capacity as it docks at Star Base provides a second performance measure for the effectiveness of these enhancements.

White 'X' For Ninth Orbit / Purple Highlight For Cruiser Speed. The user's ability to place Star Cruiser into orbit is another important performance factor. These two display enhancements should be included together when discussing this performance measure since the location of the ninth orbit and speed of the cruiser are both important factors to be considered while attempting to place the cruiser into orbit. It would be expected that those subjects who had help in locating the ninth orbit would find the task of placing Star Cruiser into orbit an easier one than those without any assistance. The group which used the enhanced display should then have required less time to place the cruiser into orbit compared to the other group. In addition, they should not have been required to apply as many thrusts to Star Cruiser in order to enter orbit. The time and number of thrusts required to obtain orbit were therefore recorded each time the user had Star Cruiser enter a solar system. If the cruiser exited the solar system before it obtained orbit, the counts were abandoned. This method was by far the best way to measure this factor with one exception. The cruiser could enter a solar system and travel to near the ninth orbit before the user ever acted upon it. Since data was not recorded by the simulation unless a mouse click occurred, the exact time the cruiser was in the solar system may not be accurate. This factor was, however, consistent for subjects in both display groups.

Purple Highlight For Cruiser Speed (Docking). As discussed previously, this display enhancement should allow the user to better monitor the cruiser's speed, especially when attempting to dock. Therefore, since they had information concerning the cruiser's speed, those subjects who used the enhanced display version should have required fewer thrusts and less time to dock the cruiser than those using the original display. A good performance measure to determine the effectiveness of this enhancement was to keep track of both the number of thrusts and time required for the user to dock Star Cruiser. The counts began when it became apparent that the user was attempting to dock the cruiser. It was determined that if the cruiser passed within fifty pixels of Star Base, then it was probably the user's intent to dock it. If the cruiser then entered a solar system or if the user performed some other action other than a thrust before the cruiser docked, the counts were reset. Otherwise, the time and number of thrusts were continually tabulated until the cruiser docked. As with measuring the performance of a user attempting to place the cruiser into orbit, the fact that data isn't recorded until a mouse click occurs presents a slight problem. As a result, the user may have the intent to dock the cruiser and send it towards Star Base while it is outside of the fifty pixel boundary. Then, without ever having to apply a thrust beforehand, as soon as the cruiser passes over the base, the user may simply apply a quick reverse thrust to dock it. This event would then be recorded as a docking where there were zero thrusts and it took zero seconds. This drawback was present across all subjects and even though it may have occurred (it only rarely did so), this means of measuring the effectiveness of this enhancement was the best possible.

<u>Change Meaning Of Color Of The Suns</u>. The enhanced display included this change in order to inform the user of those solar systems which contained the most data and resources. Therefore, subjects working with the enhanced version of **Star Cruiser** should have visited more, compared to those using the original version, solar systems that, on average, contained the most commodities. This amount includes the solar systems to which only probes were sent since what is being measured by this factor is the user's performance at determining which systems contain the most data and resources and, in addition to actually having the cruiser visit a solar system, sending a probe to a system is a method for making such a determination. The actual performance

measure here is the average amount of data plus resources for all visited or probed solar systems.

Blue 'X' For Empty Solar Systems. Due to this change in the display, subjects using the enhanced display version should have Star Cruiser visit empty solar systems less often than those using the original display. Counting the number of times the cruiser entered an empty solar system provides a measure of the effectiveness of this perceptual enhancement.

Red Highlight For Cruiser Mode. This display enhancement's purpose was to inform the user about which mode, thrusting or deployment, Star Cruiser was currently in. In other words, whether a string pull on the cruiser would result in its thrusting or in a tool being deployed. The enhanced display group, compared to the group with the original display, should make fewer errors in determining which mode the cruiser is in. This performance measure was obtained by first noting when the user had selected a probe or collection tool for deployment. It was then checked to see if the user was unable to select the cruiser at the start of the deployment process. If so, if the user attempted to deploy the tool once more before selecting it again, then this happening would be counted as an error in knowing the cruiser's mode (since missing the cruiser the first time would switch it from the deployment mode to the thrust mode). The reported total occurrences of this error was the performance measure for this enhancement.

Math Sessions

Sessions 15 and 16 required the subjects to answer the math problems as described earlier. If the display enhancements resulting from the ecological task analysis are providing the user with new or additional information needed to perform the task, or bringing information at the depth level to the surface, then there should not be as great of a demand for cognitive resources as when the user was using the original display. As a result, the subjects using the enhanced display version should be better able to handle the additional task of performing math problems while simultaneously performing the **Star Cruiser** task. This hypothesis will be supported if both groups of subjects continued to score as they had been before receiving the math problems, but the enhanced group was able to get a significantly higher percentage of the math problems correct than the original group. The hypothesis will also be supported if both groups score the same on the math problems but the original group's **Star Cruiser** scores suffered to a significantly greater extent than the enhanced group's. In addition, subject performance on each individual performance measure should be less affected by the additional task for those using the enhanced display compared to the other subject group. The **Star Cruiser** scores and other performance measures obtained during the math sessions will be compared only to those obtained during the immediately previous two sessions, Sessions 13 and 14, since these are closest to the experience level that the subjects were at when they received the math problem sessions.

Transfer Sessions

Sessions 17 and 18, the last two, were used to determine if any performance transfer would occur between the two types of displays. Those subjects who had originally been using the unmodified version were presented with the enhanced version and vice versa. It was expected that the scores of the group which initially used the enhanced version, as well as performance as measured by the individual factors, would suffer since they were no longer presented the information conveyed through the improved perceptual cues, information that they had come to rely upon. The overall performance as measured by scores and the performance of the individual tasks of the other group, it was thought, would either remain constant or improve. Performance remaining constant would suggest that even though new information was being made available, the subjects either did not have enough practice at utilizing it or they were so set in their methods of performing the task, that they ignored it. If their performance improved, it was believed to be due to the information provided through the improved perceptual cues. As with the math sessions, subjects' performance on the transfer sessions was compared only to those for Sessions 13 and 14.

CHAPTER VII

RESULTS OF DISPLAY ENHANCEMENT EVALUATION EXPERIMENT

As each subject performed the task, **Star Cruiser** recorded every action performed. This recording was accomplished by having the program write to a file the state of the simulation every time the mouse button was depressed or released. Each data entry included the time of the action, or event, recorded in sixtieths of a second. Also recorded were the type of event, the X-Y coordinates of the mouse pointer, and information concerning the status of the Star Cruiser including its X-Y coordinates, what solar system, if any, it was in, how much data and resources it had on board and how much it had unloaded at Star Base, and how much fuel was remaining. The entries also included information about which map was being viewed, and if applicable, of which solar system, and the status of each individual tool including where it was located if it was not on board the cruiser and, if it was in orbit, what orbit number it occupied.

Each data file, as it was written, was compressed and therefore needed to be converted into a readable file using a separate program. Once deciphered, the data was read by another program which converted it into the form of the previously discussed performance measures. This conversion was done for all but the training sessions. The results were organized into three groups depending on the type of sessions involved. The first series consisted of sessions 3 through 14, where the user simply performed the task, always using the same display version. Sessions 15 and 16, those which had the users answering math problems as well as performing the task, comprised the second group. Sessions 17 and 18 made up the final group. These sessions were where the user switched display versions to perform the task. The results in each group were analyzed to determine if the mean results for the subjects' overall performance and the set of ten detailed performance measures were statistically different between the two subject groups. An analysis of variance was performed on each set of results within each series of sessions to determine which variables had a significant effect (alpha = 0.05) on user performance. The actual analysis was performed using the statistical software package SAS. The main effects tested were Session number, Display type, and Subject. Also of interest was the interaction effect between Session and Display on subject performance. Following are the results obtained from the analyses of variance for each series of sessions. The results for the individual performance measures have been ordered according to the display enhancement whose effectiveness they are evaluating. For a recap of what enhancements are evaluated by which measures, refer to Table 7-1.

Sessions 3 - 14: Normal

Overall Performance

The mean score for subjects using the enhanced display version was 11350.6 with a standard deviation of 5646.9. For those using the original display, the mean score was 9165.3 with a standard deviation of 5059.8. The trends of the scores for each subject group by session is shown in Figure 7-1. An analysis of variance revealed significant effects to be Session [$F = 3.55$; $p = 0.0002$], Display [$F = 10.00$; $p = 0.0019$], and Subject [$F = 2.67$; $p = 0.0013$].

Colored Field / Background Colors Of Collection Tools

These enhancements' effectiveness were determined by the number of times the subjects selected the wrong type of tool. Only one subject ever did so. That subject was using the original display version. Therefore, while there was no mean for the

Table 7-1. Display Enhancements And Corresponding Performance Measures

Display Enhancement	Performance Measure
Overall Performance	Mean Overall Score
Colored Field / Background Colors Of Collection Tools	Select Wrong Tools
'X' - Out Tools When They Cannot Be Deployed	Select Action Errors
Change Color Of Deployment / Retrieval String	Deployment / Retrieval Errors
Use Ghost Images	Tools Out Of Commission
Alter Star Cruiser Capacity Gauges	Utilization Of Star Cruiser Capacity
White 'X' For Ninth Orbit	Time To Orbit (sec.)
Purple Highlight For Cruiser Speed (Orbiting)	Thrusts To Orbit
Purple Highlight For Cruiser Speed (Docking - Time)	Time To Dock (sec.)
Purple Highlight For Cruiser Speed (Docking - Thrusts)	Thrusts To Dock
Change Meaning Of The Color Of The Suns	Commodities In Visited Solar Systems
Blue 'X' For Empty Solar Systems	Empty Solar Systems Visited
Red Highlight For Cruiser Mode	Errors In Determining Star Cruiser Mode

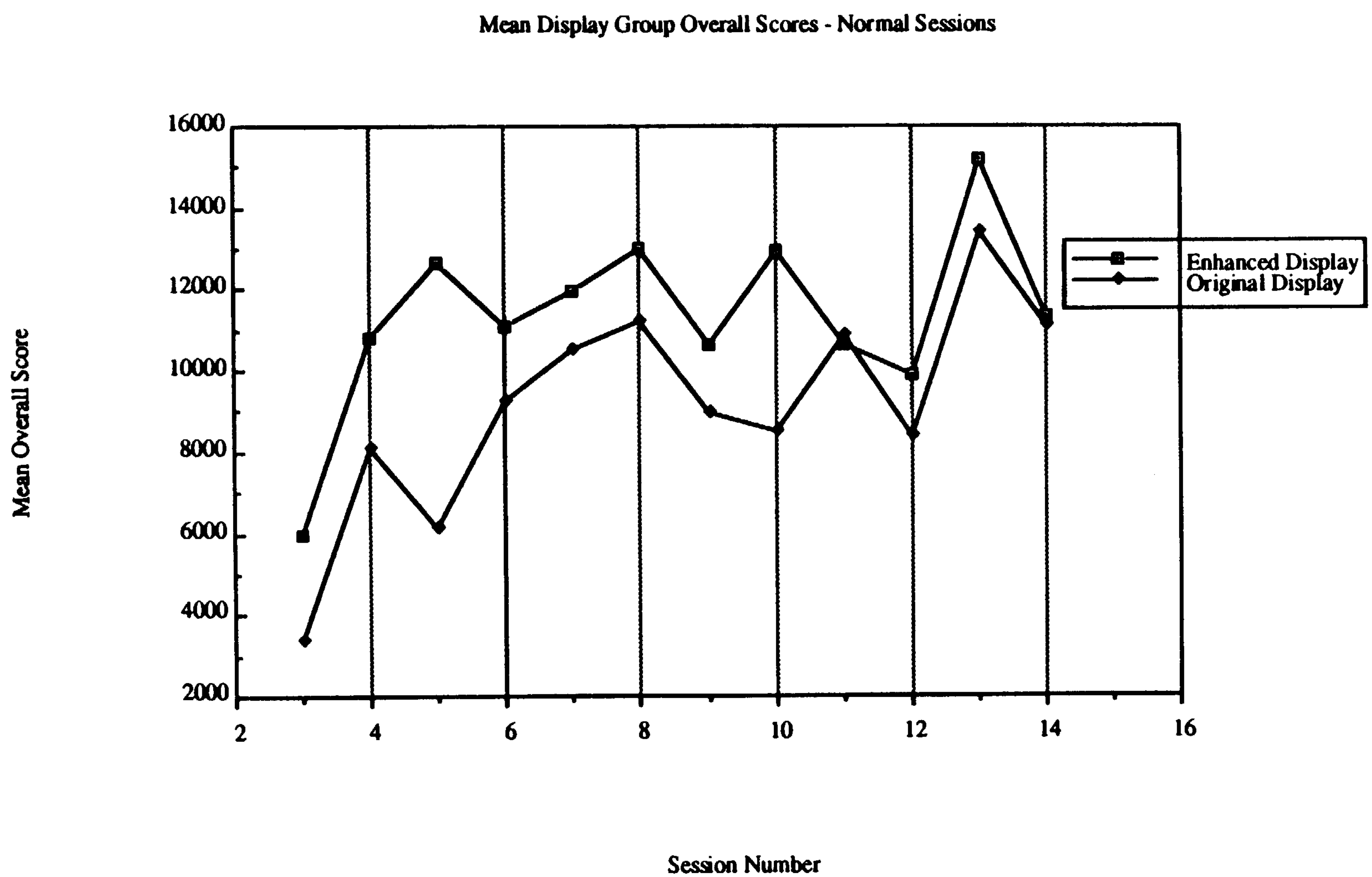

Figure 7-1. Mean Display Group Overall Scores - Normal Sessions

enhanced version group, that for the original version was 0.021 with a standard deviation of 0.144. As a result, only the Subject effect [$F = 0.0079$; $p = 0.0079$] was found to be significant after performing an analysis of variance on the data.

'X' - Out Tools When They Cannot Be Deployed

Rarely did a subject attempt to select a collection tool or probe when it was not possible to do so. The mean number of attempts at doing so for those using the enhanced display was 0.271 with a standard deviation of 1.638 while for the original group it was 0.094 with a standard deviation of 0.358. The analysis of variance failed to find any significant effects.

Change Color Of Deployment / Retrieval String

This enhancement was incorporated to reduce the amount of deployment/retrieval errors that occur. As Figure 7-2 shows, there appears to be significant differences between the number of such errors committed by the original display subjects and those using the enhanced display. The mean number of errors for the original group was 13.67 with a standard deviation of 12.95 while the mean for the other group was 5.63 with a standard deviation of 5.45. The analysis of variance reveals that all three main effects tested, Session [$F = 2.43$; $p = 0.0080$], Display [$F = 110.22$; $p = 0.0001$], and Subject [$F = 31.15$; $p = 0.0001$], were significant.

Use Ghost Images

This display change was done to reduce the number of tools that go out of commission during a session. The analysis of variance showed that only the Session effect [$F = 2.88$; $p = 0.0018$] was significant for this performance measure. The mean number of tools that went out of commission for the enhanced display user was 0.396 with a standard deviation of 1.100. The mean for the original display user was 0.292 with a standard deviation of 0.710. Figure 7-3 graphs the mean number of tools that went out of commission for each group of subjects during sessions 3 through 14.

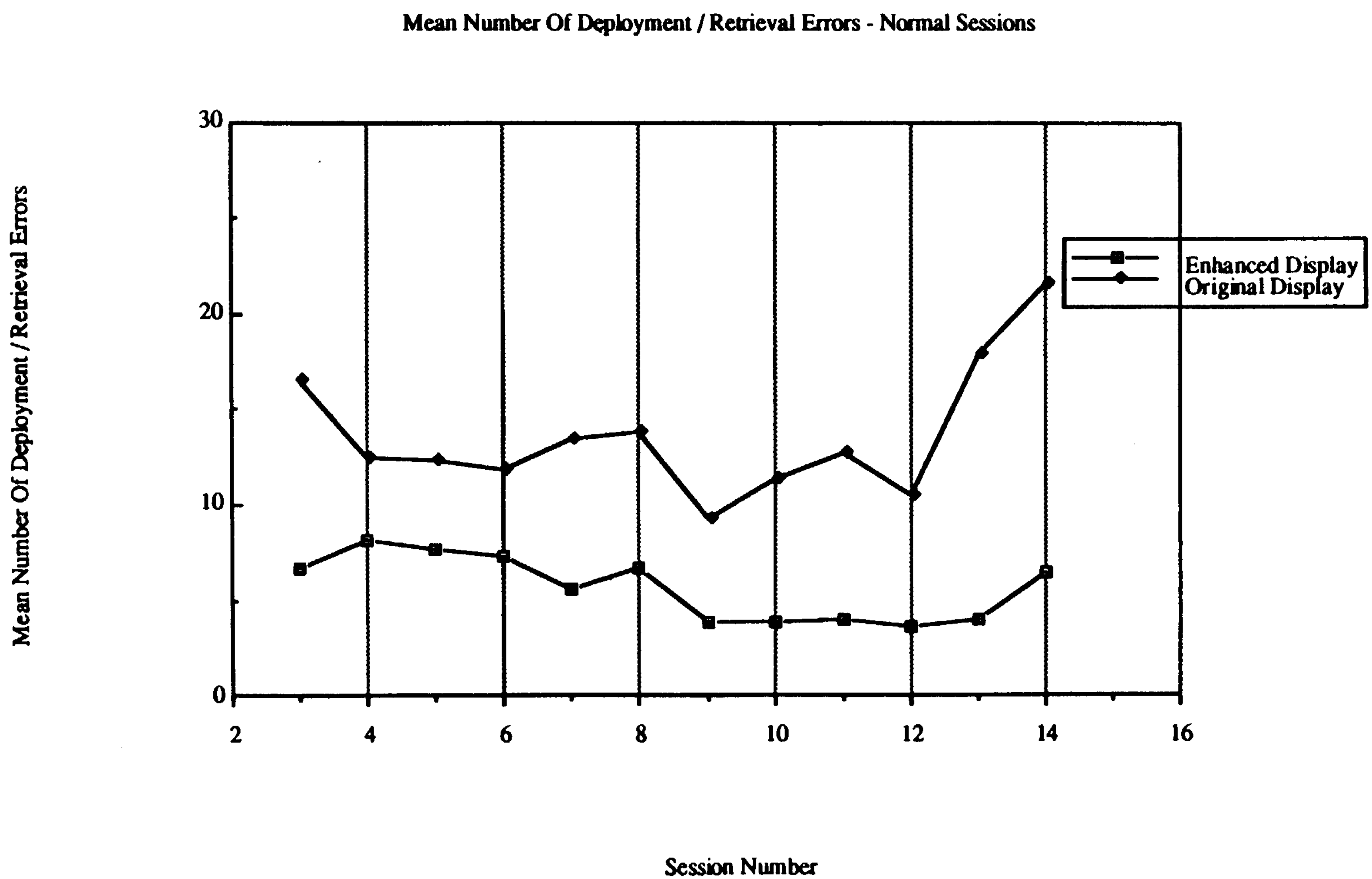

Figure 7-2. Mean Number Of Deployment / Retrieval Errors - Normal Sessions

C-2

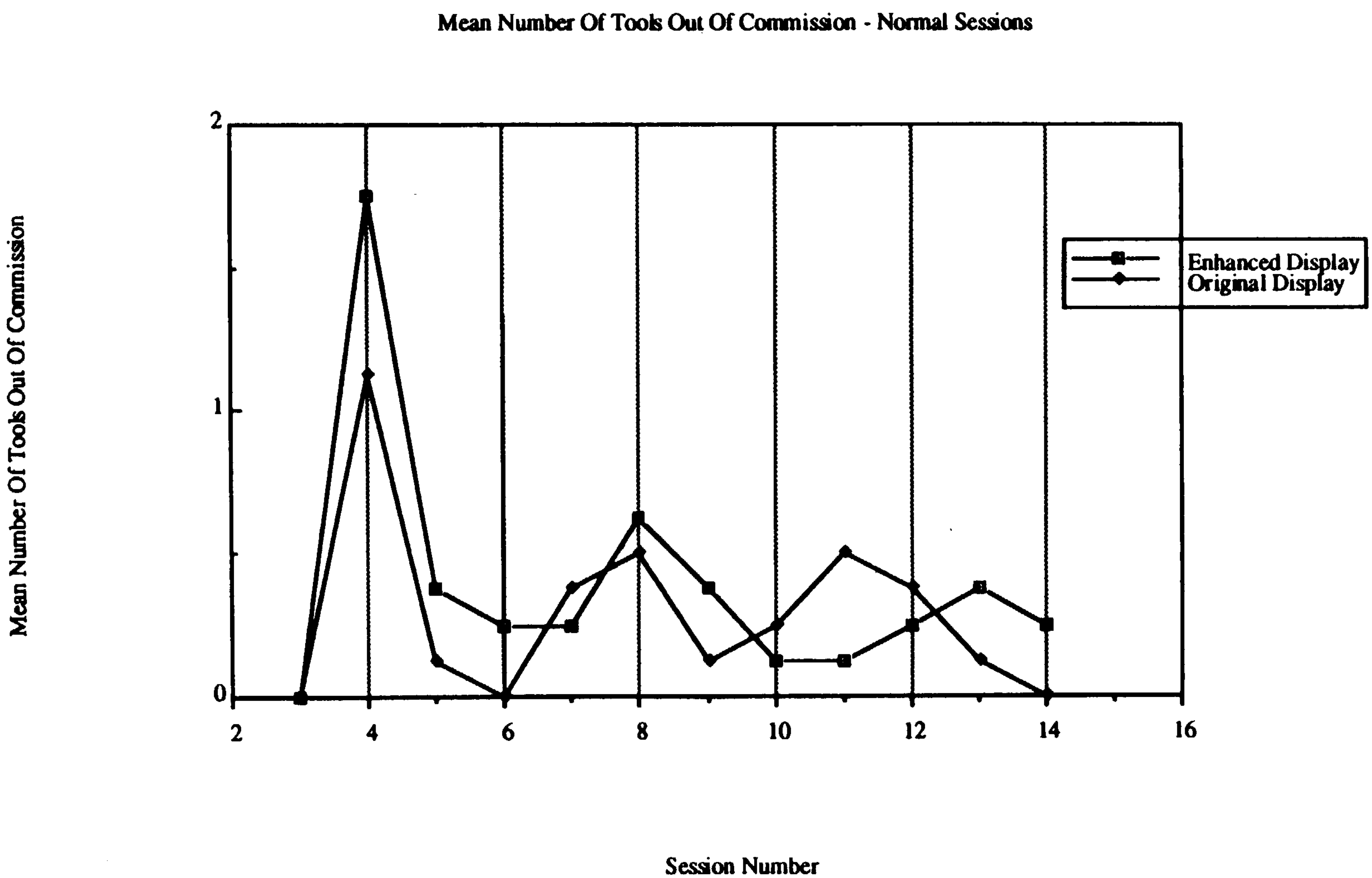

Figure 7-3. Mean Number Of Tools Out Of Commission - Normal Sessions

Alter Star Cruiser Capacity Gauges

In order to measure the effectiveness of this enhancement, the percent utilization of Star Cruiser's capacity when docking was determined. The mean percent utilization exhibited by the enhanced display subjects was 0.663 with a standard deviation of 0.150. For those subjects using the original display, the mean percentage was 0.608 with a standard deviation of 0.199. The trend over sessions of mean utilization for each subject group is shown in Figure 7-4. All effects tested during the analysis of variance proved to be significant. These effects include the main effects of Session [$F = 2.71$; $p = 0.0035$], Display [$F = 7.74$; $p = 0.0062$], and Subject [$F = 8.07$; $p = 0.0001$], as well as the interaction effect of Session and Display [$F = 2.44$; $p = 0.0083$].

White 'X' For Ninth Orbit

The primary purpose behind this enhancement was to reduce the amount of time that it took for the subject to place Star Cruiser into orbit. From the graph in Figure 7-5, it appears to have done just that. Specifically, the mean time to place the cruiser into orbit was 8.89 seconds with a standard deviation of 2.99 for those subjects who had use of the white 'X' enhancement. Those who did not, the subjects using the original display, however, had a mean time to orbit of 15.79 seconds with a standard deviation of 10.25. The analysis of variance performed on this measure revealed that all three of the main effects, Session [$F = 2.02$; $p = 0.0302$], Display [$F = 70.93$; $p = 0.0001$], and Subject [$F = 10.28$; $p = 0.0001$] were significant. This finding is not sufficient, however, for concluding that this enhancement made it easier for the user to place the cruiser into orbit. This display change assisted the subject with only one element required for completing this task: finding the ninth orbit. Cruiser speed is also an important element. Therefore, before one can state with any confidence that this

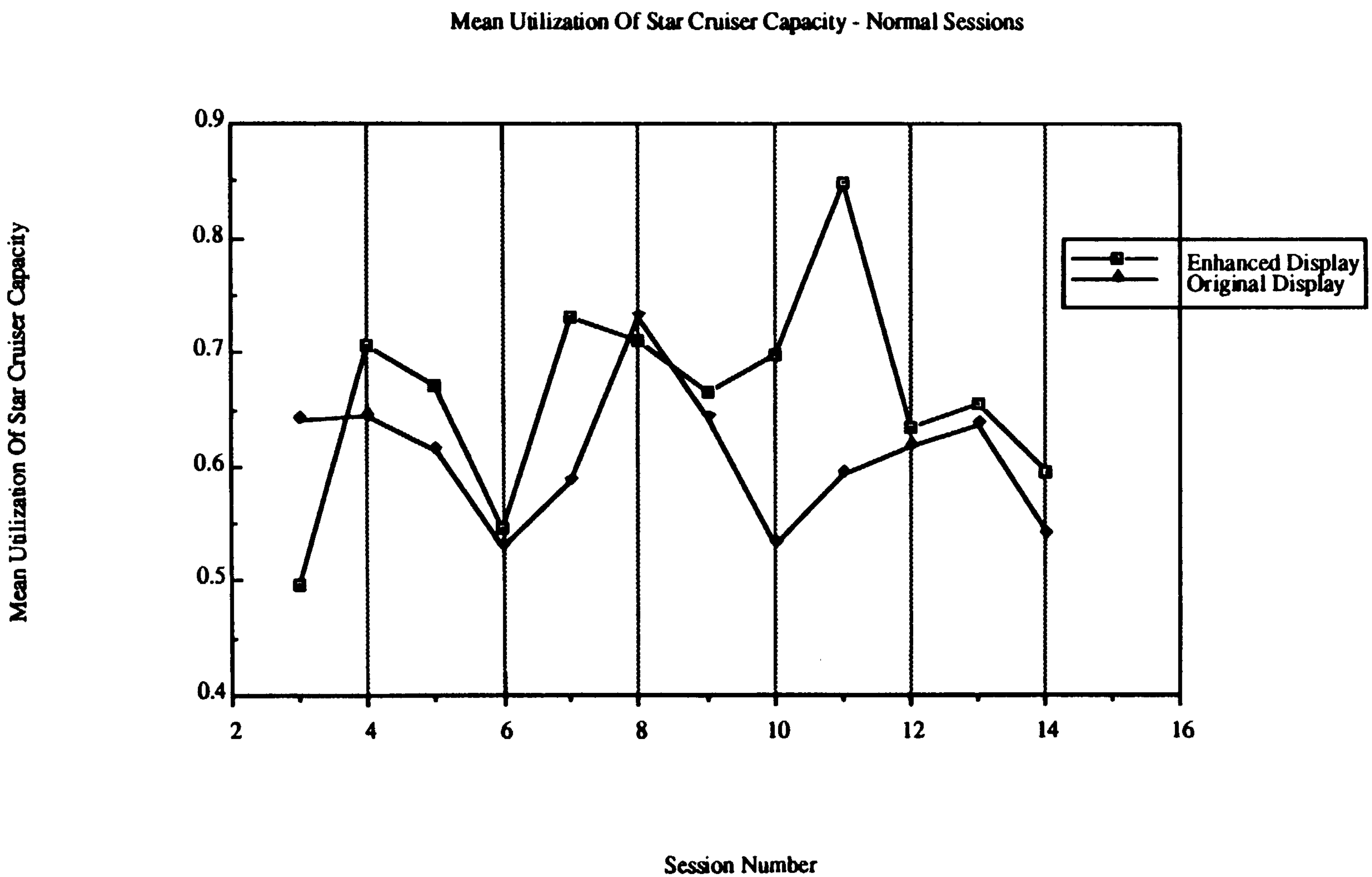

Figure 7-4. Mean Utilization Of Star Cruiser Capacity - Normal Sessions

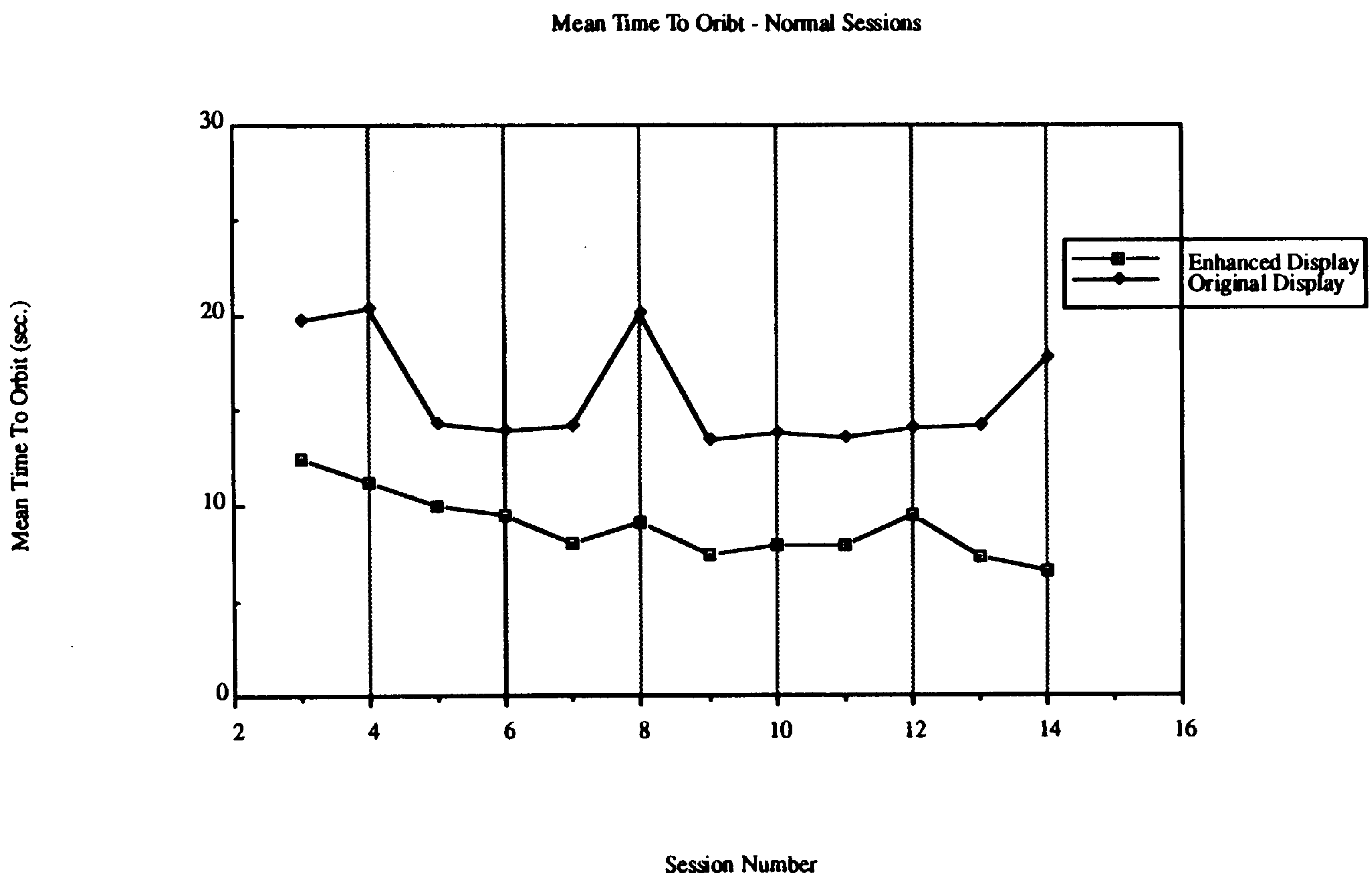

Figure 7-5. Mean Time To Orbit (sec.) - Normal Sessions

change is responsible for the improvement in the time to obtain orbit, any enhancements involving the speed of the cruiser must be considered.

Purple Highlight For Cruiser Speed (Orbiting)

As just mentioned, this enhancement is critical in determining whether or not the enhanced display, when compared to the original, made it easier for subjects to place the cruiser into orbit. The number of thrusts required to place the cruiser into orbit was taken to be a measure of how well this change informed the subjects of Star Cruiser's speed. Those using the enhanced version required a mean of 3.27 thrusts, with a standard deviation of 0.94. The subjects using the original display needed a mean of 8.58 thrusts, with a standard deviation of 7.44, to obtain orbit. The data contributing to this difference is shown in Figure 7-6. Display [$F = 111.49$; $p = 0.0001$] and Subject [$F = 17.91$; $p = 0.0001$] were found to be significant effects after performing the analysis of variance on the data.

Purple Highlight For Cruiser Speed (Docking)

In addition to placing the cruiser into orbit, this display enhancement was intended to assist the subject in docking the cruiser. This assistance was accomplished again by indicating to the user when the cruiser was at the proper speed. Two performance measures, the time to dock and the number of thrusts required to dock, were used to evaluate this enhancement. The mean number of thrusts required by those subjects using the enhanced display was 1.90 with a standard deviation of 0.72. The mean for those using the original display was 2.72 with a standard deviation of 1.38. An analysis of variance performed on the thrust data revealed that Session [$F = 2.34$; $p = 0.0114$], Display [$F = 34.29$; $p = 0.0001$], and Subject [$F = 5.37$; $p = 0.0001$] were all significant effects.

Performing an analysis of variance on the data indicating the time required to dock Star Cruiser resulted in similar findings. The same three effects, Session [F =

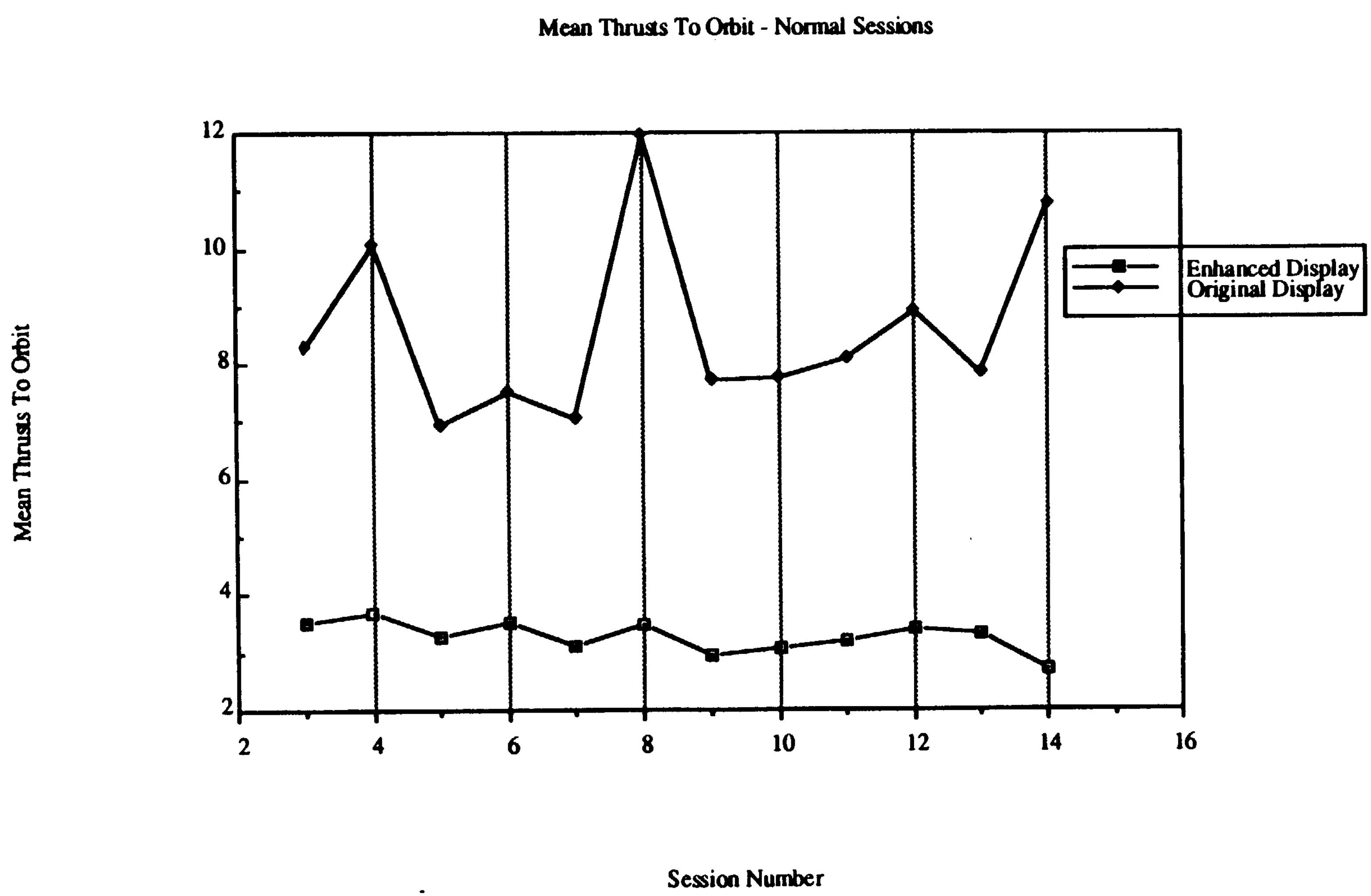

Figure 7-6. Mean Thrusts To Orbit - Normal Sessions

3.87; p = 0.0001], Display [F = 28.91; p = 0.0001], and Subject [F = 3.68; p = 0.0001], were all significant. Those using the enhanced version had a mean docking time of 4.41 seconds with a standard deviation of 1.80 while the other group had a mean time of 6.00 seconds with a standard deviation of 3.01. Figures 7-7 and 7-8 graph, by subject group and session, the mean number of thrusts required to dock the cruiser and the mean docking time respectively.

Change Meaning Of The Color Of The Suns

The purpose behind this enhancement was to inform the users about which solar systems contained the most commodities, so users would not waste effort visiting those systems where it was not efficient to spend time collecting small amounts of data and resources. In order to evaluate this enhancement, the average amount of data and resources in all visited and probed solar systems was tallied. Subjects who used the enhanced display visited solar systems which contained a mean amount of 629.5 units of data and resources with a standard deviation of 125.9. Those subjects using the original display visited solar systems which contained a mean of 570.1 units of commodities with a standard deviation of 132.6. The Session [F = 8.44; p = 0.0001], Display [F = 21.28; p = 0.0001], and Subject [F = 8.94; p = 0.0001] effects were all found to be significant upon performing an analysis of variance on this data. The data itself is displayed in the graph in Figure 7-9.

Blue 'X' For Empty Solar Systems

To prevent the user from wasting time by sending Star Cruiser into an empty solar system, a blue 'X' was placed over the sun of each such system in the global map. The performance factor used to measure the effectiveness of this display change was the number of times the cruiser did enter an empty solar system. Both Session [F = 2.10; p = 0.0232] and Subject [F = 2.18; p = 0.0091] were determined to be significant effects from the analysis of variance performed. The data, graphed in Figure 7-10, revealed

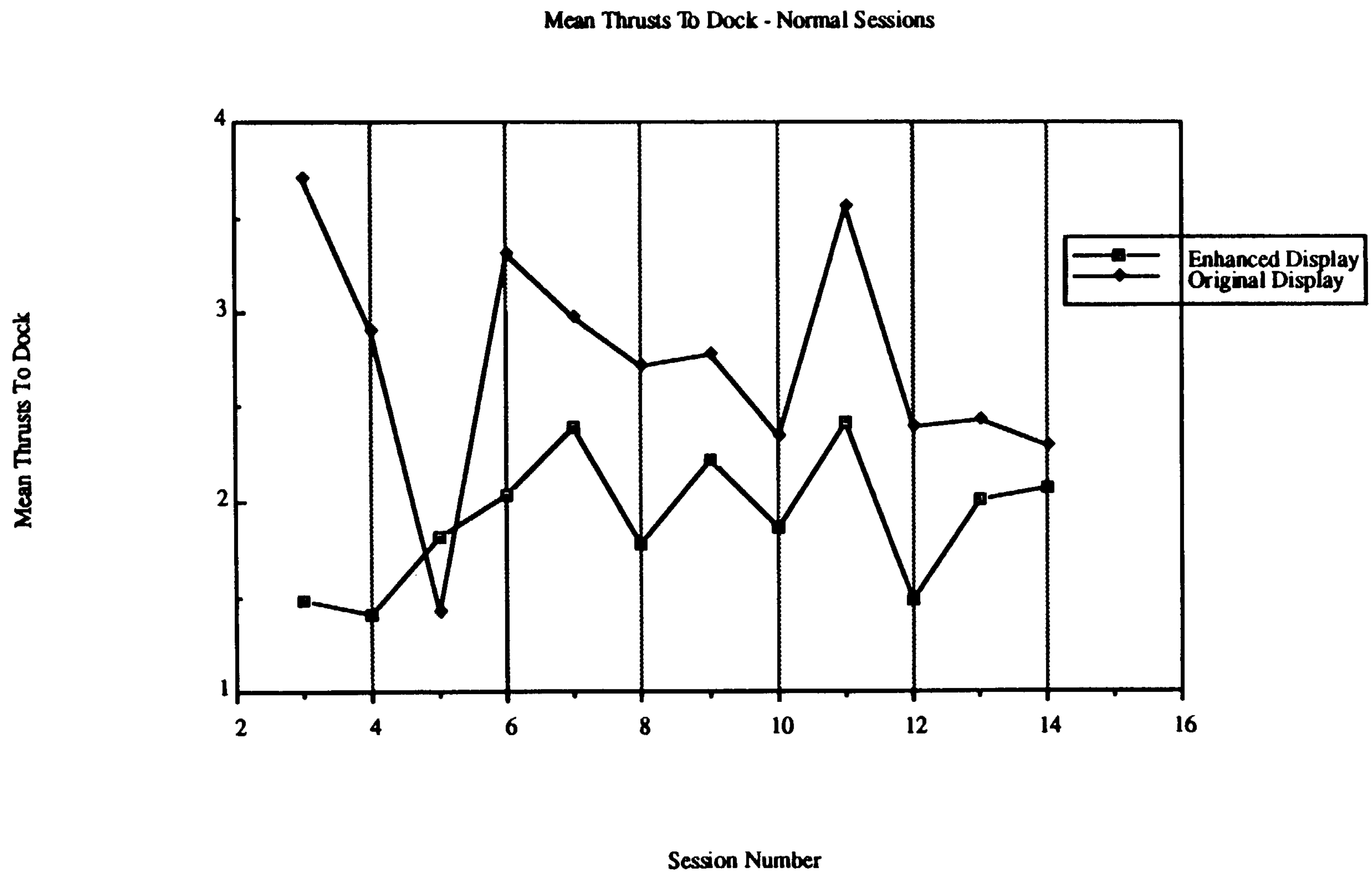

Figure 7-7. Mean Thrusts To Dock - Normal Sessions

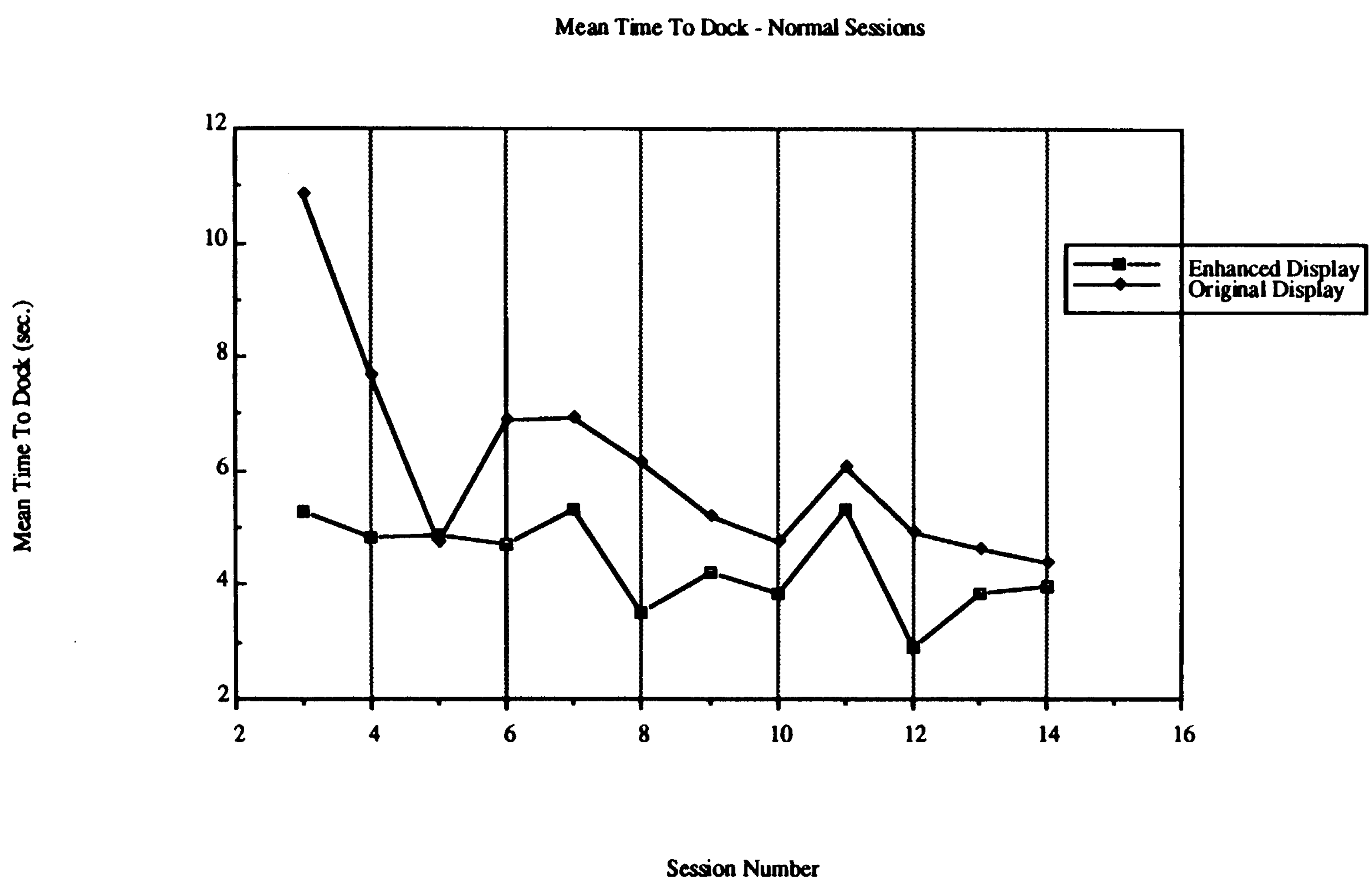

Figure 7-8. Mean Time To Dock (sec,) - Normal Sessions

Mean Commodities In Visited Solar Systems - Normal Sessions

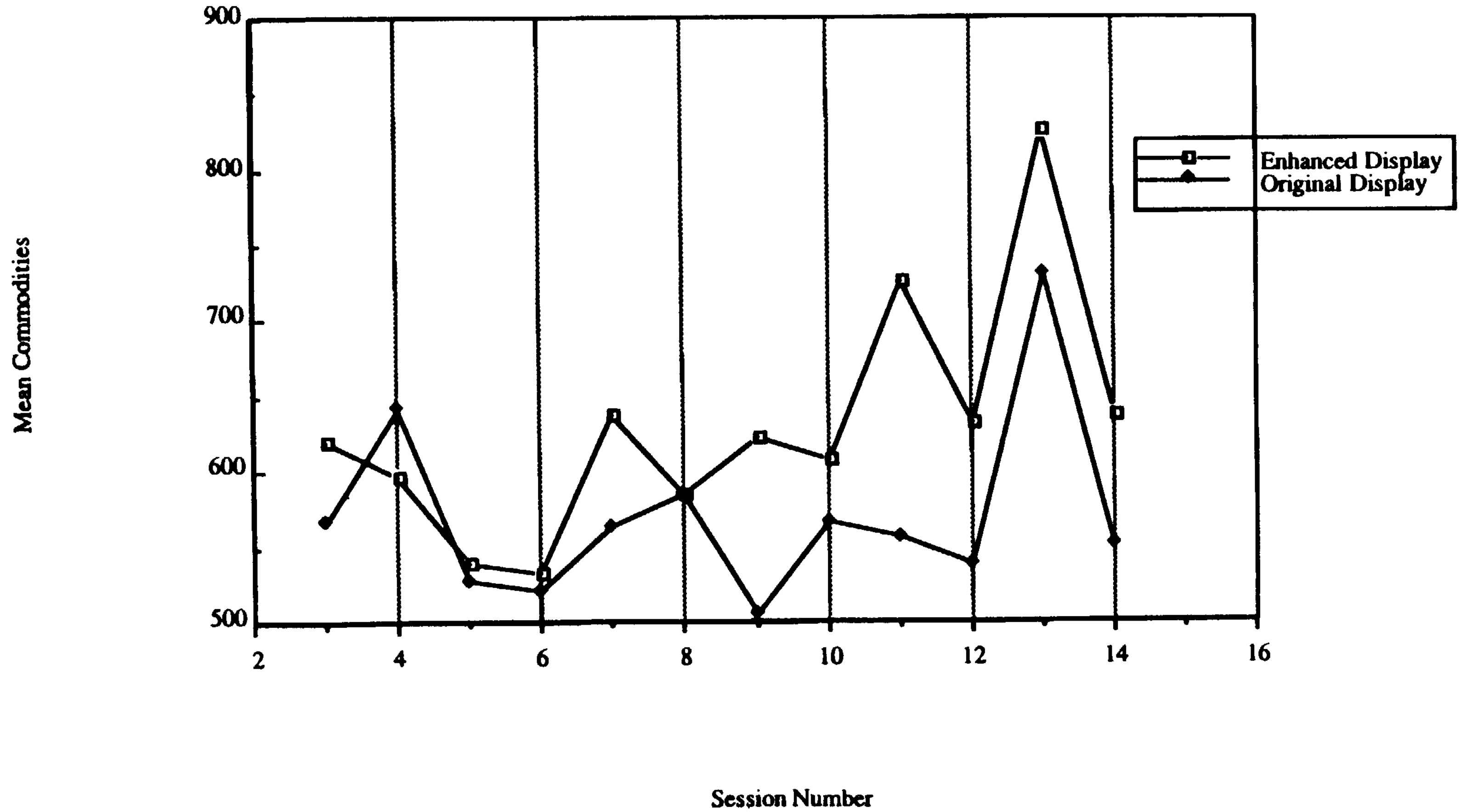

Figure 7-9. Mean Commodities In Visited Solar Systems - Normal Sessions

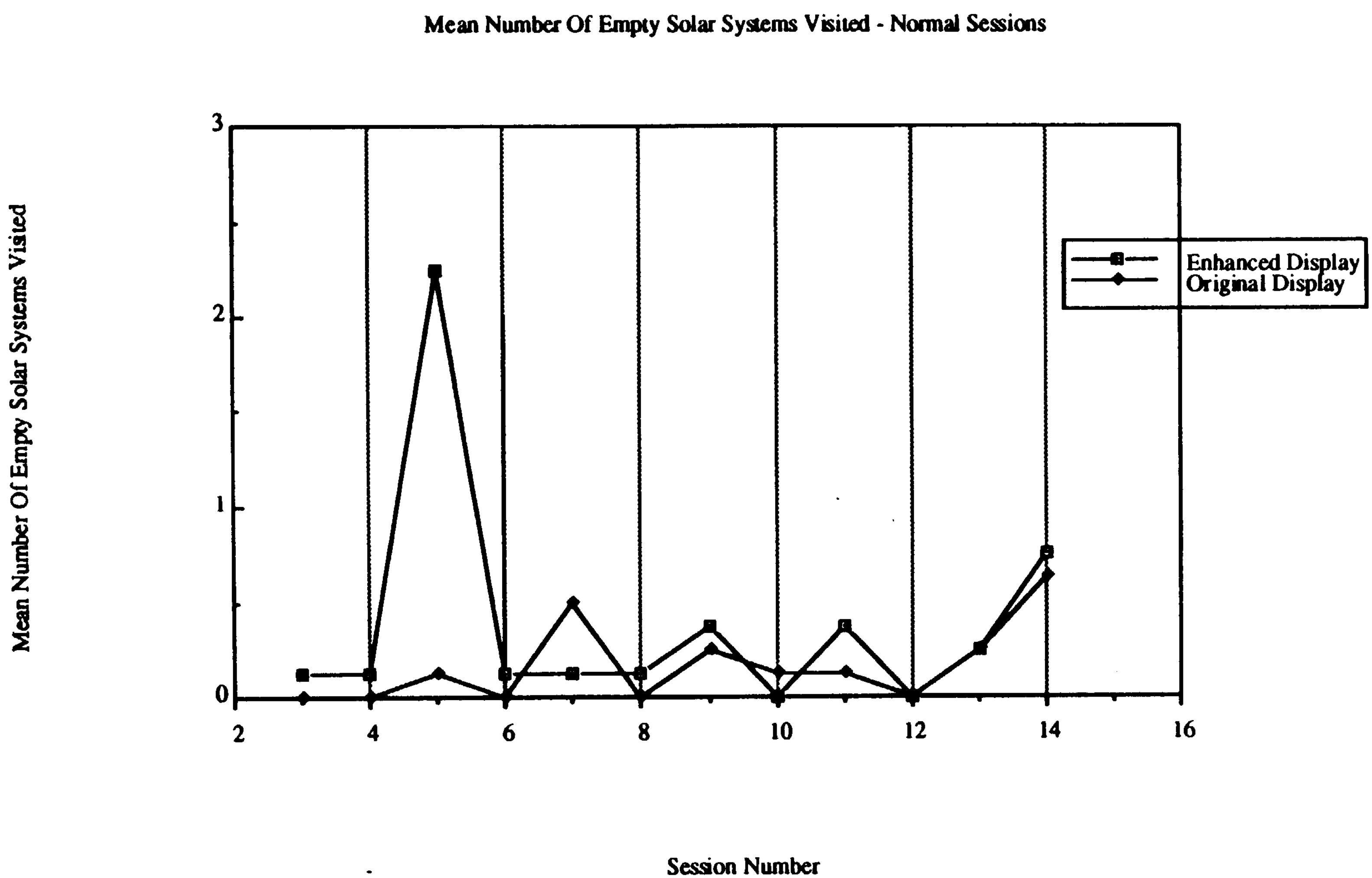

Figure 7-10. Mean Number Of Empty Solar Systems Visited - Normal Sessions

that the cruiser visited an empty solar system a mean of 0.385 times with a standard deviation of 1.395 if the subject was using an enhanced display. Otherwise, the mean was 0.167 with a standard deviation of 0.474.

Red Highlight For Cruiser Mode

This display enhancement was designed to indicate to the user what mode, deployment of thrusting, Star Cruiser was in at any given time during the task. How effective this enhancement was was determined by the number of times the users were mistaken (as indicated by their actions) about the cruiser's mode. Those subjects who were using the enhanced display committed a mean of 0.012 mistakes with a standard deviation of 0.046. A mean of 0.044 mistakes with a standard deviation of 0.123 was committed by the subjects using the original version of the display. The data for this performance measure are displayed in Figure 7-11. The results of performing an analysis of variance on the data revealed that all tested effects, Session [$F = 2.06$; $p = 0.0263$], Display [$F = 7.51$; $p = 0.0069$], Subject [$F = 2.95$; $p = 0.0004$], and the interaction of Session and Display [$F = 2.03$; $p = 0.0295$], were significant.

Sessions 15 And 16: With Math Problems

Subjects' performance during Sessions 15 and 16, the math sessions, was compared to their performance during Sessions 13 and 14, the last two normal sessions performed before the math sessions. Sessions 13 and 14 will also be referred to as the premath sessions. Even though the subjects were informed that their scores on the math sessions would be adjusted according to their percentage of correct answers to the math problems in order to determine who received the bonus money, this adjustment was not done for any of the data analyses. When performing the analyses of variance (alpha = 0.05) on this data, the main effects of interest were Condition (math versus premath),

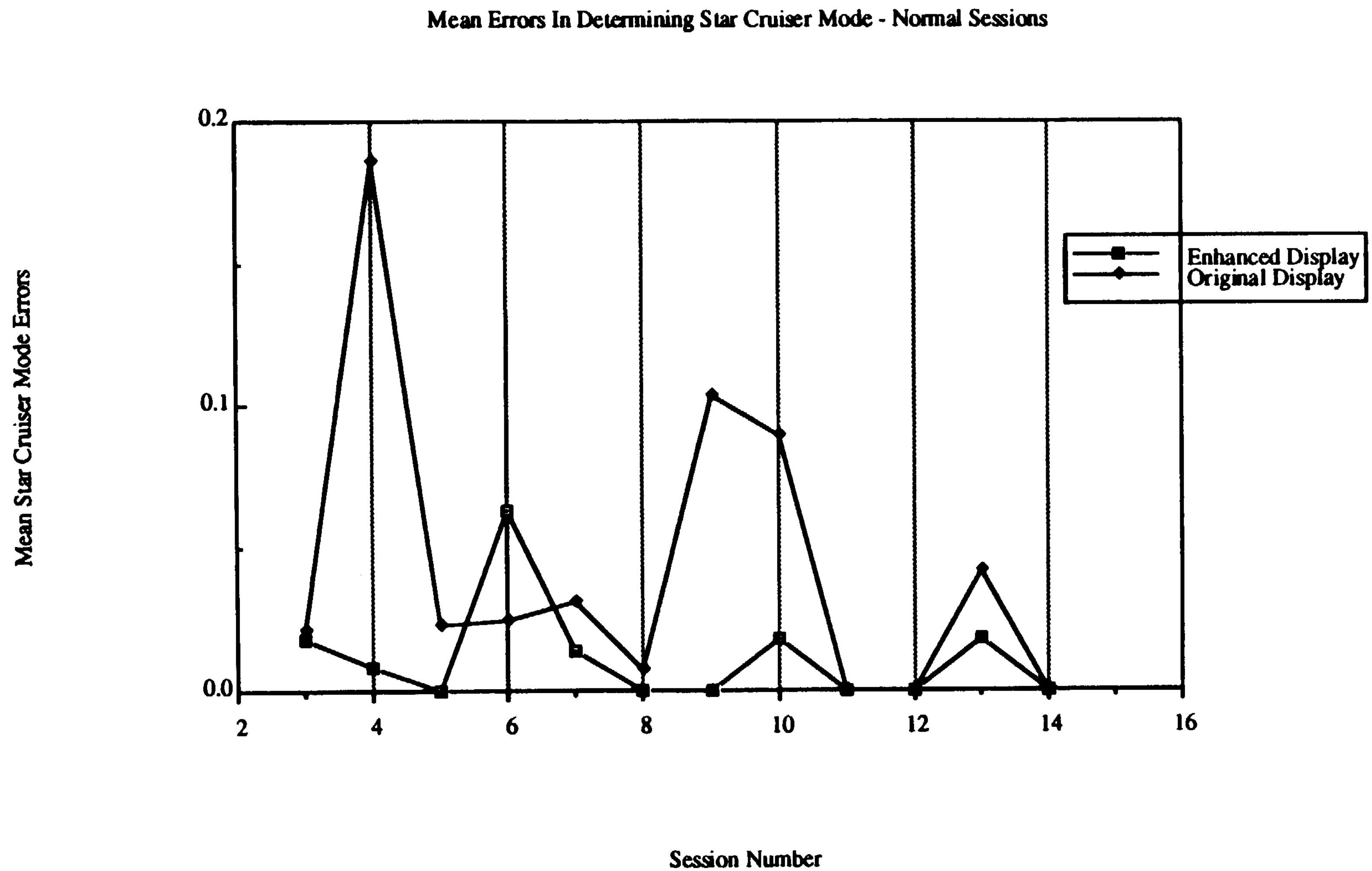

Figure 7-11. Mean Errors In Determining Star Cruiser Mode - Normal Sessions

Display type, and Subject. Also of interest were the nested effect of Session within Condition and the interaction effect of Condition and Display.

Overall Performance

Upon performing an analysis of variance on this data, two of the effects tested, Display [$F = 5.51$; $p = 0.0236$] and Subject [$F = 3.16$; $p = 0.0016$], appeared to be significant. The interaction effect of Condition and Display was determined not to be significant [$F = 2.13$; $p = 0.1514$]. The mean score for the subjects using the enhanced display on the premath sessions was 13256.3 with a standard deviation of 7194.8. When presented with the task of performing math problems simultaneously, the mean score for this group increased slightly to 13289.9 with a standard deviation of 4521.2. The subjects using the original display, during the premath sessions, had a mean score of 12254.8 with a standard deviation of 5023.1. When given the math sessions, the original display subjects' mean score was 8988.0 with a standard deviation of 5559.4. These results are displayed in Figure 7-12. The subject group mean scores for the math sessions are also plotted next to the scores from Sessions 3 through 14 for comparison in Figure 7-13.

Another possible way to measure overall performance is to monitor the number of correct answers to the math problems. Doing so would show that the subjects using the enhanced display responded to the math problems with a mean percentage of 0.940 correct answers with a standard deviation of 0.049. The other subjects had a mean percentage of 0.980 with a standard deviation of 0.019. One important factor though, prevents this data from providing a realistic assessment of the situation when analyzed. As was witnessed during the actual experiment, there is no correlation between percentage of correct answers and the subject's performance at **Star Cruiser**. For example, a subject may score very high during the cruiser task and either get a high or low percentage of correct answers. On the other hand, the subject

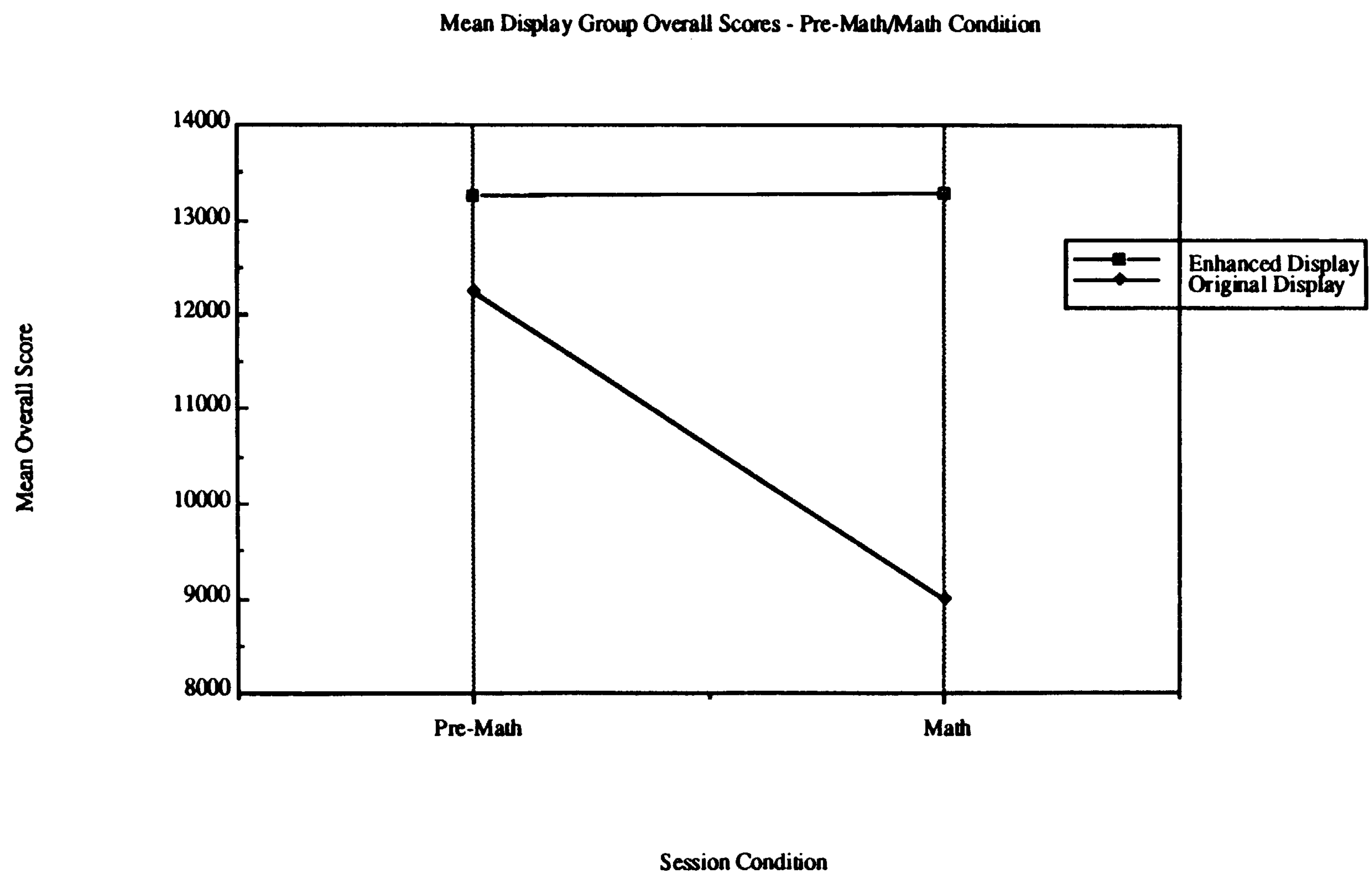

Figure 7-12. Mean Display Group Overall Scores - Pre-Math/Math Condition

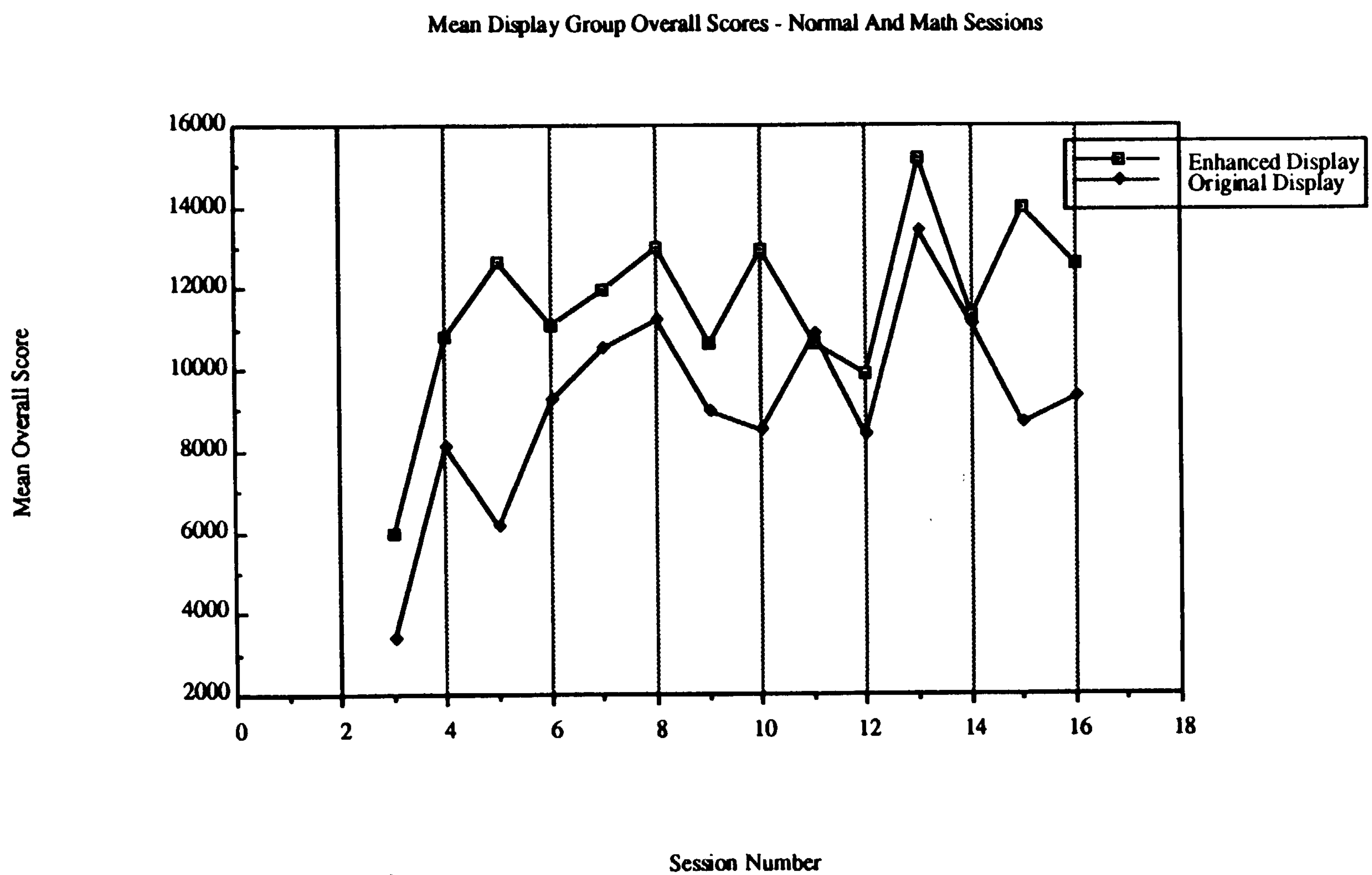

Figure 7-13. Mean Display Group Overall Scores - Normal And Math Sessions

may crash the cruiser early in the session and also either get a high percentage of correct answers (since not many problems were presented before the session ended and those few were answered correctly) or a low percentage. Therefore, as previously stated, analyzing the data associated with the percentage of correct answers to the math problems would not help in the determination of which interface is the most beneficial with respect to overall task performance.

Colored Field / Background Colors Of Collection Tools

The only occurrence of selecting a wrong tool was with the subjects using the original display during the premath sessions. A mean of 0.063 errors, with a standard deviation of 0.250, was committed. No significant effects were revealed from an analysis of variance of this data.

'X' - Out Tools When They Cannot Be Deployed

No significant effects were discovered after performing an analysis of variance on the number of selection errors committed by the subjects. The mean number of errors committed by the subjects using the enhanced display during the premath sessions was 1.188 with a standard deviation of 3.763. These subjects, however, did not commit any such errors during the math sessions. On the other hand, those using the original display committed a mean of 0.125 errors with a standard deviation of 0.342 while answering the math problems. The same subjects had a mean of 0.063 errors with a standard deviation of 0.250 during the premath sessions.

Change Color Of Deployment / Retrieval String

An analysis of variance performed on the number of retrieval / deployment errors committed revealed that all effects were significant. These effects include Condition [$F = 99999.99$; $p = 0.0001$], Display [$F = 99999.99$; $p = 0.0001$], Subject [$F = 99999.99$; $p = 0.0001$], Session nested within Condition [$F = 99999.99$; $p = 0.0001$], and the interaction of Condition and Display [$F = 99999.99$; $p = 0.0001$]. Subjects using the enhanced display committed a mean of 5.19 errors with a standard deviation of 5.96 during the premath sessions and a mean of 4.25 errors with a standard deviation of 3.36 during the math sessions. Those using the original display committed a mean of 19.75 errors with a standard deviation of 16.88 during the premath sessions and a mean of 15.25 errors with a standard deviation of 15.61 during the math sessions. These results are plotted in Figure 7-14. As mentioned, Session nested within Condition was a significant effect for this performance measure. The subjects, both groups combined, for Sessions 13, 14, 15, and 16, committed a mean of 10.98 errors (standard deviation of 13.06), 14.00 errors (standard deviation of 16.06), 10.94 errors (standard deviation of 13.85), and 8.56 errors (standard deviation of 11.17) respectively. These means are charted in Figure 7-15.

Use Ghost Images

No effects were found significant after performing an analysis of variance. Condition [$F = 4.03$; $p = 0.0511$] and Display [$F = 4.03$; $p = 0.0511$], however, were close enough to being significant to warrant mention. The data for this performance measure are pictured in Figure 7-16. The mean number of tools out of commission for the enhanced display subjects during the premath sessions to be 0.313 with a standard deviation of 0.793. During the math sessions, the mean was 0.688 with a standard deviation of 0.793. The performance of subjects using the original version resulted in a mean of 0.063 tools out of commission with a standard deviation of 0.250 without the math problems and a mean of 0.313 with a standard deviation of 0.602 while answering the problems.

Alter Star Cruiser Capacity Gauges

The mean percent utilization of Star Cruiser's capacity by the enhanced display subjects was 0.628 with a standard deviation of 0.101 during the premath sessions.

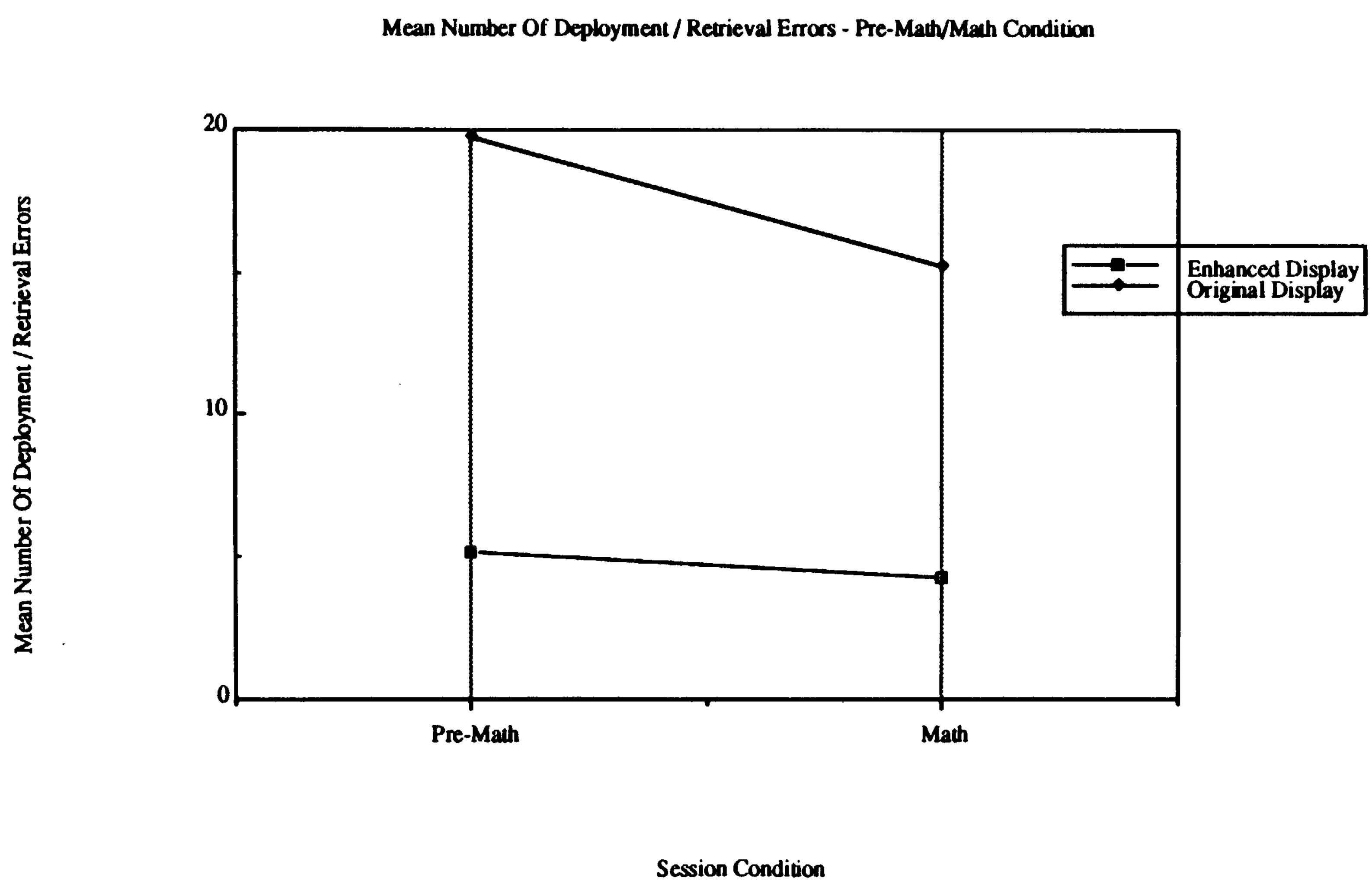

Figure 7-14. Mean Number Of Deployment / Retrieval Errors - Pre-Math/Math Condition

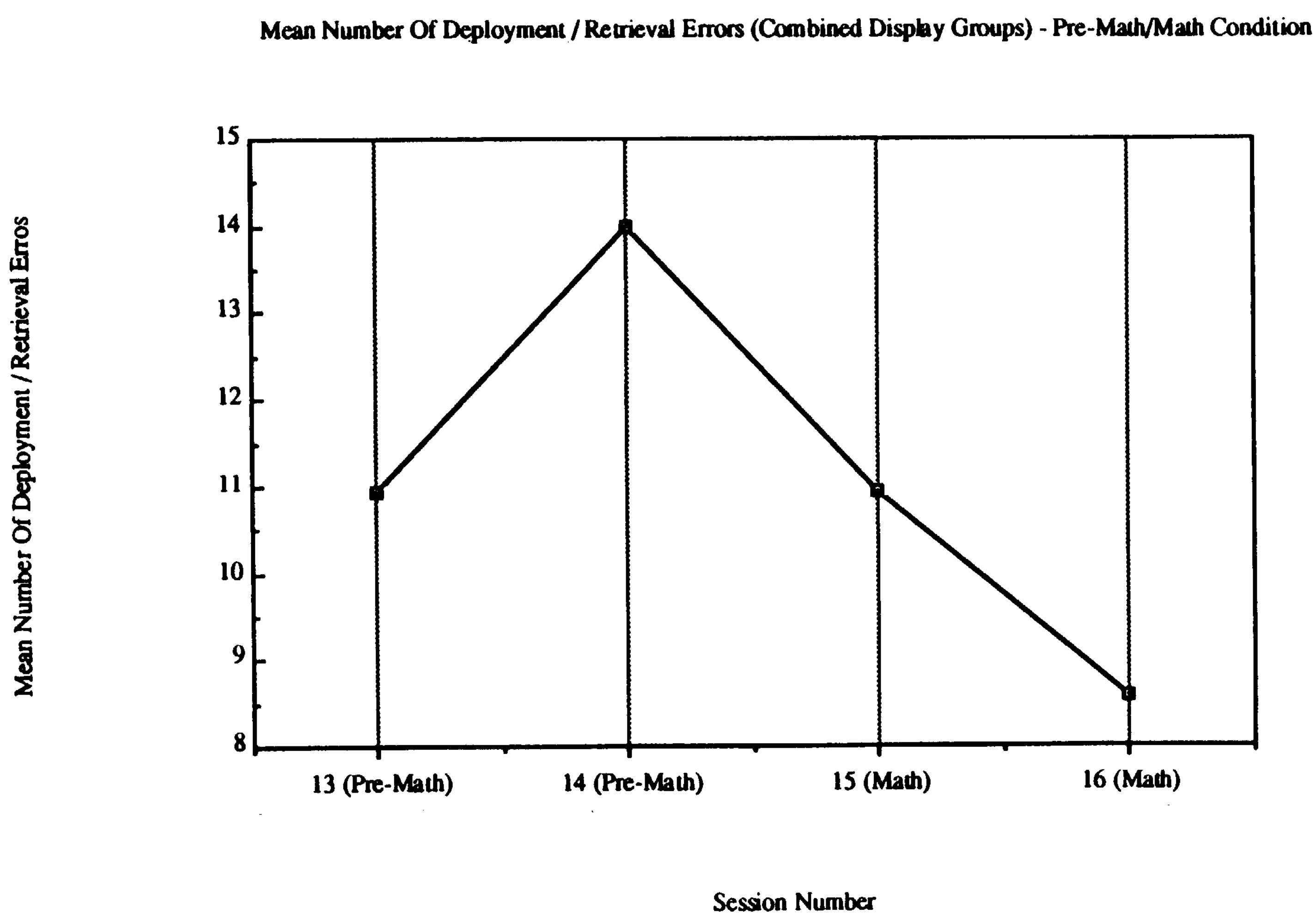

Figure 7-15. Mean Number Of Deployment / Retrieval Errors (Combined Display Groups) - Pre-Math/Math Condition

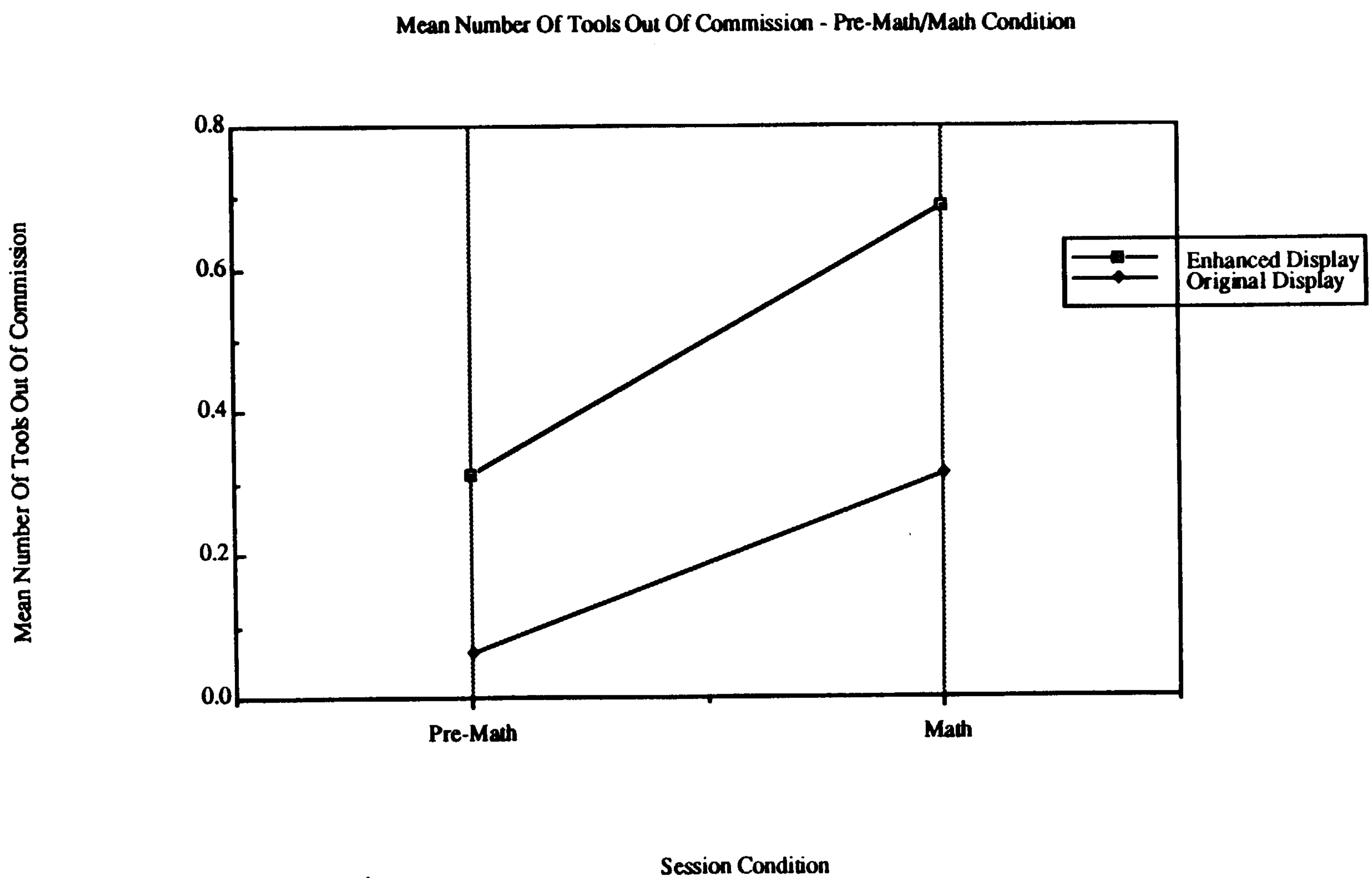

Figure 7-16. Mean Number Of Tools Out Of Commission - Pre-Math/Math Condition

During the math sessions the mean percentage for this group was 0.557 with a standard deviation of 0.133. The subject group using the original display utilized a mean percentage of 0.590 of Star Cruiser's capacity with a standard deviation of 0.184 during the premath sessions. The same group of subjects' mean percentage for the math sessions was 0.591 with a standard deviation of 0.205. None of the effects tested during the analysis of variance were found to be significant.

<u>White 'X' For Ninth Orbit</u>

The mean time required for the subjects with the enhanced display to place the cruiser into orbit was 6.94 seconds with a standard deviation of 2.13 during the premath sessions. During the math sessions, the mean time was 8.04 seconds with a standard deviation of 2.00. Subjects using the original display required a mean time of 15.99 seconds with a standard deviation of 12.76 during the premath sessions. While being administered the math problems, the original subjects mean time was 15.46 seconds with a standard deviation of 6.72. An analysis of variance found that none of the effects of question were significant.

<u>Purple Highlight For Cruiser Speed (Orbiting)</u>

An analysis of variance performed on the number of thrusts required for the cruiser to be placed into orbit found that Display [$F = 46.38$; $p = 0.0001$] and Subject [$F = 6.21$; $p = 0.0001$] were both significant effects. A mean of 2.85 thrusts with a standard deviation of 0.80 was required by subjects participating in the premath sessions using the enhanced display. For the math sessions, the same subjects required a mean of 3.07 thrusts with a standard deviation of 0.60. Those subjects using the original display used a mean of 9.30 thrusts with a standard deviation of 8.88 during sessions 13 and 14 and a mean of 8.98 with a standard deviation of 6.08 during the later two sessions. These results have been plotted in Figure 7-17.

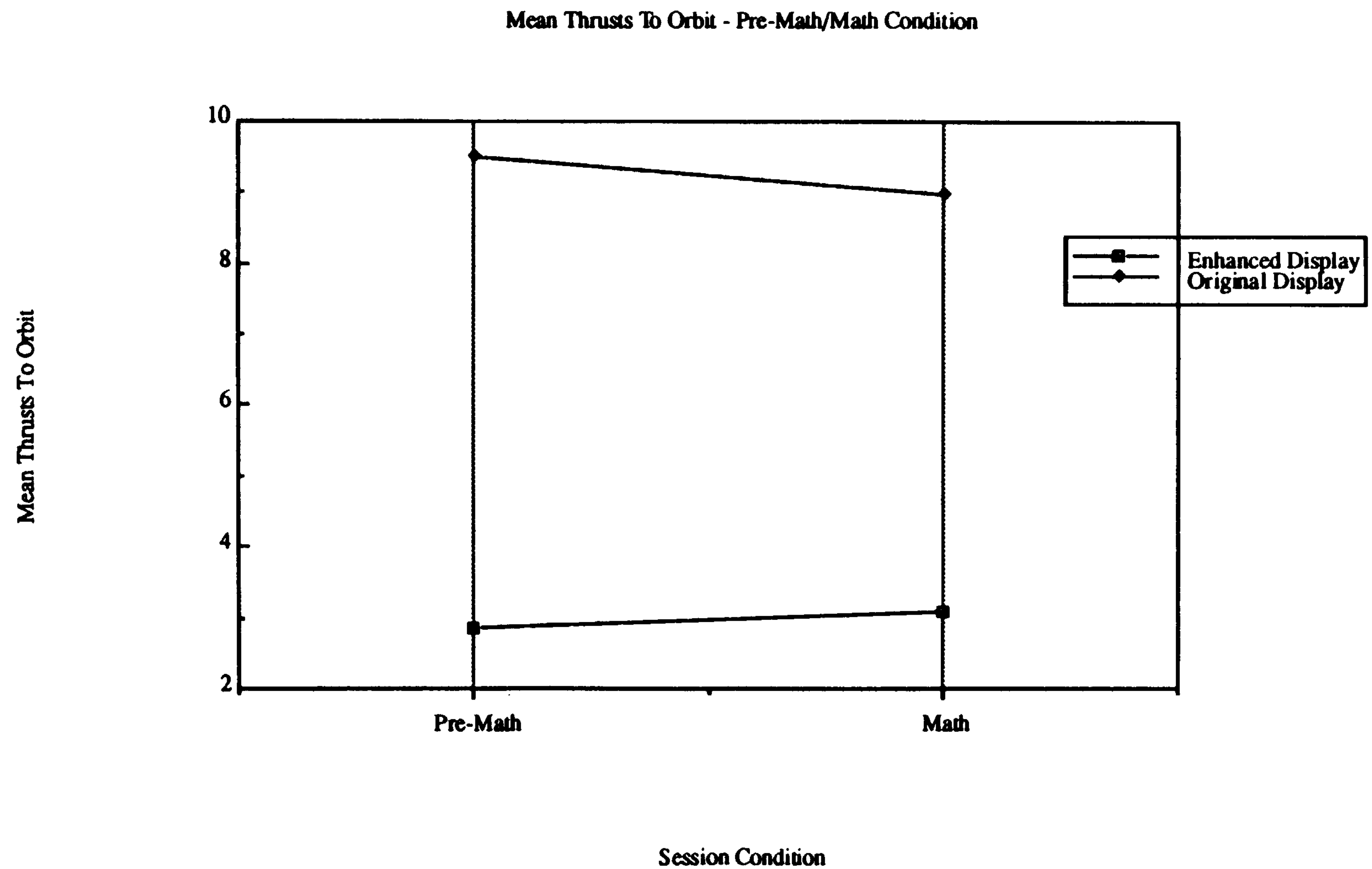

Figure 7-17. Mean Thrusts To Orbit - Pre-Math/Math Condition

Purple Highlight For Cruiser Speed (Docking)

The mean docking time required of the subjects using the enhanced display during the premath sessions was 3.91 seconds with a standard deviation of 1.57 while during the math sessions it was 4.18 with a standard deviation of 1.00. The original display subjects for the premath sessions required a mean docking time of 4.51 seconds with a standard deviation of 2.01. For the math sessions, their mean docking time was 4.57 with a standard deviation of 2.45. No effects were found to be significant after performing an analysis of variance on this data.

The other performance measure for this display enhancement, number of thrusts required to dock the cruiser, did have significant effects. Display [$F = 4.87$; $p = 0.0332$] and Subject [$F = 2.25$; $p = 0.0234$] were found to be significant after performing the necessary analysis of variance. The original display subjects required a mean of 2.36 thrusts with a standard deviation of 1.08 for the premath sessions and a mean of 2.28 thrusts with a standard deviation of 1.12 for the math sessions. The subject group using the enhanced display required a mean of 2.04 thrusts to dock with a standard deviation of 0.71 for the premath sessions. During the math sessions, they required a mean of 1.75 thrusts with a standard deviation of 0.40. This data is graphed in Figure 7-18.

Change Meaning Of The Color Of The Suns

An analysis of variance on this performance measure, the average amount of commodities in visited or probed solar systems, revealed that Condition [$F = 13.77$; $p = 0.0006$], Display [$F = 20.20$; $p = 0.0001$], Subject [$F = 7.57$; $p = 0.0001$], and Session nested within Condition [$F = 10.85$; $p = 0.0002$] were all significant. The mean amount of commodities in the solar systems for the enhanced display subjects in the premath sessions was 731.7 with a standard deviation of 112.7. For the math sessions, the mean amount was 618.9 with a standard deviation of 103.6. The subject group using the

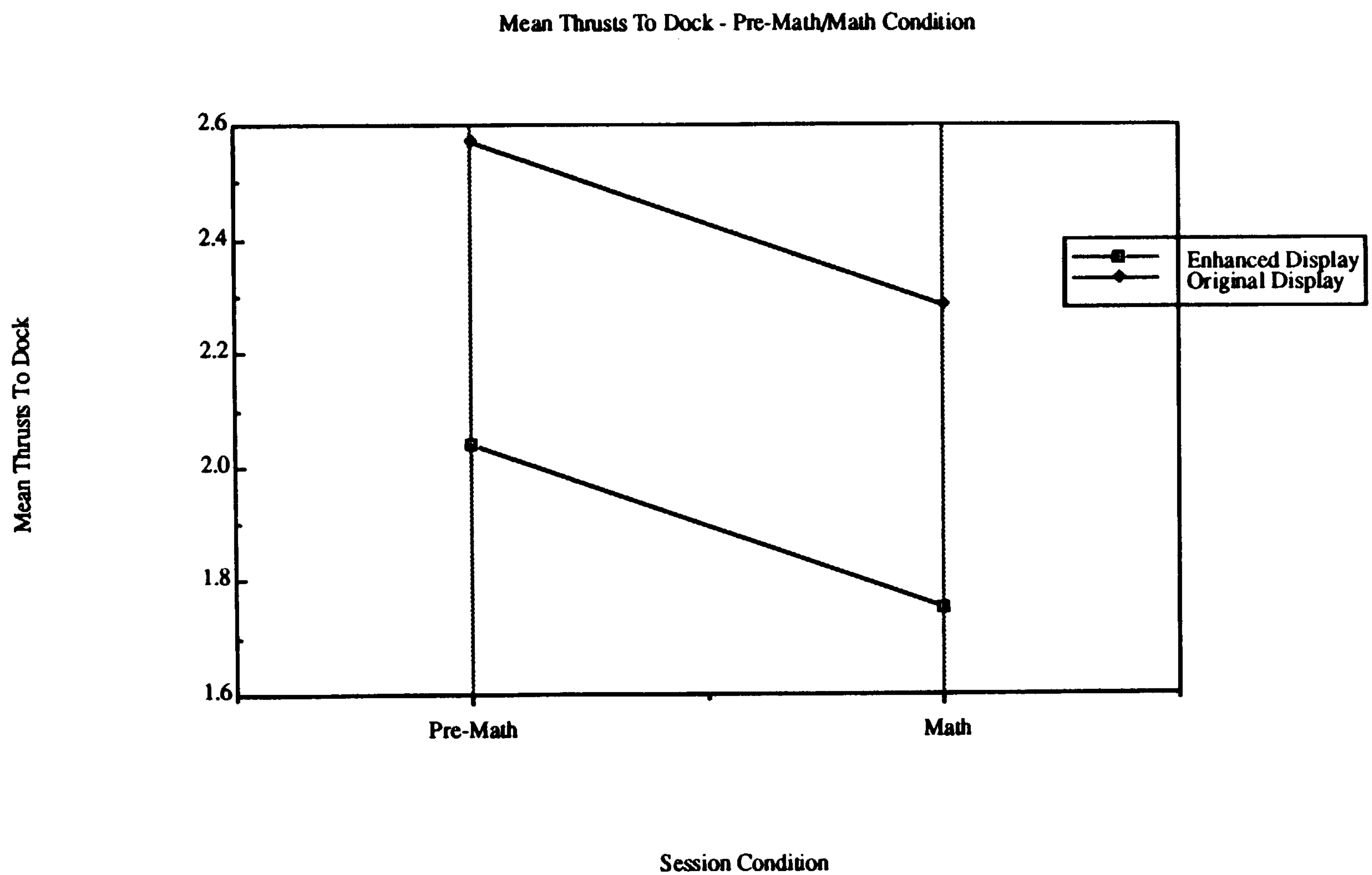

Figure 7-18. Mean Thrusts To Dock - Pre-Math/Math Condition

original display visited solar systems with a mean amount of commodities of 639.4 with a standard deviation of 159.2 during the premath sessions and a mean of 545.6 with standard deviation of 156.8 for the math sessions. As the subjects performed the task using sessions 13, 14, 15, and 16, the mean amounts of commodities contained by the visited solar systems in each session was 778.2 (standard deviation of 97.2), 592.9 (standard deviation of 121.8), 569.3 (standard deviation of 154.9) and 595.3 (standard deviation of 117.7) respectively. The mean amounts across Condition and Display type have been plotted in Figure 7-19. The means across Session have been graphed in Figure 7-20.

Blue 'X' For Empty Solar Systems

Subjects in neither group ever entered an empty solar system during the math sessions. They did, however, do so during the premath sessions. Those subjects using the enhanced display entered an empty solar system a mean of 0.500 times with a standard deviation of 1.033. The users of the original display entered empty systems a mean of 0.438 times with a standard deviation of 0.814. These results are depicted in Figure 7-21. An analysis of variance conducted on this performance measure revealed that Condition [$F = 8.55$; $p = 0.0055$] was a significant effect.

Red Highlight For Cruiser Mode

There were only a few occurrence of errors resulting from not knowing what mode Star Cruiser was in during these four sessions. Subjects using the enhanced display had a mean of 0.009 errors with a standard deviation of 0.036 during the premath sessions and a mean of 0.028 with a standard deviation of 0.077 during the math sessions. The subject group using the original display committed a mean of 0.021 errors with a standard deviation of 0.083 during the premath sessions and, during the math sessions, a mean of 0.016 with a standard deviation of 0.063. An analysis of variance performed on this data did not reveal any significant effects.

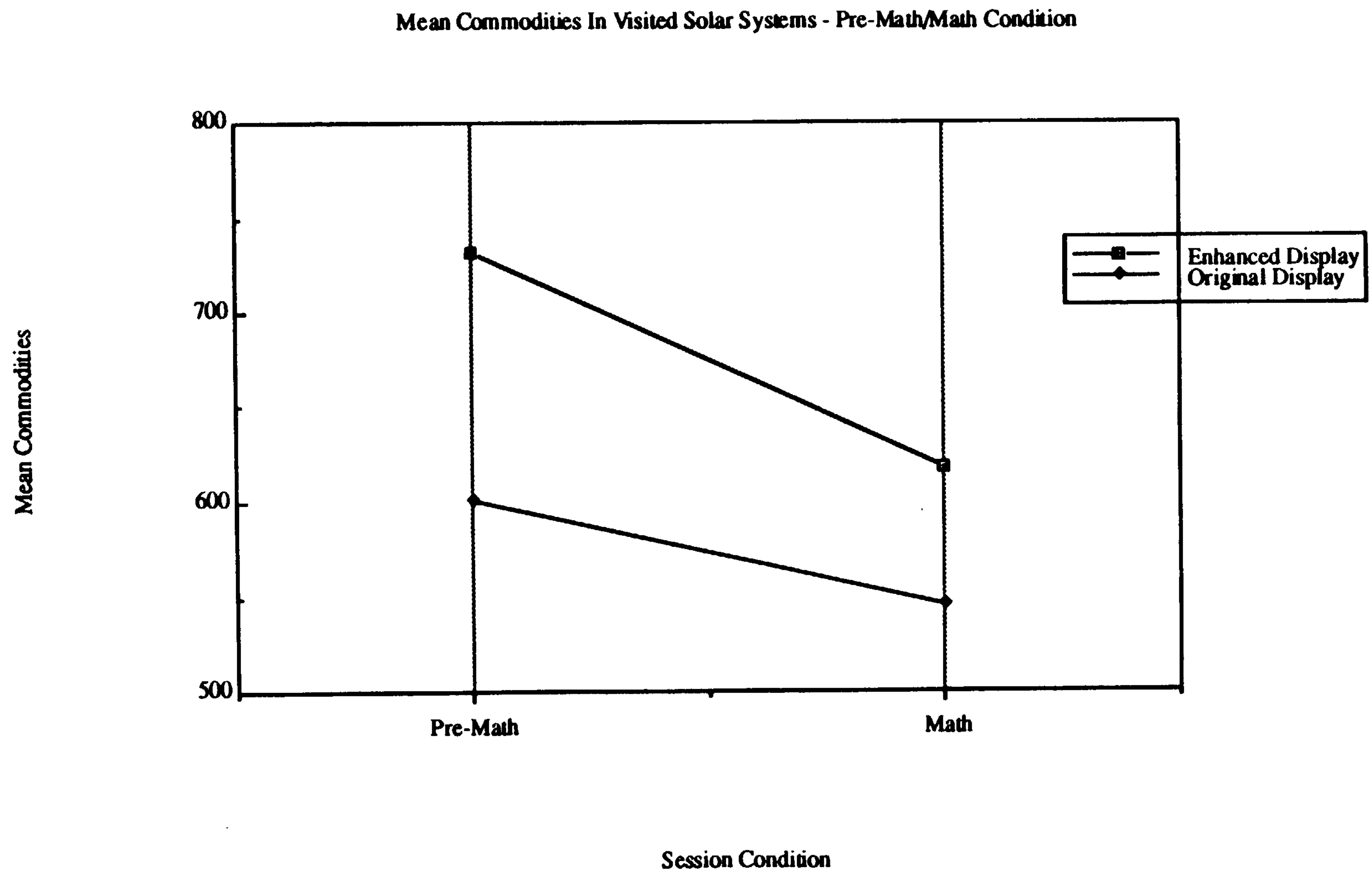

Figure 7-19. Mean Commodities In Visited Solar Systems - Pre-Math/Math Condition

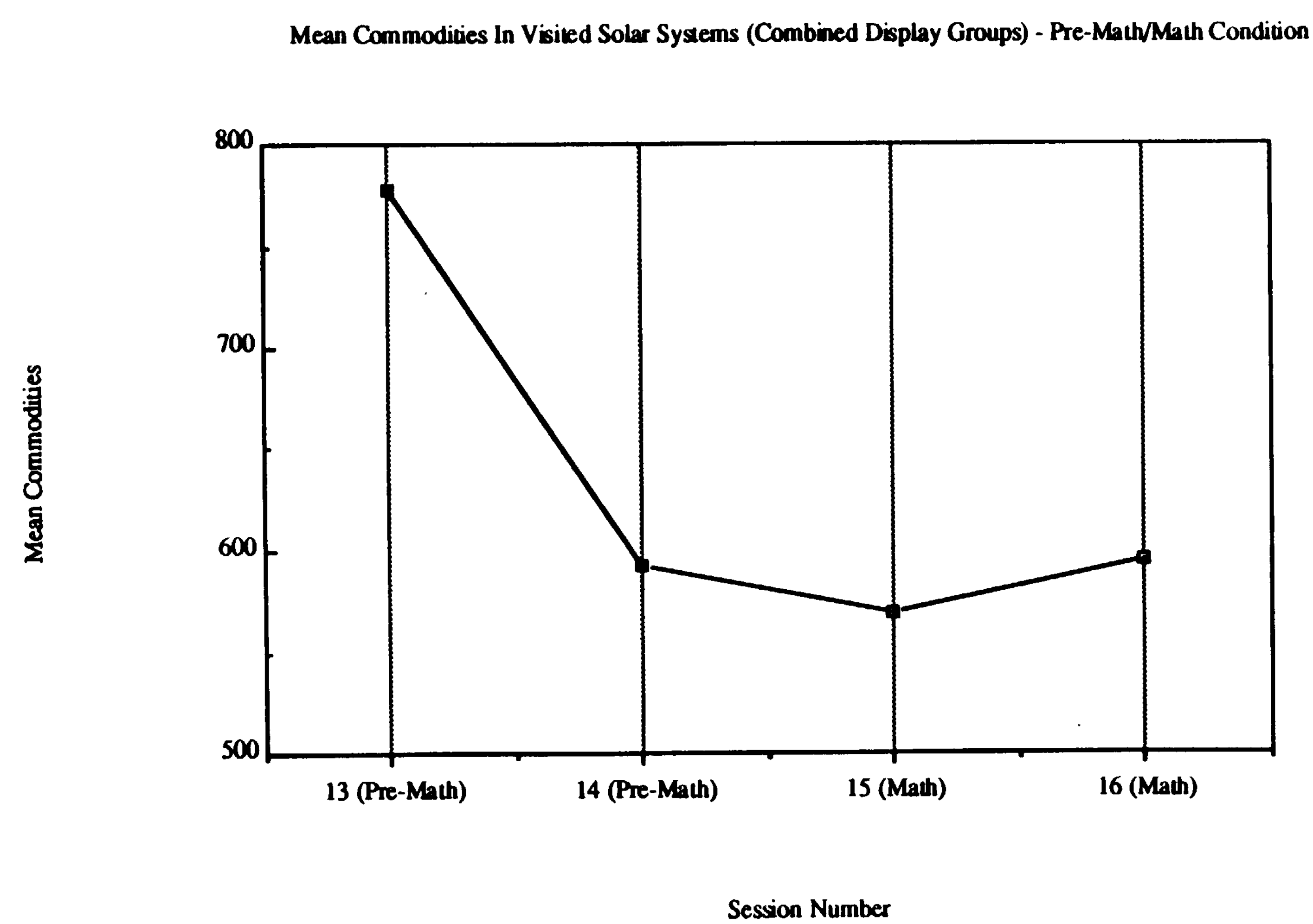

Figure 7-20. Mean Commodities In Visited Solar Systems
(Combined Display Groups) - Pre-Math/Math Condition

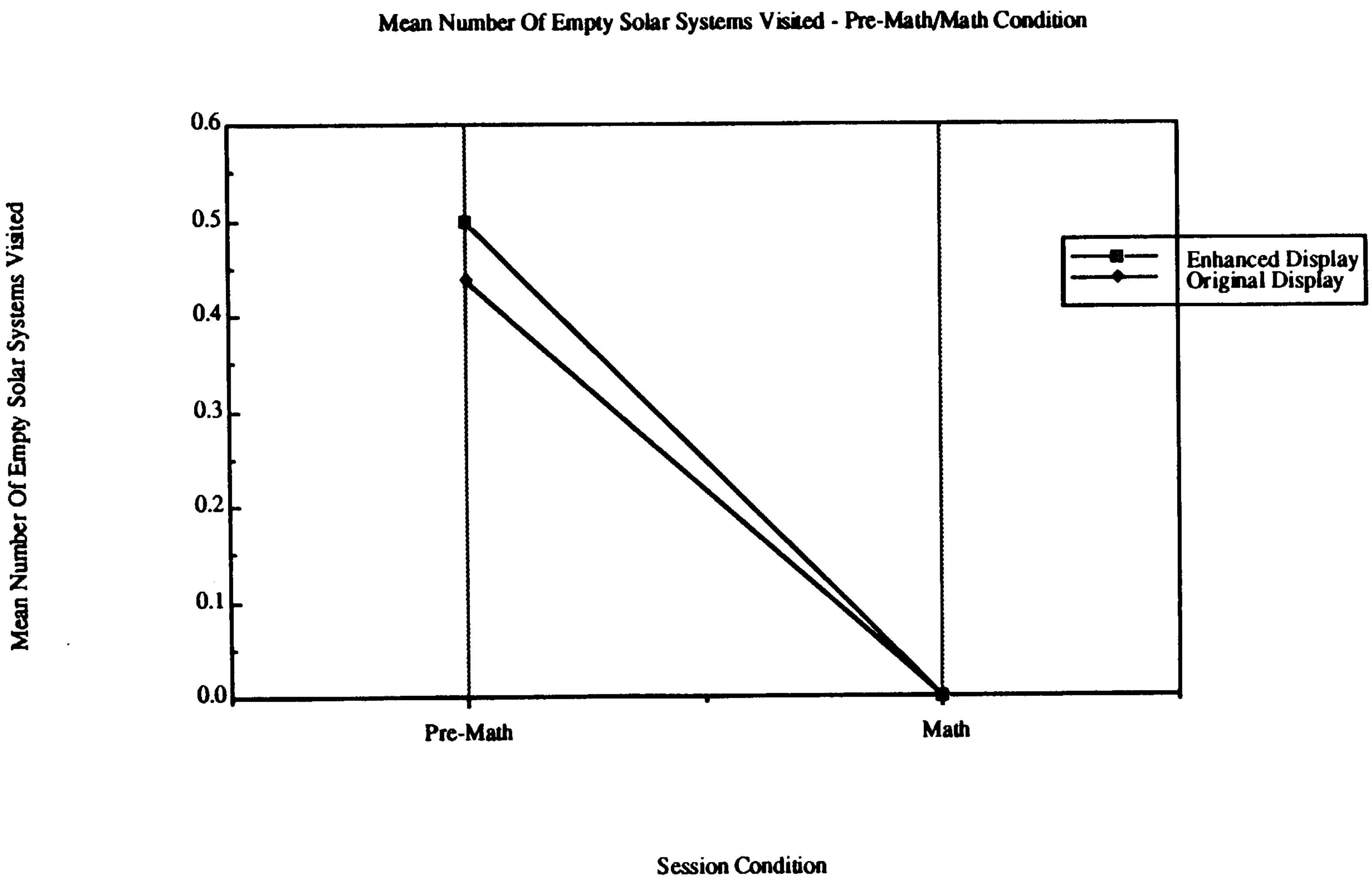

Figure 7-21. Mean Number Of Empty Solar Systems Visited - Pre-Math/Math Condition

Sessions 17 And 18: Transfer To Other Display

These two sessions had the subjects performing the task as usual with the one exception of switching to the other display. As with the sessions involving the math problems, subject performance on these sessions were compared to Sessions 13 and 14 (previously referred to as the "premath" sessions). Since the means and standard deviations associated with each performance measure for Sessions 13 and 14 are the same as reported in the preceding section, they will not be repeated in the following discussion. They are presented, however, in Table 7-2 for reference purposes. As a reminder, these are the results obtained while the subjects were using the same display as they had been throughout the normal sessions. The data reported in the following sections are those that resulted from the subjects switching display types during Sessions 17 and 18. The analyses of variance performed on all of this data were used to determine the significance (alpha = 0.05) of the effects on performance associated with Condition (display used during normal sessions versus display transferred to for these sessions), Display type, Subject, Session nested within Condition, and the interaction effect between Condition and Display.

Overall Performance

When performing the task with the original display, those subjects who originally used the enhanced version had a mean score of 15878.6 with a standard deviation of 5485.9. The other subject group, having to use the enhanced display for these last two sessions, had a mean score of 14559.1 with a standard deviation of 3331.3. These mean scores are compared to the subject performances on Sessions 13 and 14 as depicted in Figure 7-22. In addition, the scores obtained for Sessions 17 and 18 are plotted alongside the scores from the normal sessions in Figure 7-23. When an analysis of variance was performed on this data, none

Table 7-2. Means And Standard Deviations Of Pre-Condition Sessions (Sessions 13 and 14)

		Original Display		Enhanced Display	
Display Enhancement	Performance Measure	Mean	Standard Deviation	Mean	Standard Deviation
Overall Performance	Mean Overall Score	12254.8	5023.1	13256.3	7194.8
Colored Field / Background Colors Of Collection Tools	Select Wrong Tools	0.063	0.250	0.000	0.000
'X' - Out Tools When They Cannot Be Deployed	Select Action Errors	0.063	0.250	1.188	3.763
Change Color Of Deployment / Retrieval String	Deployment / Retrieval Errors	19.75	16.88	5.19	5.96
Use Ghost Images	Tools Out Of Commission	0.063	0.250	0.313	0.793
Alter Star Cruiser Capacity Gauges	Utilization Of Star Cruiser Capacity	0.590	0.184	0.628	0.101
White 'X' For Ninth Orbit	Time To Orbit (sec.)	15.99	12.76	6.94	2.13
Purple Highlight For Cruiser Speed (Orbiting)	Thrusts To Orbit	9.30	8.88	2.85	0.80
Purple Highlight For Cruiser Speed (Docking - Time)	Time To Dock (sec.)	4.51	2.01	3.91	1.57
Purple Highlight For Cruiser Speed (Docking - Thrusts)	Thrusts To Dock	2.36	1.08	2.04	0.71
Change Meaning Of The Color Of The Suns	Commodities In Visited Solar Systems	639.4	159.2	731.7	112.7
Blue 'X' For Empty Solar Systems	Empty Solar Systems Visited	0.438	0.814	0.500	1.033
Red Highlight For Cruiser Mode	Errors In Determining Star Cruiser Mode	0.021	0.083	0.009	0.036

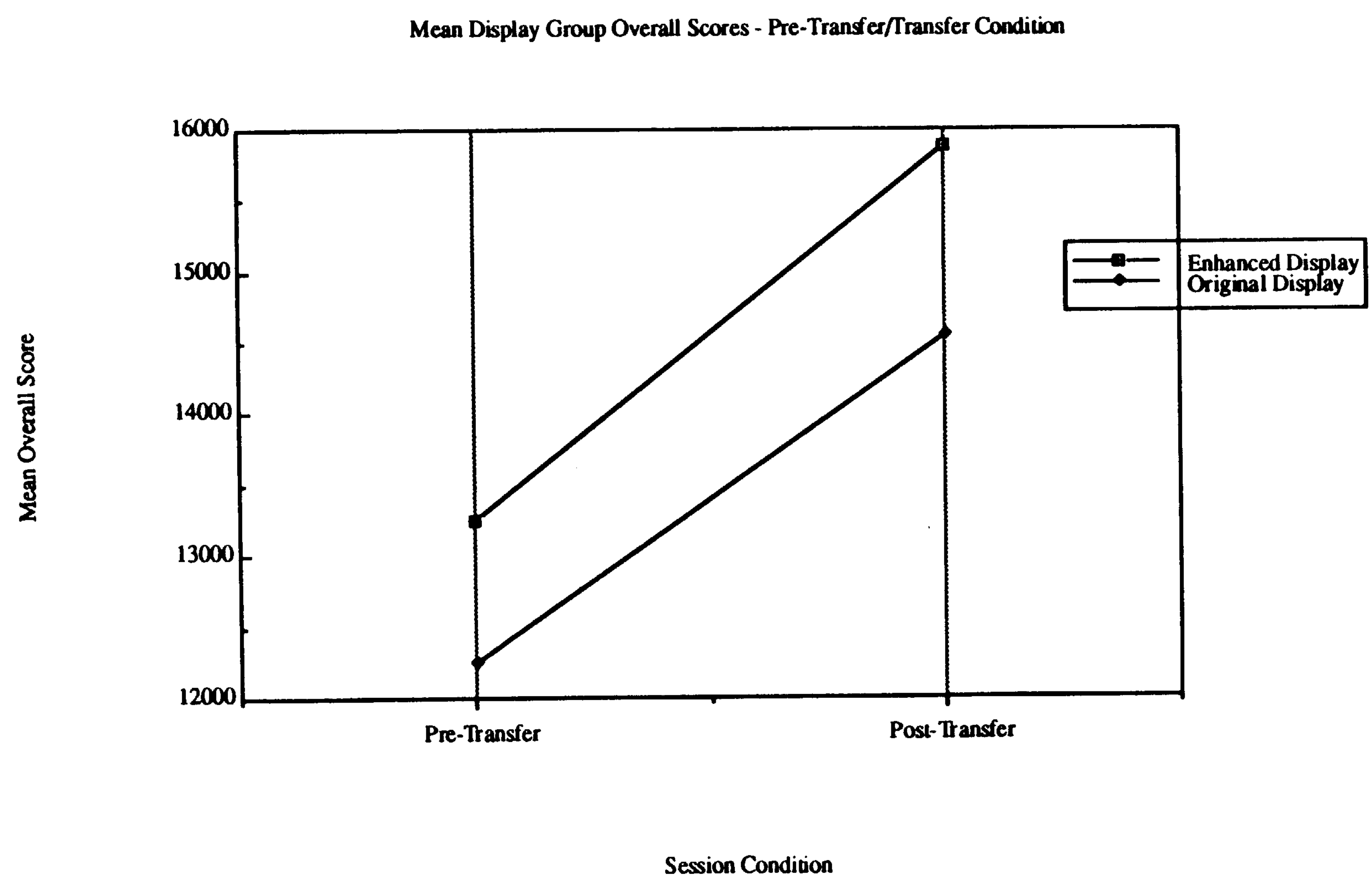

Figure 7-22. Mean Display Group Overall Scores - Pre-Transfer/Transfer Condition

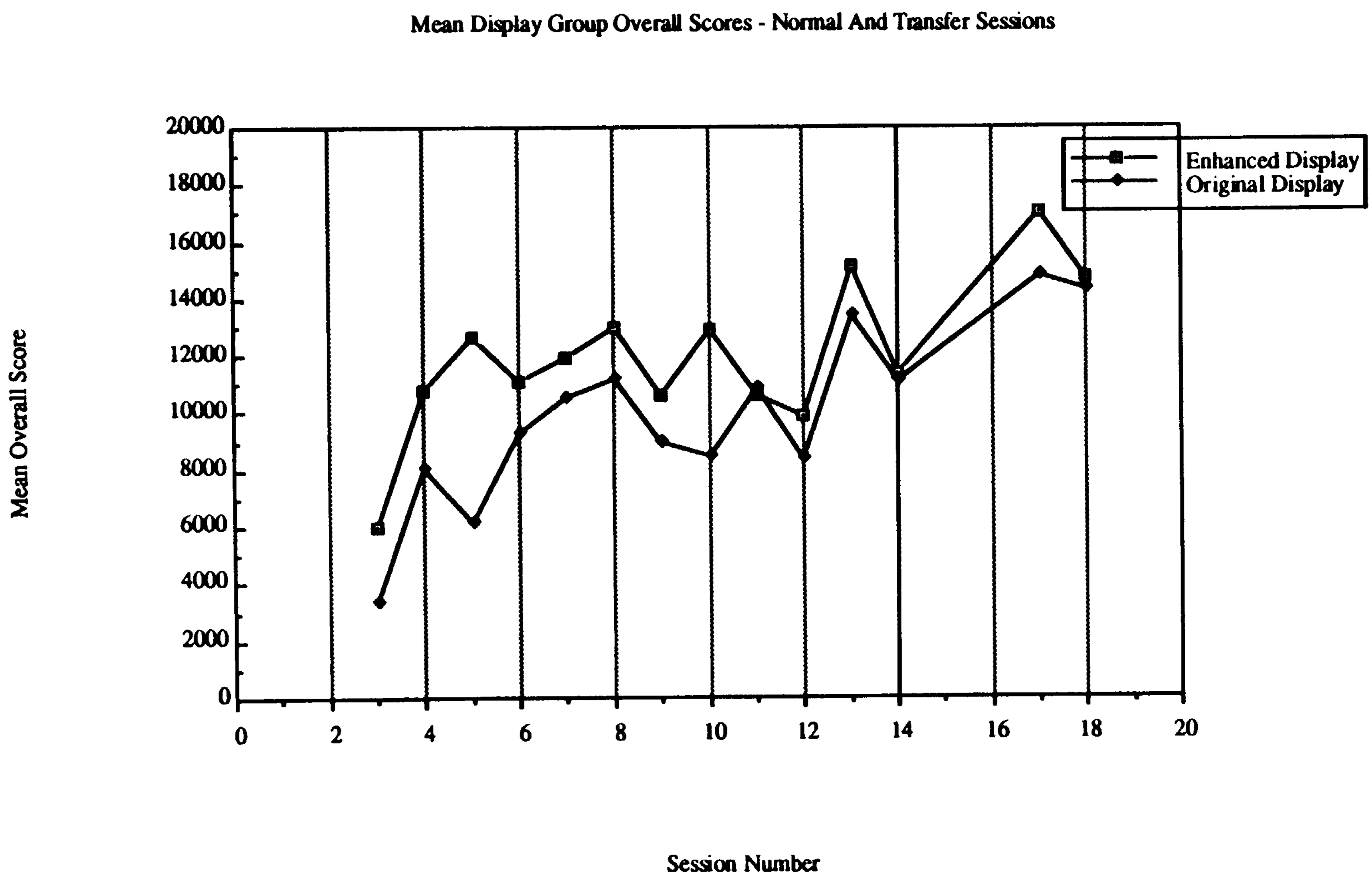

Figure 7-23. Mean Display Group Overall Scores - Normal And Transfer Sessions

of the effects were significant at the 0.05 level. The effect of Condition [F = 3.81; p = 0.0574] was, however, close to being significant.

Colored Field / Background Colors Of Collection Tools

None of the effects were significant when the analysis of variance was conducted on the performance measure of selecting the wrong tool. Neither subject group experienced any errors of this sort after they had switched displays.

'X' - Out Tools When They Cannot Be Deployed

The analysis of variance also showed that no significant effects existed for the performance measure of attempting to select a tool for deployment when it was not possible to do so. Few errors of this type occurred. A mean of 0.250 errors with a standard deviation of 0.683 was committed by those subjects who were presented the original display for the first time. The group which previously had performed the task using the original display and transferred to the enhanced version committed a mean of 0.063 errors with a standard deviation of 0.250.

Change Color Of Deployment / Retrieval String

The subject group which switched from the enhanced display to the original committed more deployment / retrieval errors than in the pretransfer sessions while the group which switched from the original display to the enhanced version had fewer such errors than before. This result is pictured in the graph in Figure 7-24. The group which switched to the original version committed a mean of 12.1 errors with a standard deviation of 9.2. The other group had a mean of 11.0 errors with a standard deviation of 7.5. An analysis of variance revealed that Display [F = 10.31; p = 0.0025] and Subject [F = 3.50; p = 0.0006] were significant main effects on this performance measure. The interaction effect of Condition and Display [F = 13.81; p = 0.0006] was also significant.

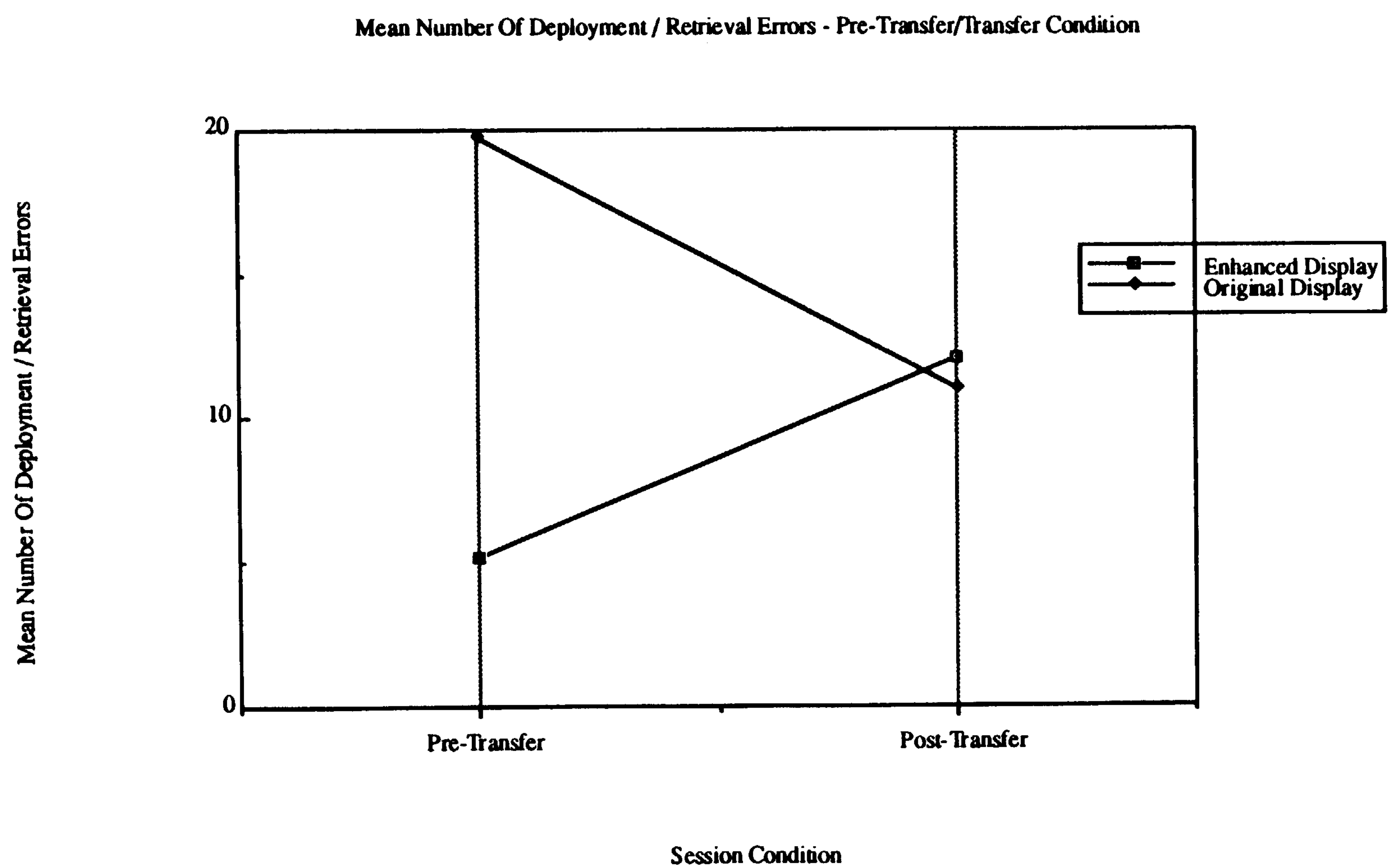

Figure 7-24. Mean Number Of Deployment / Retrieval Errors - Pre-Transfer/Transfer Condition

Use Ghost Images

When presented the original display in Sessions 17 and 18, the group which had only previously worked with the enhanced version had a mean of 0.313 tools go out of commission with a standard deviation of 0.873. The other group, having used the enhanced display for the first time in these later sessions, had a mean of 0.250 tools go out of commission with a standard deviation of 0.577. No measures, however, as tested by the analysis of variance, were found to be significant.

Alter Star Cruiser Capacity Gauges

The group which switched from the enhanced display to the original had a mean percentage of 0.726 with a standard deviation of 0.111. The other subject group which went from using the original version to the enhanced had a mean percentage of 0.692 with a standard deviation of 0.173. The analysis of variance though, did not reveal any significant effects.

White 'X' For Ninth Orbit

Switching the subject group from the enhanced display to the original resulted in their mean time to place the cruiser into orbit equaling 14.58 seconds with a standard deviation of 6.29. The other group's mean time, after being switched to the enhanced display, was 9.17 seconds with a standard deviation of 2.62. None of the differences resulting from the effects tested by the analysis of variance were found to be significant.

Purple Highlight For Cruiser Speed (Orbiting)

Having the subject groups switch displays affected the number of thrusts they required to place the cruiser into orbit. The subjects which switched to the original display increased their mean number of thrusts of 7.57 with a standard deviation of 3.52. The group using the enhanced display during Sessions 17 and 18 required fewer than before, committing a mean of 3.81 thrusts with a standard deviation of 0.94. An analysis of variance on this data showed that the effect of Subject [$F = 2.14$; $p = 0.0258$]

was significant and the interaction of Condition and Display [F = 22.86; p = 0.0001] was significant.

Purple Highlight For Cruiser Speed (Docking)

Those subjects that switched to the original display required a mean 3.55 seconds with a standard deviation of 1.64. The subjects who switched to the enhanced display needed 4.66 seconds to dock with a standard deviation of 1.13. None of the effects tested during the analysis of variance proved to be significant.

The mean number of thrusts to dock the cruiser required by the subject group which switched to the original display was 1.74 with a standard deviation of 0.63. Those using the enhanced display during Sessions 17 and 18 required a mean of 2.54 thrusts with a standard deviation of 0.90, a slight increase over the earlier two sessions. These changes are graphed in Figure 7-25. The effects of Display [F = 5.59; p = 0.0230] and Subject [F = 2.25; p = 0.0228] were determined to be significant by the analysis of variance.

Change Meaning Of The Color Of The Suns

An analysis of variance on the data indicating the average amount of commodities present in a visited or probed solar system revealed that Display [F = 7.38; p = 0.0095], Subject [F = 5.48; p = 0.0001], and Session nested within Condition [F = 8.56; p = 0.0007] were all significant effects. Subjects who switched to the original display version visited solar systems with a mean amount of commodities of

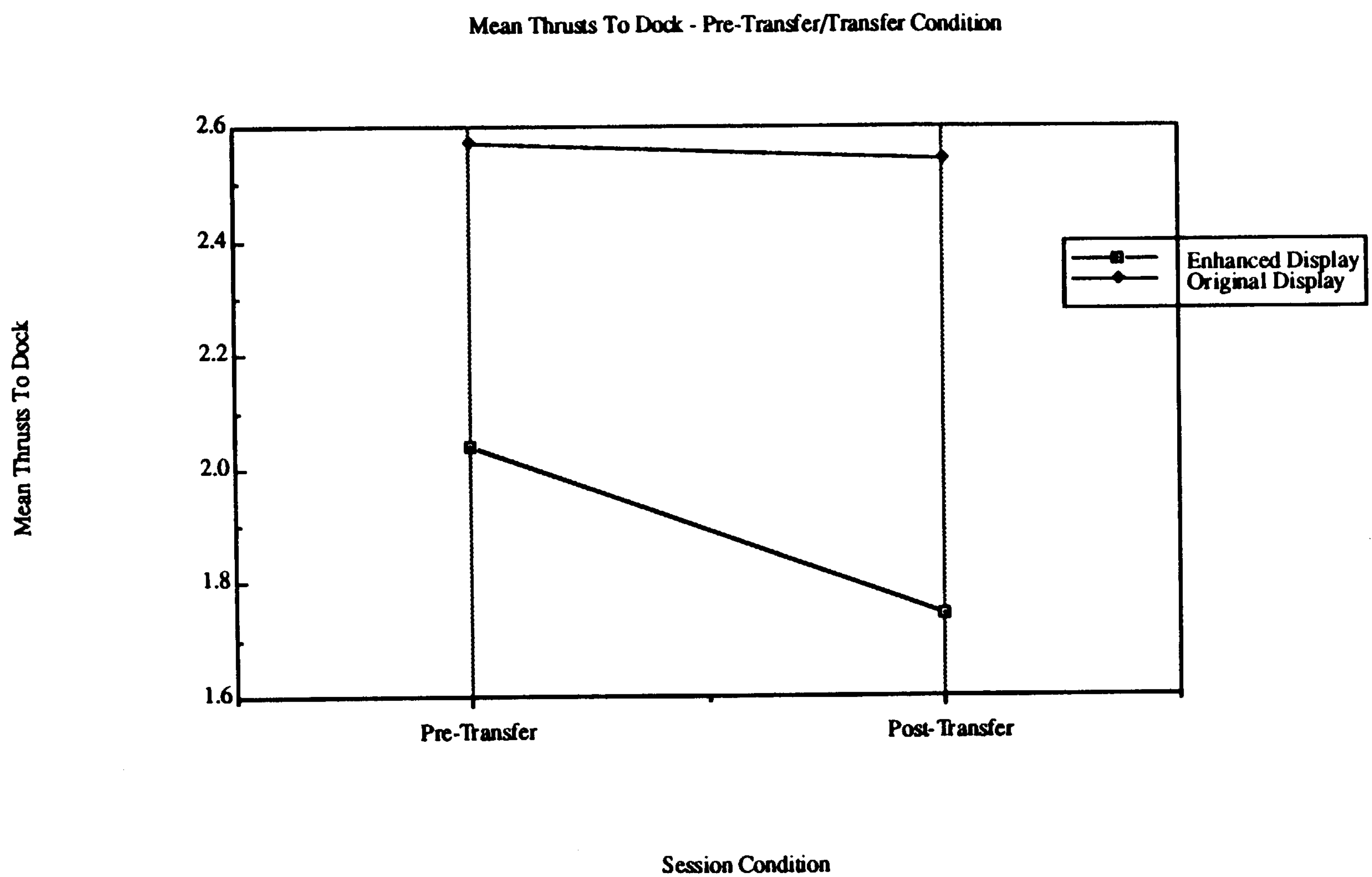

Figure 7-25. Mean Thrusts To Dock - Pre-Transfer/Transfer Condition

685.5 with a standard deviation of 91.1. Those whose display changed to the enhanced version visited solar systems with a mean amount of 662.2 with a standard deviation of 225.4. The fact that the mean for those using the enhanced version increased while that for the other group decreased compared to Sessions 13 and 14 can be seen in the graph in Figure 7-26. Figure 7-27 contains a graph showing the change in means over session. The mean amounts of commodities in visited solar systems for sessions 13, 14, 17, and 18 are 778.2 (standard deviation of 97.2), 592.9 (standard deviation of 121.8), 635.8 (standard deviation of 150.3), and 711.9 (standard deviation of 183.7) respectively.

Blue 'X' For Empty Solar Systems

The subject group which switched to the original display visited a mean of 0.063 empty solar systems with a standard deviation of 0.250. This result is the same as for the other group when they switched to the enhanced version. Both groups showed a reduction in the amount of empty solar systems visited when compared to Sessions 13 and 14 as depicted in Figure 7-28. Comparing these sets of results using an analysis of variance showed that Condition [F = 5.96; p = 0.0188] was a significant effect.

Red Highlight For Cruiser Mode

The analysis of variance did not reveal any significant effects. The subject group which switched to the original display from the enhanced committed a mean of 0.079 errors with a standard deviation of 0.148. The group which switched to the enhanced version from the original committed a mean 0.025 errors with a standard deviation of 0.070.

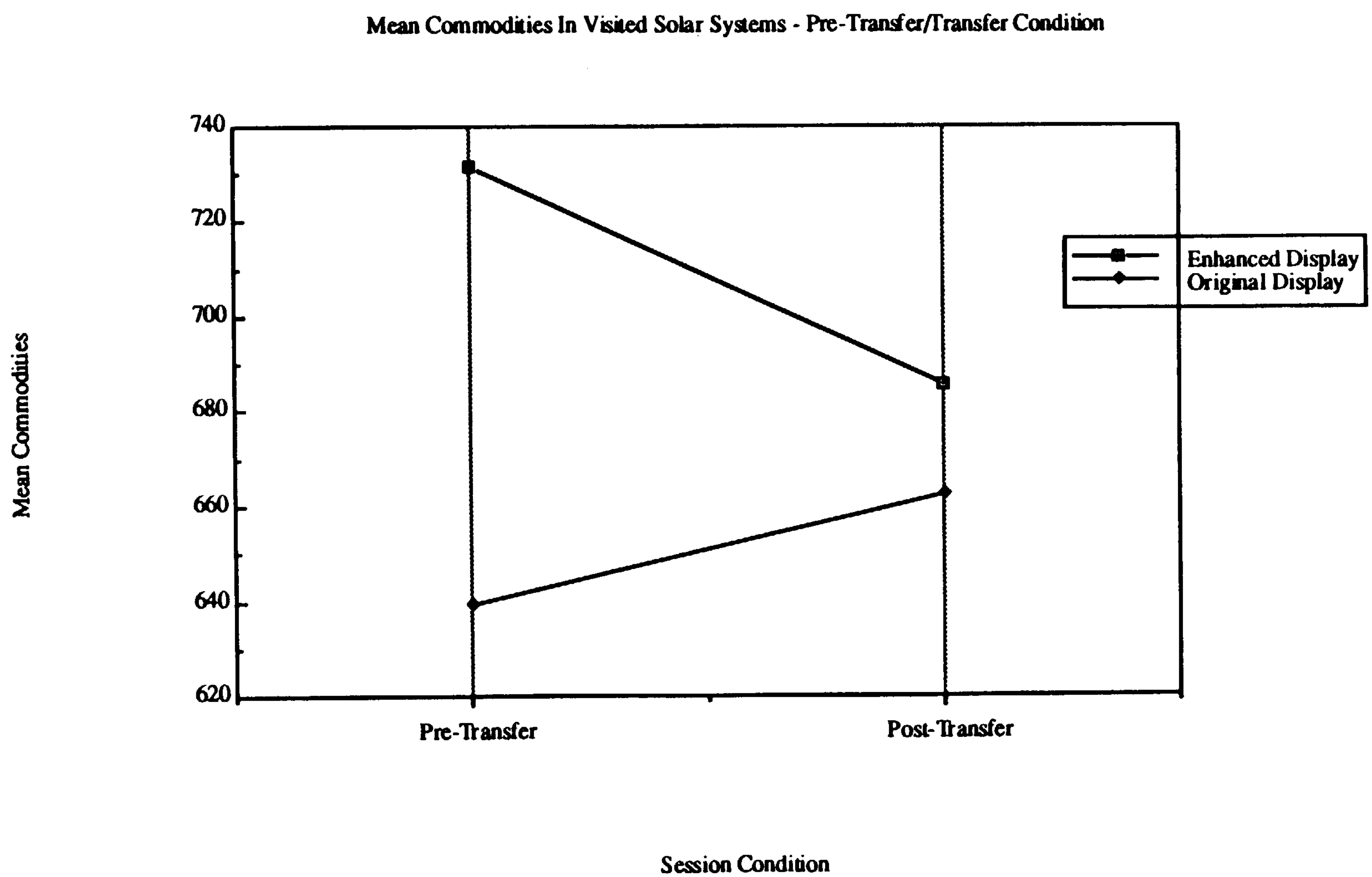

Figure 7-26. Mean Commodities In Visited Solar Systems - Pre-Transfer/Transfer Condition

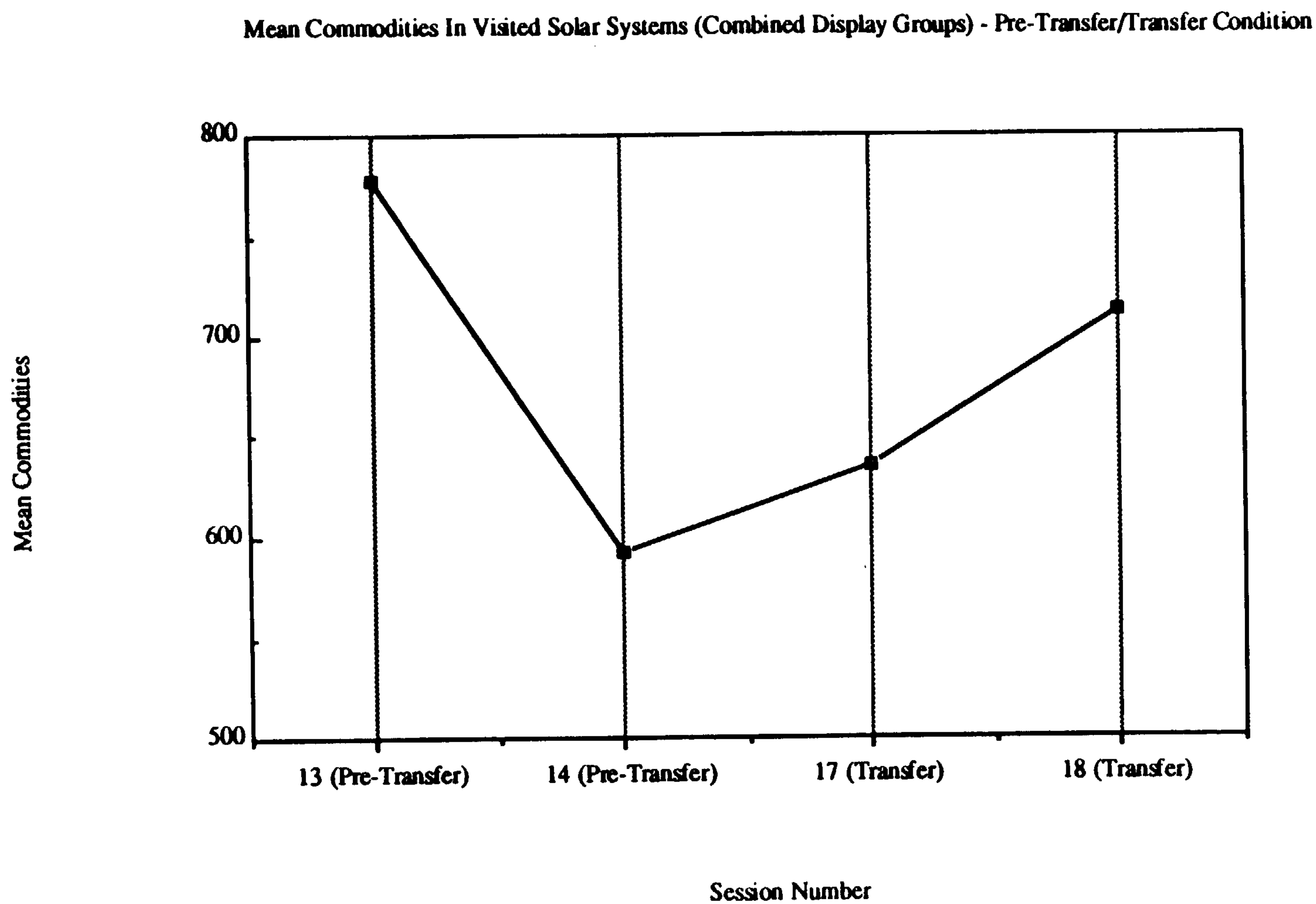

Figure 7-27. Mean Commodities In Visited Solar Systems (Combined Display Groups) - Pre-Transfer/Transfer Condition

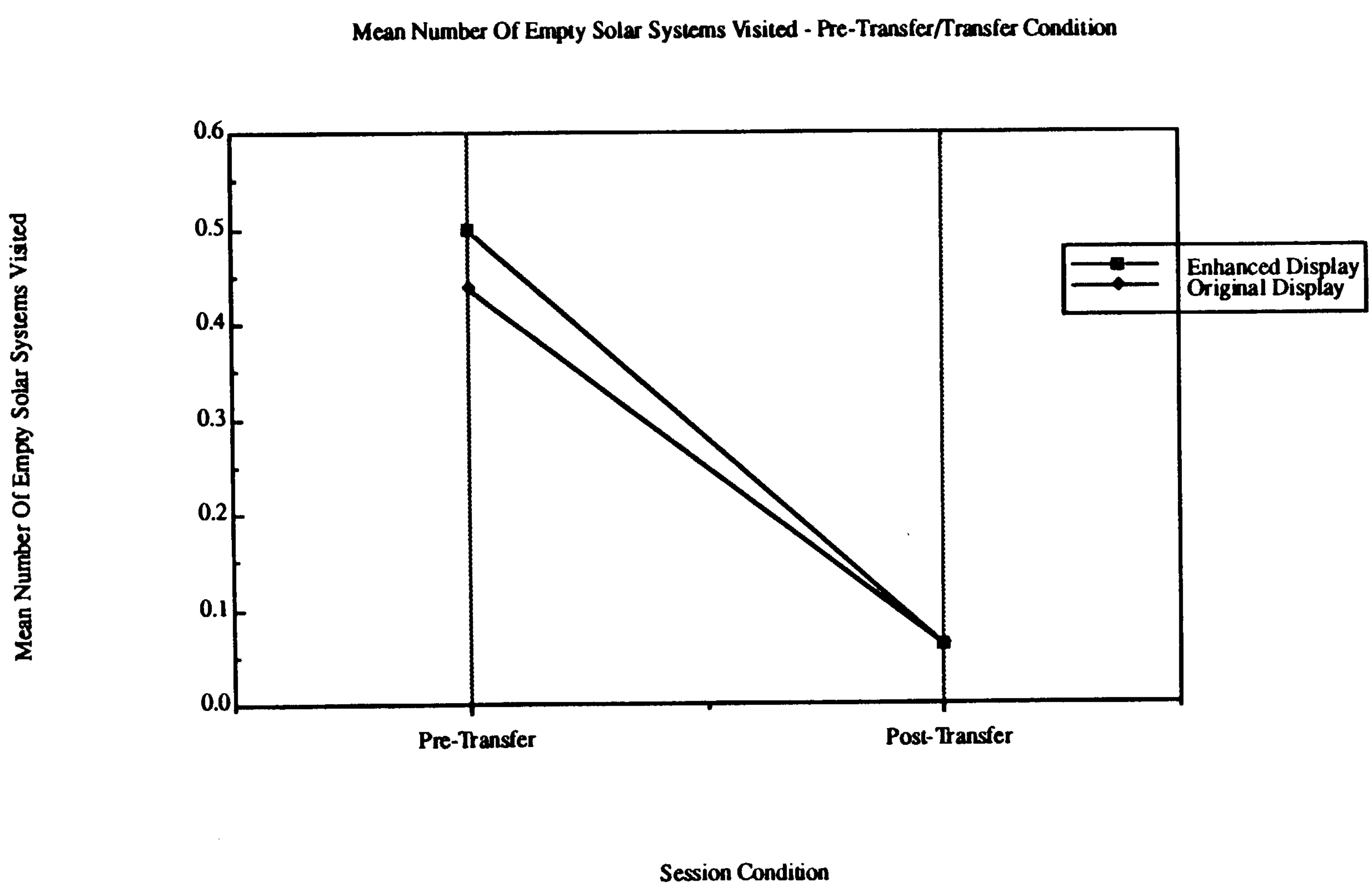

Figure 7-28. Mean Number Of Empty Solar Systems Visited - Pre-Transfer/Transfer Condition

CHAPTER VIII

DISCUSSION OF RESULTS

From the results just presented, it is apparent that the display enhancements made to **Star Cruiser** did indeed have a positive effect on subject performance. This conclusion is even true when one considers the effects of Subject variation. Such differences between the subjects generally led to high variances in the data within subject groups. The individual scenarios also appeared to account for some of the variation. Thus, they were not as similar, in respect to difficulty level, as believed when creating them. Since, however, each subject was presented the same session at the same point in the experiment, any effect caused by scenario features would affect all subjects. As a result, if Session was the only factor to influence subject performance, then the overall scores and individual performance factors would behave similarly and no other effects would be noticed. Since this situation did not occur, other factors must have had an effect on performance as well. Display type and Condition (premath versus math and first display versus switching displays) are other such factors that could have provided such an influence. These two factors contributed to many significant effects as discovered by the analyses of variance that were performed and previously discussed.

For the most part, the display enhancements improved subject performance. In some cases, though, that no differences were found and in other instances the opposite of what was expected occurred. The following discussion attempts to explain the implications of these differences, or absence of differences, in performance.

During Sessions 15 and 16, the subjects encountered the additional task of having to perform simple arithmetic problems. The question is not whether or not performance suffers, but which display group's performance is affected the most by the added task. Performance is expected to suffer for both groups simply because another task was added to an already complex one. It was believed that the enhanced subjects' performance would not suffer as greatly as the original display group since the display enhancements would allow those subjects to devote more cognitive resources to answering the math problems without greatly sacrificing any used to perform the **Star Cruiser** task. Below, the subject groups' overall performance is compared as well as the results from the individual performance measures. Data for Sessions 15 and 16 are compared between display groups to determine if the addition of the math problems affected the groups differently and, if so, how. The same data for each group is then compared to Sessions 13 and 14 to determine what type of effect the added task had on performance.

Sessions 17 and 18 involved both subject groups transferring between display types. As with the math sessions, overall and individual performance measures were compared to Sessions 13 and 14. This comparison was done in order to determine how well the subjects' performances transfer to a display with which they are not familiar. Performance was expected to decrease for those who switched to the original display version. Performance for the other subject group was expected to remain constant or increase upon switching to the enhanced version. Of concern is whether the sudden absence or presence of certain perceptual cues will affect subject performance. In the following, the Condition effect refers to any differences (Pre-Math/Math; Pre-Transfer/Transfer) between the sessions being analyzed.

Overall Performance

Normal Sessions: Sessions 3 Through 14

It was originally thought that those subjects using the enhanced display would perform, as measured by score, better at the **Star Cruiser** task than those using the original display. From the data, it appears that this hypothesis was confirmed. Display type was shown to be a significant effect in the subjects' ability to score well. Session was also found to be significant, indicating a possible learning effect and also the possibility that the sessions varied in difficulty. The Subject effect was also determined to be significant, as is typically the case in studies of complex human performance. At a general level, however, one can say with some confidence that the display enhancements as proposed by the ecological task analysis helped contribute to better overall task performance. How these changes aided the users are addressed by the individual performance measures discussed shortly.

Also of question was how these display enhancements would affect learning to perform the task. By studying the trend of scores during Sessions 3 through 14 for both subject groups, an important insight can be gained. This insight is that the subject group using the enhanced display began the sessions immediately after training already scoring higher than the other group. This result suggests that the display enhancements were a factor in how well the subjects initially learned the task.

With only two exceptions, the mean scores for both groups increase and decrease together depending on the session. The scores are approximately the same starting at Session 11 with the original display subject group actually having a higher mean score than the enhanced group on Session 11. Given this result and the fact that there is a maximum score that can be obtained (though given the time limit on the session, this score was unattainable), one is led to believe that those using the enhanced display were able to reach this maximum potential sooner than the other subjects. After a while though, the subjects using the original display were able to match the performance of the enhanced display users. Thus, it seems that the enhanced display subject group was able to learn the **Star Cruiser** task, not necessarily better than, but more quickly than the original display subject group.

Math Sessions: Sessions 15 And 16

The data for the subjects' scores during the math sessions show that the performance of the subjects using the enhanced display remained fairly constant while the performance of the group using the original display decreased. The Condition effect (math versus premath) was found to be not significant. This result makes sense since otherwise both subject groups would have seen their performance worsen. The Subject effect, however, was found to be significant. This result reflects the large variance in means scores that exists within subject groups. The Display effect, which was found to be significant, accounts for the differences in mean scores of the two groups. This result is expected as similar results discussed for the Normal sessions revealed that differences in overall performance do exist between display types. Since the interaction effect of Condition and Display was not significant, the extent to which the enhanced display allowed the subjects to better reallocate their resources for performing both tasks is questionable. Though overall performance may not have differed significantly due to the interaction effect between the display types and the introduction of a second task, performance along the individual performance measures may have.

Transfer Sessions: Sessions 17 And 18

Upon switching display versions, both subject groups experienced increases in their scores. In addition, the Condition effect was found to be nearly significant [$F = 3.81$; $p = 0.0574$]. This outcome indicates that the increase in mean scores for both subject groups was due to switching displays. The fact that subject performance improved for those who switched to the enhanced version was not a surprise. It was believed that, given the additional perceptual cues and the information they provide, the subjects would discover the task to be easier than while using the original version. It was quite surprising, however, to find that the subjects who originally used the enhanced display also improved their performance scores after switching to the original display.

Two possible explanations exist for why the enhanced subjects performed just as well on the task using the original display. The first is that because they were presented something new, in this case in the form of a different display with certain perceptual cues lacking, the subjects concentrated more on performing the task. This concentrated effort may have compensated more than enough for the loss of information due to the missing cues and, as a result, task performance was as high or higher than before. This rationale may also be adapted to apply to those subjects who switched to the enhanced display and performed better. The second possible explanation is that the display enhancements allowed the subjects to learn more about the **Star Cruiser** task than what was presented at the display surface level. As a result, this added knowledge transferred with the subjects as they switched screens. Since the subjects had learned from the display enhancements how to acquire this embedded information from the task, independent of the cues themselves, they were able to continue to perform the task well, and in some cases, better.

Individual Performance Measures

Each performance measure that was monitored during the experiment was associated with one or more of the display enhancements. Each enhancement is discussed in terms of how it affected performance during the normal, math, and transfer sessions. The effect each display enhancement had on performance is considered in the discussion of the data from the normal sessions. The following discussion is also concerned with how the additional task requirements of answering math problems affected the effects of the display enhancements. In other words, would the arithmetic demands affect subject performance equally, if at all, regardless of display type? Or would it affect one subject group more than the other? Each display enhancement's individual performance measure was also analyzed to determine if switching displays had any effect on subject performance. This analysis would allow one to determine which measures were affected and how they were affected which would then allow one to conceptualize, with a little more reliability, a theory to explain why overall performance improved for both subject groups during the transfer sessions.

Colored Field / Background Colors Of Collection Tools

The intent behind this change was to assist the user in determining the functions and limitations of the collection tools. As seen in the data, during the normal and transfer sessions, only one subject selected the wrong type of tool. Therefore, it appears that this enhancement did not have any effect on subject performance during Sessions 3 through 14 or during the transfer sessions. In addition, this display enhancement did not have an affect during the math sessions.

It would seem that this particular enhancement would have its biggest influence during the earlier sessions. This enhancement may have been one of the reasons why the enhanced display group was able to perform so much better than the original display subjects right after completing the training. The addition of math problems may also affect performance on this measure during training. Switching the display versions also may have possibly had a bigger impact on performance if it occurred during training since training is where these errors are most likely to be common. Unfortunately, since none of the data for the first two days was analyzed, this theory is largely speculation.

'X'-Out Tools When They Cannot Be Deployed

This enhancement did not seem to have a major effect on the users' performance during any of the sessions. Similar to the previous display change, however, this change would also seem to have the most potential benefit during early sessions since its primary purpose was to inform the user of the situations when a tool could not be deployed. After a while, these instances should be learned by the subjects and thus, selection errors should not occur as often. This enhancement may have also been a contributing factor to the enhanced display subjects increased performance right after the training sessions.

Change Color Of Deployment / Retrieval String

According to the data, during Sessions 3 through 14, those subjects who used the enhanced display were better able to deploy and retrieve tools than the other subjects. In addition, both Subject and Session effects were found to be significant on this measure. The differences in the mean number of deployment / retrieval errors committed by each subject group can be attributed to the differences in displays. As reported, the Display effect was significant. By observing the subjects during the experiment, it became obvious that this display change provided subjects the necessary information for determining when to release the mouse button to complete the deployment / retrieval action. In addition, since the difference in means appeared to remain relatively constant, this tracking task was not one that improved quickly over time. Consequently, since a subject's ability to perform this task can greatly influence not only the collection of the commodities but how much time is remaining to do other tasks, it is fair to say that this display enhancement contributed to the differences in overall performance exhibited by the two groups during the normal sessions.

As discussed in the ecological task analysis, subjects considered the tasks of deploying and retrieving tools as two of the most difficult. Thus, the addition of the math problems would lead one to believe that an increase in deployment and retrieval errors would result. The opposite, however, occurred. Both subject groups reduced their mean number of errors committed during the math sessions. This result could have been simply accounted for by a learning effect and improved abilities at performing this action except that all effects were determined to be significant. The fact that the Session effect nested within the Condition effect was significant indicates that the differences between the session scenarios, regardless of whether or not the sessions involved the math problems, attributed to some of the variation in the number of errors committed. The Display effect would reflect the differences between the means of both subject groups. The fact that Condition was significant indicates that the presentation of math problems to the subject groups did have an influence on their performance. The interaction effect between Condition and Display would signify that this effect varied depending on the display type.

The effect of Condition, contrary to earlier conjecture, improved the subjects' ability at performing this task. It appeared to have improved the original display subjects' performance to a slightly greater degree than the enhanced display group. A possible explanation for this result is that the subjects, faced with the even more difficult challenge of having to perform this action while answering math problems, simply tried harder, paid more attention, and/or took their time in performing the deployment and retrieval actions. Or possibly, the Star Cruiser task can be performed better while not thinking about it, like quickly running down the stairs. In any case, the result would be fewer errors committed by the subjects. One can still state with confidence that this display enhancement did in fact contribute to improved overall performance even with the presence of the additional task of answering math problems. Whether or not an additional task would force subjects to try harder at this action in the future, and thus perhaps increase their overall score, would depend on the motivation of the subjects and on the difficulty of the additional task.

The mean number of deployment and retrieval errors committed by the subjects who switched from the enhanced display to the original display increased. The mean number decreased for those who transferred from the original to the enhanced display. The Display effect was also significant and would account for the large differences in the means between each subject group. The interaction effect of Condition and Display, which was significant, indicates the fact that switching displays had a definite effect on this performance measure. As was expected, those subjects who switched to the original display version, since they lost the use of this perceptual cue, committed significantly more deployment / retrieval errors than before they made the change. The other subject group, which transferred from the original to the enhanced display, committed significantly fewer errors than before since they now had the benefit of the perceptual cue. These results would help explain why the subject group which went from the original to the enhanced display were able to improve their overall performance. The fact though, that the other group's performance on this measure worsened indicates that this enhancement was not responsible for those subjects' improved overall performance.

Use Ghost Images

Both subject groups seemed to be equally likely to render a tool out of commission while performing the **Star Cruiser** task during the normal sessions. As a result, neither the Subject nor Display effects were found to be significant. The Session effect was, though, determined to be significant. This result is not surprising. The likelihood of overloading the Star Cruiser seemed to be dependent on the distribution of data and resources to the various solar systems within the galaxy. If a galaxy contained any systems which possessed enough commodities to overload the cruiser, than it would increase the subjects' chances of placing a tool out of commission. Since each galaxy varied with each scenario and session, the opportunity existed for variation in subject performance on this measure. As a result, high variation in the subject data occurred and the effect due to Session was found to be significant.

One surprising result was that the enhanced display group allowed more tools to go out of commission than the original display group during the math sessions. The difference between the group means can be accounted for by the nearly significant effects of Display [$F = 4.03$; $p = 0.0511$] and Condition [$F = 4.03$; $p = 0.0511$]. With regard to Condition, it is obvious from the data that performing the math problems hampered subjects' abilities to determine properly when the data or resources collected by a tool would overload the cruiser upon retrieval. It also appears that those subjects using the original display were better able to make this determination than those using the enhanced display, thus explaining the significance of the Display effect.

It may, however, not be the case that the original display was better suited for this performance measure, but rather the enhanced display simply suffered to a greater extent due to the additional task. This conclusion is supported by the fact that during the normal sessions there was no significant difference between the two displays. Though speculative, a possible explanation for these results is that, due to having to answer the math problems, the subjects using the enhanced display did not attend to the information this enhancement provided. Perhaps they felt so comfortable enough in performing the action that they could ignore the cue. Thus, they became overconfident in their abilities to do the action and they committed more mistakes. This behavior is in contrast to the original display group which never had the perceptual cue in the first place. These subjects did not have the additional information with which to ignore and, therefore, proceeded to perform this action as they would normally do. As a result, this performance measure did not suffer as greatly for the original display subjects as for the enhanced version subjects. It is cases such as this one where the introduction of an additional task might result in the display enhancement hindering overall performance.

Switching display versions did not have any apparent effect on the subjects' abilities to prevent tools from going out of commission. Furthermore, the analysis of variance failed to find any factors which were significant. It is as if the subjects who lost the use of the perceptual cue were able to remember what data and resources had been collected and those which gained the cue never truly relied on it. This data therefore suggests that this cue was not a factor in determining overall performance.

Alter Star Cruiser Capacity Gauges

This enhancement was designed to bring to the display surface information regarding the current, exact percent utilization of Star Cruiser's capacity. Before enhancement, it was often difficult to determine utilization due to the differences between the pie graphs on the planets and the bar graphs used to indicate capacity. The data from the normal sessions suggest that this display enhancement resulted in subjects docking at Star Base with a higher percent utilization of Star Cruiser's storage capacity than those subjects using the original display. Both Subject and Session were also revealed to be significant effects on this measure. This finding explains the considerable variation that existed within subject group means. Display type was also significant as was the interaction between Session and Display.

The fact that the interaction effect was so significant for these sessions would indicate that possibly the effectiveness of the display type was dependent on the session configuration or the different subjects' ability to learn over the sessions how to use the gauges. As previously mentioned, each scenario varied in the amount of commodities present in each solar system. Therefore, some scenarios made it slightly difficult for the subjects to fill the cruiser to near capacity. For those particular sessions then, the enhanced display subjects performed better along this measure. For those sessions where it was very simple or not the best option to load the cruiser to near capacity, than no differences would have existed. Those sessions where the original subject group had a higher percent utilization than the enhanced display subjects would be indicative of these types of sessions. Since this situation occurred but a few times (Sessions 3 and 8), some of the performance differences along this measure can be attributed to variation in displays alone. Furthermore, since overall performance is measured by how many commodities are returned to Star Base, the higher the percent utilization the better. Hence, the enhanced gauge display did contribute to the subject groups' differences in overall performance during the normal sessions.

The performance measure associated with this display enhancement did not show any significant effects, for either group of subjects, as a result of the math sessions. Therefore, it seems as if the effectiveness of this display change was not affected by the addition of the math problems as it neither assisted nor hindered the subjects during these sessions. As a result, the overall performances of the subjects was not influenced.

No significant effects were found by conducting an analysis of variance on the performance data for this enhancement during the transfer sessions. The absence of an effect though, lends support to one of the explanations of why the enhanced-to-original display subject group did not show a decrease in overall performance. It is possible that, over time, these subjects were able to learn exactly how much data and resources Star Cruiser could carry. This theory is quite reasonable since the perceptual cue for this performance measure in the enhanced version was essentially a number of empty planets representing the total cruiser capacity. Since they had learned what the exact capacity was and since the sudden absence of this cue did not mean that the capacity changed, these subjects were able to perform the task using the original display as they had been before with the enhanced display. Thus, performance remained fairly consistent across session types.

White 'X' For Ninth Orbit

Hidden within the depth structure of the original display are clues that can be used by the subject to locate the ninth orbit. The use of the white 'X' was intended to inform the subject of the location clearly and accurately. The data suggests that this display enhancement accomplished just that. Never once did the original display subject group have an overall mean orbiting time less than the enhanced display group during the normal sessions. In addition, the effect of Session was determined to be significant while that of Subject was significant. Display was also significant which would account for the large differences in mean times between the two groups of subjects. This enhancement contributed to the enhanced display subjects' increased overall performance by locating the proper orbit which essentially gave them more time to perform other aspects of the **Star Cruiser** task. Whether or not it was easier for those subjects using the enhanced display during the normal sessions to place the cruiser into orbit cannot be determined without discussing how proficient the subjects were at controlling the cruiser's speed in order to place it into orbit.

In addition, no significant effects were found when analyzing the subjects' mean times to orbit during the math sessions. Consequently, it appears as if the added task of the math problems did not result in any differences between the displays or between sessions 13 through 16. As a result, one may state that the additional cognitive task did not affect this display enhancement's effectiveness in any way and, therefore, did not affect overall performance.

Though the enhanced display subjects saw their mean time to orbit increase upon switching to the original display during the transfer sessions, and though the times for when the original display subjects switched displays decreased, no significant effects were found. These results suggest that the enhanced display subjects were able to learn how to extract the information, normally provided by the perceptual cue, from the depth structure of the display without having to rely on the cue itself. Therefore, one can not state with any certainty that final subject performance on each display type differed due to the loss or gain of perceptual cues and the information they conveyed.

Purple Highlight For Cruiser Speed (Orbiting)

The only way users were able to determine Star Cruiser's speed was by associating speed with how quickly it transverses the screen. The purple highlight ring was designed to let the subject know when the cruiser's speed had reached the maximum allowed for obtaining orbit. Counting the number of thrusts the subjects needed to apply before the cruiser entered orbit revealed how well they were aware of the cruiser's speed. The data from the normal sessions shows that those using the enhanced version performed fewer thrusts than the subjects using the original version. Though this finding may be partially attributable to being able to locate the ninth orbit more easily (as previously discussed), it is also due to having the information concerning the cruiser's speed displayed.

The effect of Subject differences was determined to be significant. Though not much variation in the number of thrusts applied was present in the enhanced subject group, the extreme amount in the other group was enough to cause this effect to be so significant. The fact that Display was a significant effect supports the claim that this enhancement proved useful in improving subject performance during these sessions along this measure. Since the enhanced display provided for better subject performance along both measures, cruiser speed and the location of the ninth orbit, which must be considered to place the cruiser into orbit, it is reasonable to state that the subjects using the enhanced display were better able to place the cruiser into orbit compared to the other subject group. Therefore, without a doubt, these last two display enhancements contributed significantly to the increase in the subjects' overall performance of **Star Cruiser** during normal sessions.

Similarly, both Subject and Display effects were significant for the math sessions. This result is still indicative of the large variation within the subject groups as well as the difference in mean thrusts required for orbiting between the two groups. The fact that Condition was not significant indicates that the extra effort required to perform the additional math task did not effect this display enhancement's effectiveness. Even during these sessions the display change helped to improve overall performance.

The fact that the Subject effect was significant for this performance measure during the transfer sessions accounts for the relatively high variation that exists within the subject groups in the mean number of thrusts required to place Star Cruiser into orbit. As was expected, the enhanced-to-original display subject group experienced an increase in their mean number of required thrusts. The original-to-enhanced display group required fewer thrusts. Not only was this outcome so, but when subjects, regardless of subject group, used the enhanced display, they would require fewer thrusts to orbit the cruiser. This finding explains why the interaction effect of Condition and Display was significant on this measure. No effects, however, were found significant for the other factor, the time to place the cruiser into orbit. Hence, whether or not the enhancement improves overall performance based on a subject's ability to place the cruiser into orbit is unknown for when the users switch display types.

Purple Highlight For Cruiser Speed (Docking)

The purple highlight enhancement was also intended to improve a user's ability to dock Star Cruiser at Star Base. As with placing the cruiser into orbit, both the time and the number of thrusts required to complete the action are important in determining the effectiveness of this display change. As the graph of the data from the normal sessions showed, the subject group using the enhanced display required less mean time to dock the cruiser for every session but one (Session 5). The analysis of variance for the amount of time required to dock the cruiser during these normal sessions revealed that Session, Subject, and Display were all significant effects. Once again, Subject and Session differences explain the large variances in the times required, especially for the group of subjects using the original display. The difference in mean times required can be attributed to the Display factor.

Having to answer math problems while performing this activity, as measured by the time required to dock, did not have any significant effect on the subjects' abilities to do so. Nor was any one subject group better able to perform the action than the other. As a result, the additional math task did not affect this enhancement's assistance to the user in docking Star Cruiser. Switching display types also had no effect on the amount of time the subjects required to dock the cruiser at Star Base. The analysis of variance failed to identify any factors which significantly affected performance of this action. Therefore, it is also safe to state that this display enhancement did not aid or hinder the subjects upon switching display versions in the time required to dock the cruiser.

The graph depicting the number of thrusts required to dock the cruiser during the normal sessions also shows that only during Session 5 did the subject group using the original display have a lower mean. The effects of Subject, which was significant, and Session, which was significant, account for the large differences in number of thrusts required within subject groups. The significant Display effect accounts for the difference in the means between the two groups. Both the mean time and thrusts required for docking were significantly lower for the subject group using the enhanced display compared to the group using the original version during the normal sessions. Thus, as with placing the cruiser into orbit, it appears as if the display enhancement of highlighting the cruiser when it has reached the proper docking speed, by bringing to the display surface information regarding cruiser speed, allowed subjects to better perform this action, at least during the normal sessions. Being able to better perform this action then allowed the enhanced subjects more time to perform other tasks within **Star Cruiser** and therefore improve their overall performance over the original display subjects.

Both Subject and Display were also found to have significantly effected the subjects' abilities to dock the cruiser as measured by the number of thrusts required during the math sessions. As before, the Subject effect is noticeable in the large variation within subject groups. The Display effect is seen in the enhanced display subjects requiring fewer thrusts to dock the cruiser than the original display subjects. Again, since the Condition effect was not significant, the math problems did not affect the subjects' performances along this measure. Whether or not the display enhancements supporting the activity of docking the cruiser are effective or not during these sessions cannot be concluded since no significant Display effect existed for the time required to dock. It can be stated, though, with confidence that the additional math task did not interfere with any of the enhancement's effectiveness.

The number of thrusts required to dock the cruiser during the transfer sessions also resulted in the Display and Subject effects being significant. Those subjects who switched from the enhanced display to the original required fewer thrusts to dock the cruiser during Sessions 17 and 18 than during Sessions 13 and 14. The other subject group required slightly less as well. The high variation in mean thrusts required within each subject group is responsible for the significance of the Subject effect. The Display effect is caused by the difference in the means between the two types of displays. The fact that the original-to-enhanced display subject group had better performance can possibly be attributed to the gain of the information provided by the perceptual cue. More than likely though, it is for the same reason that the enhanced-to-original group's performance also improved. Both groups, by this time, had been so well-practiced at the task of docking the cruiser that the presence or absence of the cue and its information did not matter. Therefore, at least after the subject has become highly skilled at the task, the highlighting of the cruiser for docking purposes has little, if any, effect on the performance of this action or, for that matter, overall task performance.

Change Meaning Of The Color Of Suns

It was thought that if users were better informed as to which solar systems contained the most commodities compared to the others, then they would be able to send the cruiser to them and thus maximize their collection efficiency. This display enhancement was intended to make the information concerning the solar systems' contents clearer and more accurate. The change seemed to have helped during the normal sessions as the enhanced display subjects visited and probed solar systems which contained, on average, more commodities than those visited and probed by the original display subjects. This result occurred during every normal session except for

Session 4. Once again, there was relatively high variation in the means within the subject groups. This result correlates with both the Subject and Session effects being significant. The extreme significance of the Display effect helps to explain the differences between the subject group means. This finding suggests that this display enhancement allowed the subjects to better determine which solar systems contained the most data and resources. As a result, the enhancement also helped to improve overall task performance since the subjects were not only able to collect more commodities while visiting fewer solar systems, but were also better able to determine which systems would fill the cruiser to near maximum capacity.

The effects of Condition, Display, Subject, and Session nested within Condition on which solar systems the subjects decided to visit or probe during the math sessions were all determined to be significant. Once again, the Subject and Session effects account for the relative high variances in the performance measures within the subject groups. The Display effect signifies the differences that exist between the subject groups. The Condition effect is indicative of the additional math task having an influence on the subjects' performance. The ability of each subject group to visit or probe those systems containing the most data and resources suffered as a result of having to answer the math problems. The fact that the enhanced display group still performed this activity better than the other group suggests that even though they were required to perform an additional task, it did not affect this enhancement's effectiveness in helping the enhanced version subjects achieve a higher overall performance for these sessions.

Depending on how the galaxy and its solar systems in each session are configured, subject performance at visiting or probing those which contain the most data and resources will vary. Thus, as was found, during the transfer sessions, the effect of Session nested within Condition was significant. The analysis of variance performed on this performance measure also revealed the Subject and Display effects to be significant. As the data revealed, subjects who switched to the enhanced version were then more likely to visit those solar systems which contained the most commodities than when they were using the original display. On the other hand, those who switched to the original display from the enhanced version became less likely to visit those systems more plentiful in data and resources.

The information this cue provides cannot be learned by the subjects since the actual meaning of it changes with display type. This reasoning would explain the worsened performance along this factor for those subjects who switched to the original display. Hence, the perceptual cue of the color of the sun and, most importantly, the meaning associated with it, were an influence in determining where the subjects sent the cruiser. Since the amount of data and resources they will be able to return to Star Base is dependent on where they steer Star Cruiser to, this display enhancement has an effect on the subjects' overall performance. It may be concluded, however, that this enhancement does not have a great impact on overall performance as demonstrated by the enhanced-to-original subject group's ability to still improve their overall performance.

Blue 'X' For Empty Solar Systems

This display enhancement was also intended to assist the user in determining where, and where not, to send the cruiser. The original display does not provide the user with any information concerning whether or not a solar system is completely empty (it contains no tools or commodities). Anytime the cruiser enters one of these systems, it only wastes time and prevents the user from performing other actions which may be more beneficial. By placing an 'X' over the sun to indicate empty solar systems in the enhanced display, it was expected that the subject group using that display would visit fewer empty solar systems than the group using the original display. The data from the normal sessions, however, revealed no significant differences existed between the two display types, as this situation did not occur very frequently. The analysis of variance did though, find Session to be significant. This finding makes sense since the different galaxy scenarios would make some sessions more likely to contain empty solar systems than others, thus increasing the chance of the subjects entering one. The effect due to Subject was also found to be significant. The high variations within subject groups on this performance measure are explained by the significance of these two effects. Since Display type was not significant, however, it cannot be stated that this enhancement helped improve the enhanced display subjects' overall performance.

Neither subject group had Star Cruiser enter an empty solar system during the math sessions. Considering that during Sessions 13 and 14 subjects in both groups did so, Condition was a significant effect. This result is most likely due to one of several reasons. The solar system scenarios may have been created so that there were fewer opportunities for the subjects to enter empty systems during the transfer sessions. Even though the Session nested within Condition effect was not found to be significant, this difference between the scenarios could explain the differences in the data. Another, more plausible explanation is that the criteria judged by subjects when determining whether to perform this task, combined with the differences in session scenarios, did not warrant entering empty solar systems. Finally, the subjects' may have learned to avoid the empty systems. Whichever applies here, the fact remains that since there were no significant effects from the differences in the display types, this display enhancement is not affected by the additional task.

The only effect found significant regarding this enhancement during the transfer sessions was Condition. Subjects visited more empty solar systems in the sessions before they switched displays. Differences in the scenarios, subject methods for performing the task, and/or subject learning may have contributed to the subjects visiting fewer empty solar systems. No matter the case though, this display enhancement does not seem to affect the subjects' performances of this factor, or overall performance therefore, as they become more experienced at the task.

Red Highlight For Cruiser Mode

Users often do not realize what effect a string pull will have on Star Cruiser. Often, if a user fails to select the cruiser while trying to deploy a tool, the user will not realize that a string pull performed immediately will apply a thrust to the cruiser rather than deploy a tool. This problem arises because the original display presents no cues which inform the users of Star Cruiser's mode. The red highlight ring was designed to provide this information. The effectiveness of this enhancement was measured by counting the number of errors the subjects committed because they were unaware of what the cruiser's mode was. Therefore, those subjects using the enhanced display should have committed fewer such errors.

Though few of these errors did actually occur during the normal sessions, the graphed data clearly shows that subjects using the enhanced display only once (Session 6) committed more errors than the other subjects. The relatively large variances within the subject groups can be attributed to the significant effect of Session and the significant Subject effect. The differences in means between the two groups are accounted for by the Display effect, which was significant, and the significant interaction effect between Display and Session. The fact that the interaction effect was also significant is a possible indication that the Display effect varied depending on the Session. One can state with confidence that, during the normal sessions, the red highlight enhancement prevented the subjects from committing more time costly errors, errors which could also result in the cruiser crashing into the sun, compared to the other subject group and thus helped to better their overall performance.

Requiring the subjects to answer math problems in addition to performing the **Star Cruiser** task did not appear to have any effect on their ability to determine the mode of Star Cruiser. In addition, the performance of those subjects using the enhanced display did not seem to differ from those of the original version. This finding is supported by the absence of any significant effects during the math sessions. Therefore, one may conclude that the performance of the additional task does not interfere with the effectiveness of this display enhancement in contributing to overall performance as demonstrated in the normal sessions.

An analysis of variance on the number of errors committed due to not realizing the cruiser mode during the transfer sessions did not indicate any significant effects. It appears then that, over time, the subjects became better able at determining the cruiser's mode to the point where the information provided by the cue was not necessary. Thus, this display enhancement did not affect overall performance during these later sessions.

Recap Of Results And Discussion

After determining the effects each of the twelve display enhancements had on overall performance, some interesting conclusions can be drawn. First, though, it must be mentioned that the display changes can be divided into two groups: those which affect the user's choice of action and those which affect the manner in which an action is performed. In the following, the former are referred to as action-selection enhancements while the latter will be considered as action-performance enhancements. The enhancements are listed in Table 8-1 according to which type they are.

User performance is definitely affected by the display enhancements as the results have demonstrated. During the normal sessions, all five of the action-performance enhancements contributed to improving the enhanced display group's

Table 8-1. Action-Selection And Action-Performance Enhancements

<u>Action-Selection Enhancements</u>
Colored Field
Background Colors Of Collection Tools
'X' - Out Tools When They Cannot Be Deployed
Use Ghost Images
Alter Star Cruiser Capacity Gauges
Change Meaning Of The Color Of The Suns
Blue 'X' For Empty Solar Systems
Red Highlight For Cruiser Mode
<u>Action-Performance Enhancements</u>
White 'X' For Ninth Orbit
Change Color Of Deployment / Retrieval String
Purple Highlight For Cruiser Speed (Orbiting)
Purple Highlight For Cruiser Speed (Docking - Time)
Purple Highlight For Cruiser Speed (Docking - Thrusts)

performance. In addition, two of the action-selection enhancements (Star Cruiser Capacity Gauges and Color Of The Suns) also helped to improve performance. Three other action-selection enhancements (Colored Field, Background Colors, 'X'-Out Tools) were speculated to be more beneficial during the training sessions. Thus, it appears that, with regards to normal task performance, those enhancements which aid the user in action-performance will contribute to overall improvements in performance. Those enhancements which help the user to decide which possible action to perform, though some apparently influenced the subjects' performances during the normal sessions, mainly help the user, if at all, during training. This theory seems logical since rules and constraints governing action-selection usually occurs during these sessions.

During the math sessions, only half of the enhancements influenced subjects performances. Of those, only two enhancements were not affected by the presence of the math problems. The effectiveness of the enhancements involving the purple highlight for orbiting and docking, both designed to increase skill acquisition, was not influenced by the subjects' reallocating their cognitive resources to answer the math problems. The other four enhancements were, however, affected. It seems as though those actions involving these changes (Ghost Images, Sun Color, Blue 'X', String Color) demanded more cognitive resources than the subjects' were able to devote to them while performing the math sessions. The fact that three of these enhancements were involved with action-selection (Ghost Images, Sun Color, Blue 'X') is not surprising since those type would generally require the additional mental attention of the user more often than a action-performance enhancement. Though the other enhancement was to improve the subjects' performance at the action (String Color), since it was rated as the most difficult actions during the task analysis, it would seem that it would require a greater deal of mental resources than the other actions. Therefore, performance would suffer more.

When subjects performing a complex task are presented with another non-menial task, those activities which compete for similar resources, in this case mental, will suffer (Wickens, 1984). As a result, depending on how much performance at those activities suffers, overall performance may be affected as well. With respect to the overall performance of the subjects during the math sessions, the fact that the original subject group experienced a decrease in their mean performance would be supported by this finding. That those who used the enhanced version did not suffer would suggest two hypotheses. The first is that these enhancements were able to reduce the amount of resources necessary to perform the task so that the presence of the math problems did not create a lack of available resources. The second is that the additional task of doing math problems was not complex or difficult enough for those using the enhanced display and as a result, did not require many cognitive resources. When performing this type of experiment in the future, it will be best to make sure that the additional task presented to the users is of sufficient difficulty to ensure the need for extra physical or cognitive resources. That way, the true effectiveness of the enhancements can be learned.

Overall performance was affected when the subject groups switched displays because some of the enhancements significantly affected how a subject performed the task. Two of the enhancements that the enhanced-to-original group did not have advantage of were associated with action-performance (String Color and Purple Highlight-Orbiting). The actions associated with these display changes had been rated as difficult and therefore it is not surprising to notice that performance suffered without their aid. The action-selection enhancement of the Blue 'X' also affected overall performance when the subjects switched displays. Thus it appears that certain action-selection enhancements may just as equally be missed. Since the effectiveness on overall performance of the remaining enhancements had not been affected by switching displays, one can reason that those display changes were able to increase the enhanced groups' performance beyond what would suffer from their absence and/or the subjects were able to perform the task based on other information and cues embedded within the display. Table 8-2 summarizes the most interesting results of this research.

Final Conclusions

The display enhancements incorporated into the display of the **Star Cruiser** task had a significant, positive impact on user performance during early sessions. The enhancements were developed from the results of an ecological task analysis performed on a version of **Star Cruiser**. Since the enhancements helped to improve the users' abilities at performing the task, procedures for performing the task analysis as outlined by the Ecological Task Analysis framework would be considered useful, reliable, and valid for enhancing the display of this task.

Future work in this area should, however, investigate the framework's usefulness, reliability, and validity as it is used on other complex tasks. In addition, several questions should be addressed. One question is the effect such enhancements have on task learning. Unfortunately, data from the training sessions of this experiment were not analyzed. If they were, possible results would have shown why enhanced display subjects performed better right after training when compared to original display subjects. Another issue to consider is the type of information that should be presented by the enhancements. The results of an ecological task analysis focus on areas of the task where problems exist because information is lacking or misleading The results do not instruct the display designer as to what information should be presented to help alleviate those problems. Possible future research could include investigating how different types of information can affect the effectiveness of the task analysis. Besides the question of what information to present, the question of how to present it is also

Table 8-2. Summary Of Interesting Results

Normal Sessions

- Enhanced-display subject performance better than original-display
- All five action-performance enhancements contributed to improving enhanced-display group's performance
- Two action-selection enhancements did also
  (Star Cruiser Capacity Gauges and Color Of Suns)
- Three other action-selection enhancements were thought more beneficial during training
  (Colored Field, Background Colors, 'X'-Out Tools)

Math Sessions

- Original-display subject performance suffered; Enhanced-display subject performance did NOT suffer
- Two action-performance enhancements affected performance, but were not influenced by math problems
  (Purple Highlight - Orbiting and Purple Highlight - Docking)
- Three action-selection enhancements and one action-performance enhancement affected performance and were affected by the math problems
  (Ghost Images, Sun Color, Blue 'X'; String Color)

Transfer Sessions

- Overall subject performance did NOT suffer regardless of display
- Absence of two action-performance enhancements affected enhanced-to-original group
  (String Color, Purple Highlight-Orbiting)
- Absence of one action-selection enhancement affected enhanced-to-original group
  (Blue 'X')

interesting. This research involved conveying the information via perceptual cues. Perhaps different perceptual cues, some which present the same information, than those used could have improved performance further. Or perhaps they could have worsened performance. Therefore, investigating how the use of different cues might affect performance is another future research area. It is apparent that before a general statement covering many different types of complex tasks concerning the effectiveness of the Ecological Task Analysis framework can be made, further work in the aforementioned areas should be performed. It is obvious that many factors will contribute to the framework's potential success.

APPENDICES

[redacted]

APPENDIX A

PHOTOGRAPHS OF STAR CRUISER INTERFACES

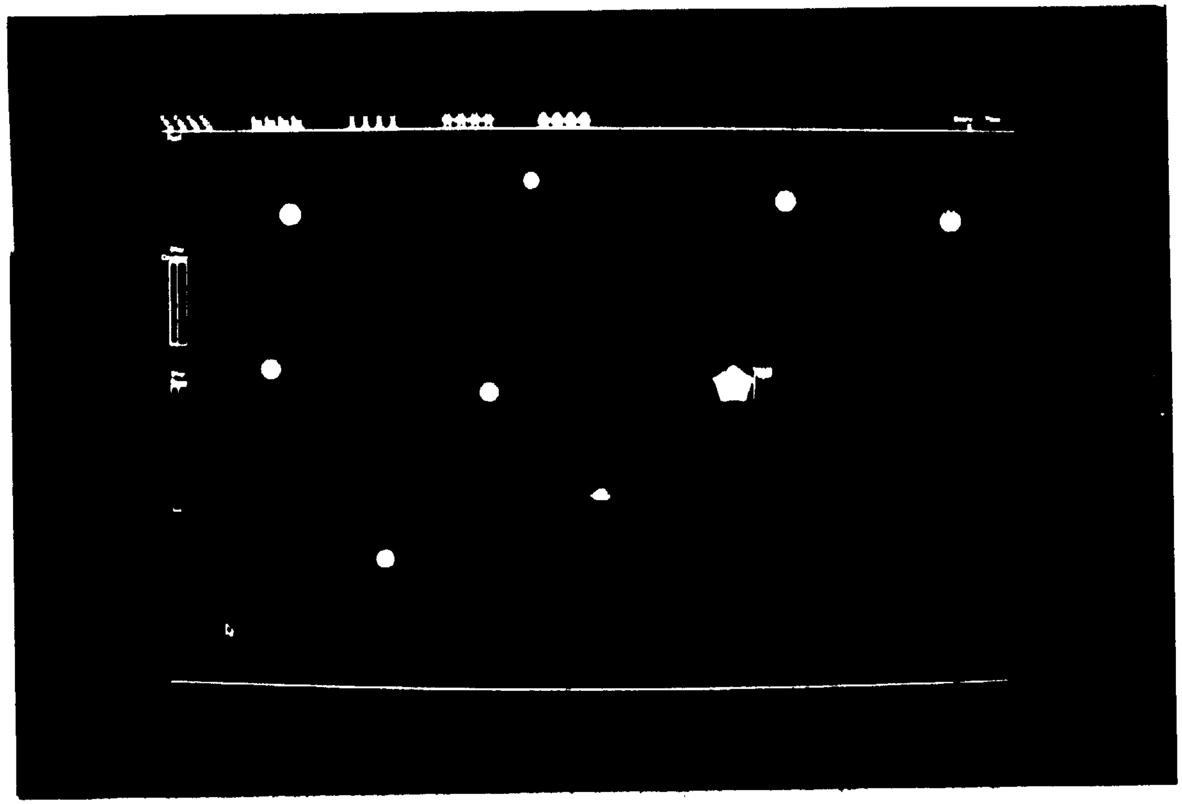

Figure A-1. Star Cruiser Interface - Global View (Original Display Version)

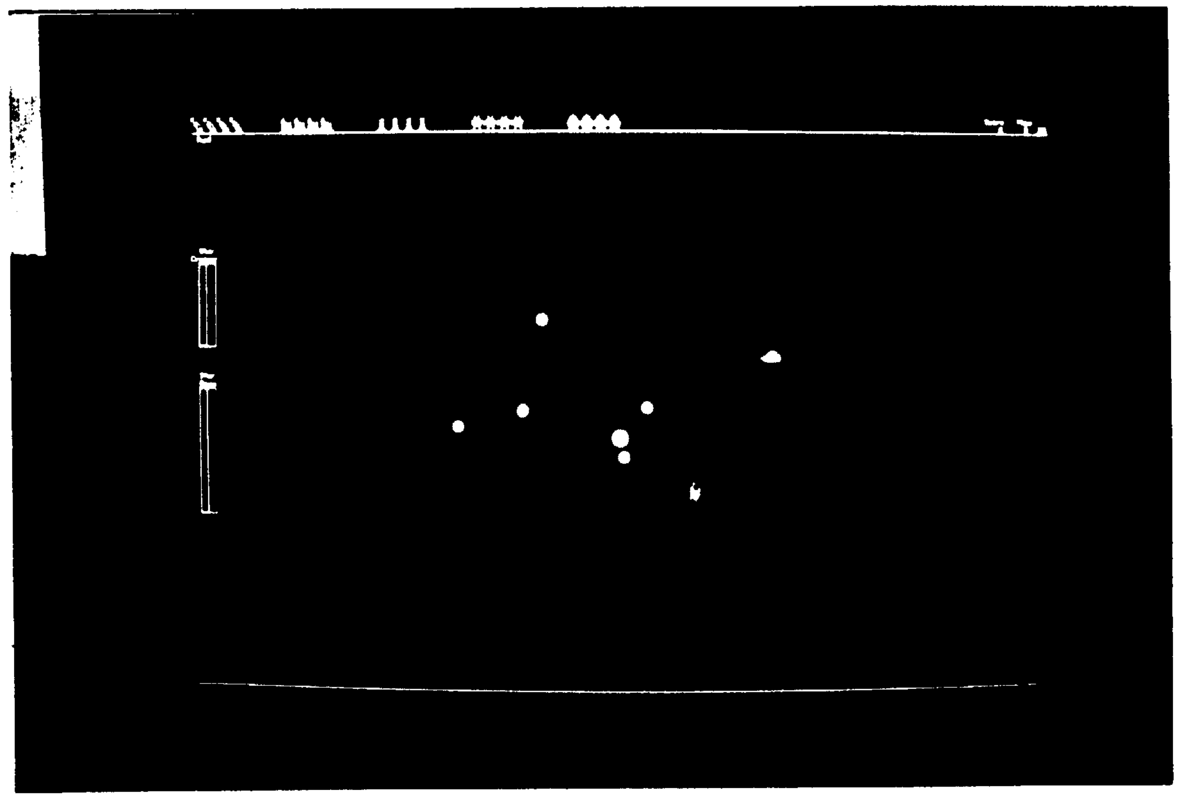

Figure A-2. Star Cruiser Interface - Local View (Original Display Version)

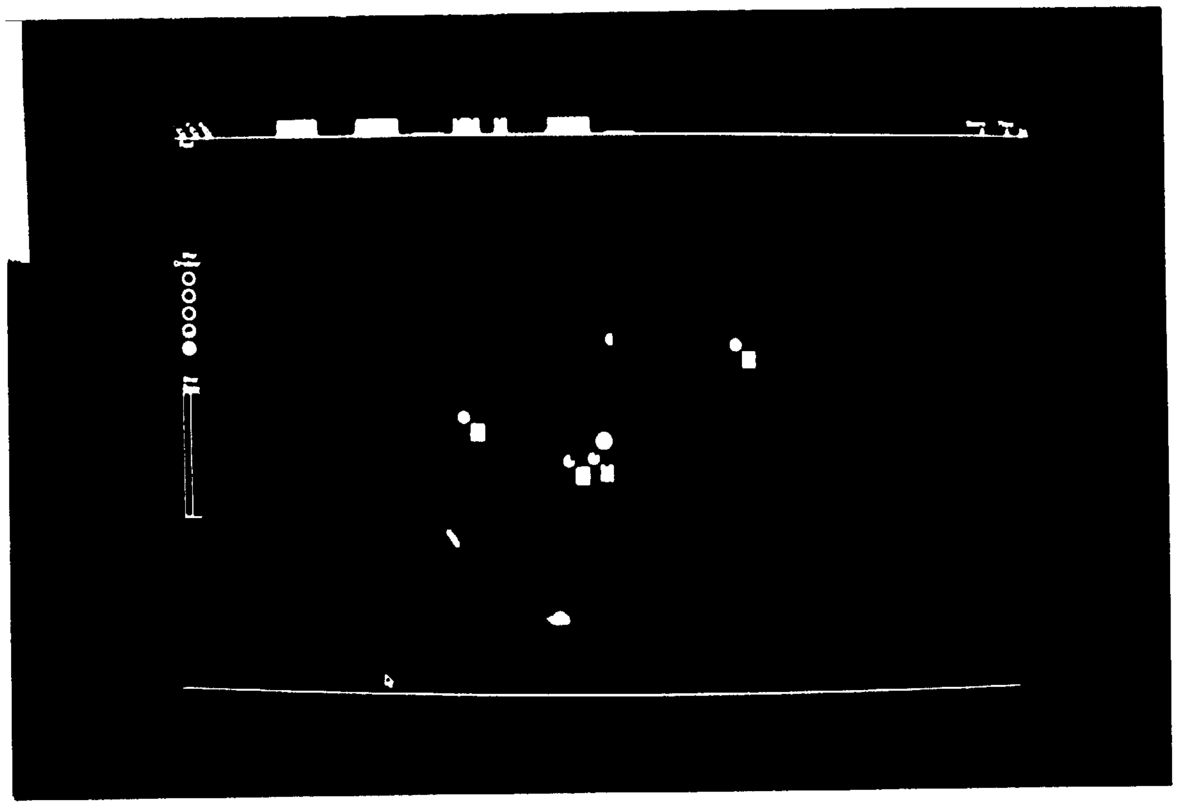

Figure A-3. Star Cruiser Interface - Local View / Star Cruiser In Orbit
(Enhanced Display Version)

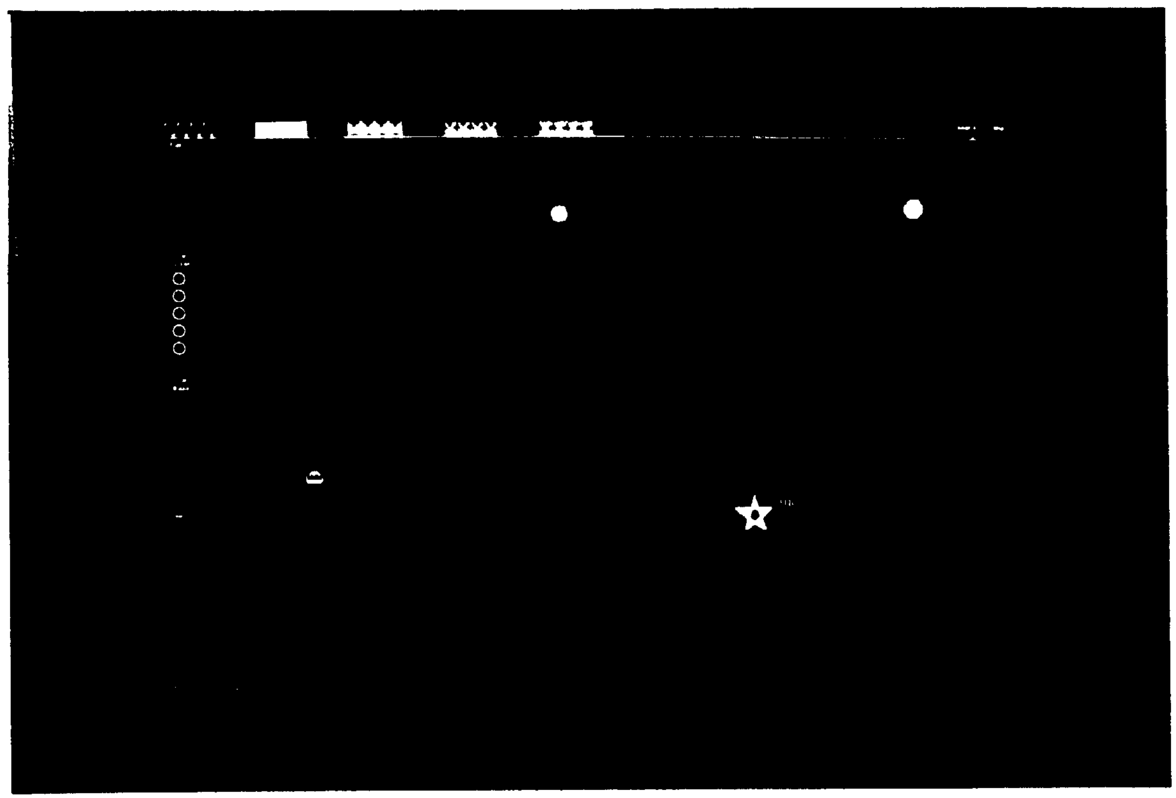

Figure A-4. Star Cruiser Interface - Global View (Enhanced Display Version)

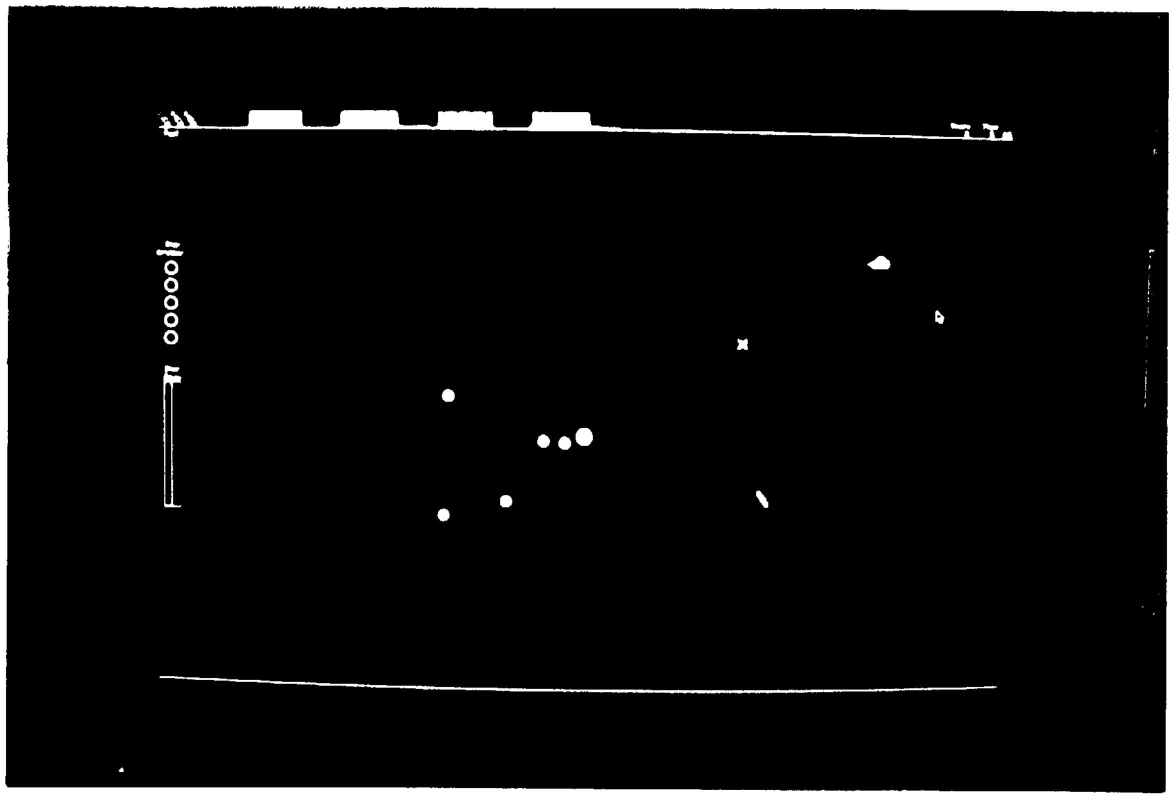

Figure A-5. Star Cruiser Interface - Local View (Enhanced Display Version)

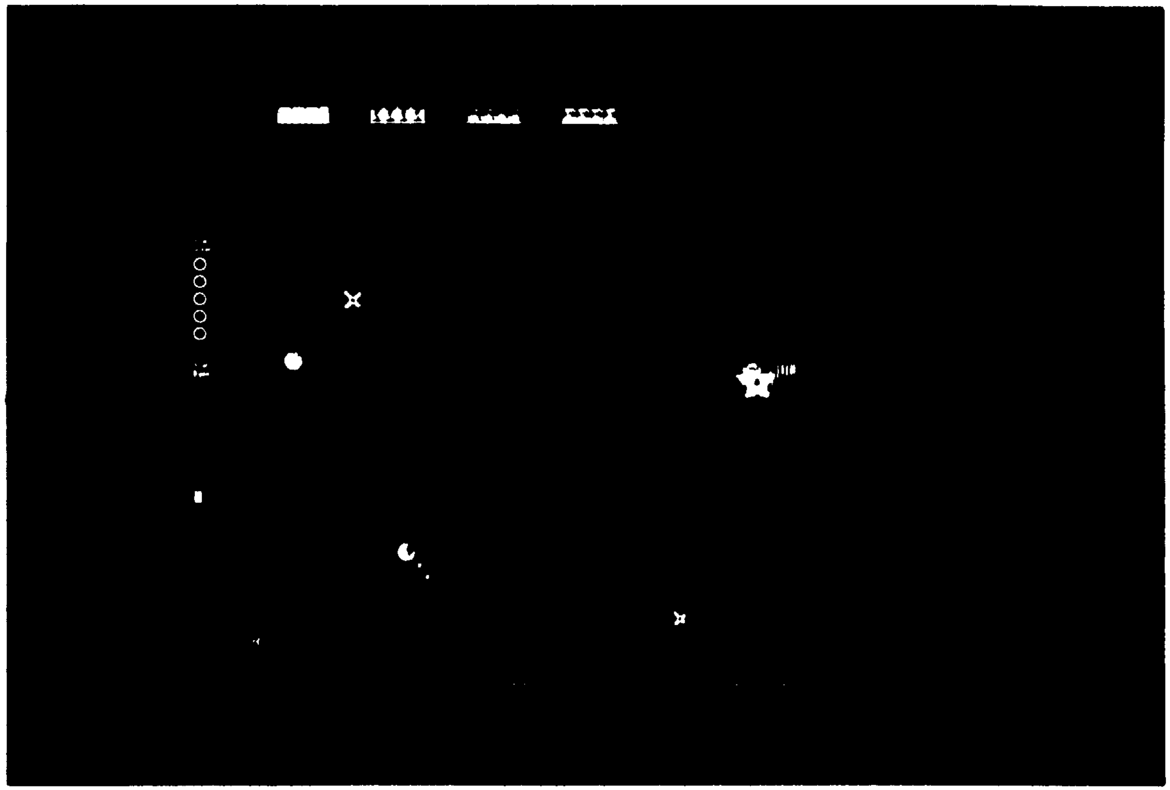

Figure A-6. Star Cruiser Interface - Global View / Star Cruiser Docked
(Enhanced Display Version)

APPENDIX B

STAR CRUISER SCENARIO FILE VARIABLES

The following is a listing of the variables present in a **Star Cruiser** scenario file. The file is accessed by the simulation at the beginning of each session. The galaxy configuration, certain Star Cruiser movement variables, and other session parameters depend on the values listed in the file.

SB

- Star Base location in the galaxy (X and Y coordinates)

SC

- Star Cruiser starting location in the galaxy (X and Y coordinates);
- maximum amount of data Star Cruiser can carry;
- maximum amount of resources Star Cruiser can carry

S1 - S12

- location of Solar System number *x* (X and Y coordinates);
- age of the solar system's sun;
- radius of the solar system's sun;
- number of planets in the solar system

P1 - P6

- location of Planet *x* in solar system (X and Y coordinates);
- orbital number of the planet;
- amount of data available on the planet;
- amount of resources available on the planet;
- whether or not planet supports life

PR

- number of PRobes onboard Star Cruiser at start of simulation

ST

- number of Satellites onboard Star Cruiser at start of simulation

SS

- number of Science Ships onboard Star Cruiser at start of simulation

RM

- number of Robot Miners onboard Star Cruiser at start of simulation

MS

- number of Miner Ships onboard Star Cruiser at start of simulation

PDP

- Points scored for each Data Package returned to Star Base

PRC

- Points scored for each ResourCes package returned to Star Base

FCR

- Fuel Consumption Rate

PT

- Planet Toggle - determines whether or not information about planets' commodities in a solar system is displayed on the sun in the global map

OS

- Orbital Speed of planets

GS

- Gain attributed to the Sun's pull

DB

- DeadBand on the mouse movement

MI

- Minimum Inertia - used to determine Star Cruiser's momentum

TS

- Track Scale - gain on the track (actual path of movement) of Star Cruiser

FS

- Force Scale - gain on the force applied with a pull of the thrust string

EV

- Entry Velocity - maximum allowable velocity of Star Cruiser for it to obtain orbit

OB

- Orbital Buffer - number of pixels from the orbit that the midpoint of Star Cruiser must be within before cruiser obtains orbit

BOF

- Break Orbit Force - BOF value times mass (radius) of sun equals force required to remove Star Cruiser from orbit around that sun

LM

- Length of Mission (minutes)

APPENDIX C

ANALYSIS OF VARIANCE TABLES

NORMAL SESSIONS

OVERALL SCORE

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
SESSION	11	896188239.92	81471658.17	3.55	0.0002
DISPLAY	1	229228354.69	229228354.69	10.00	0.0019
SUBJECT	15	916220832.33	61081388.82	2.67	0.0013
SESSION*DISPLAY	11	142587344.81	12962485.89	0.57	0.8543
Error	153	3506523148.9	22918452.0		
Corrected Total	191	5690747920.7			

SELECT WRONG TOOL

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
SESSION	11	0.10416667	0.00946970	1.01	0.4421
DISPLAY	1	0.02083333	0.02083333	2.22	0.1385
SUBJECT	15	0.31250000	0.02083333	2.22	0.0079
SESSION*DISPLAY	11	0.10416667	0.00946970	1.01	0.4421
Error	153	1.43750000	0.00939542		
Corrected Total	191	1.97916667			

SELECTION ACTION ERROR

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
SESSION	11	12.43229167	1.13020833	0.81	0.6301
DISPLAY	1	1.50520833	1.50520833	1.08	0.3006
SUBJECT	15	25.86979167	1.72465278	1.24	0.2509
SESSION*DISPLAY	11	15.30729167	1.39157197	1.00	0.4515
Error	153	213.50520833	1.39545888		
Corrected Total	191	268.61979167			

DEPLOYMENT / RETRIEVAL ERROR

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
SESSION	11	754.291667	68.571970	2.43	0.0080
DISPLAY	1	3104.083333	3104.083333	110.22	0.0001
SUBJECT	15	13157.916667	877.194444	31.15	0.0001
SESSION*DISPLAY	11	540.791667	49.162879	1.75	0.0684
Error	153	4308.833333	28.162309		
Corrected Total	191	21865.916667			

TOOLS OUT OF COMMISSION

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
SESSION	11	24.18750000	2.19886364	2.88	0.0018
DISPLAY	1	0.52083333	0.52083333	0.68	0.4099
SUBJECT	15	18.81250000	1.25416667	1.64	0.0682
SESSION*DISPLAY	11	3.10416667	0.28219697	0.37	0.9658
Error	153	116.68750000	0.76266340		
Corrected Total	191	163.31250000			

UTILIZATION OF STAR CRUISER CAPACITY

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
SESSION	11	0.51641392	0.04694672	2.71	0.0035
DISPLAY	1	0.13383315	0.13383315	7.74	0.0062
SUBJECT	14	1.95561891	0.13968706	8.07	0.0001
SESSION*DISPLAY	11	0.46452340	0.04222940	2.44	0.0083
Error	133	2.30094987	0.01730037		
Corrected Total	170	5.37133924			

TIME TO ORBIT

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
SESSION	11	712.7425870	64.7947806	2.02	0.0302
DISPLAY	1	2278.3763070	2278.3763070	70.93	0.0001
SUBJECT	15	4954.9391598	330.3292773	10.28	0.0001
SESSION*DISPLAY	11	250.6358256	22.7850751	0.71	0.7283
Error	153	4914.6544900	32.1219248		
Corrected Total	191	13111.3483694			

THRUSTS TO ORBIT

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
SESSION	11	114.1872979	10.3806634	0.86	0.5852
DISPLAY	1	1352.7894937	1352.7894937	111.49	0.0001
SUBJECT	15	3259.9653378	217.3310225	17.91	0.0001
SESSION*DISPLAY	11	106.3929894	9.6720899	0.80	0.6427
Error	153	1856.4544087	12.1336889		
Corrected Total	191	6689.7895275			

THRUSTS TO DOCK

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
SESSION	11	20.81844219	1.89258565	2.34	0.0114
DISPLAY	1	27.71658441	27.71658441	34.29	0.0001
SUBJECT	14	60.75254976	4.33946784	5.37	0.0001
SESSION*DISPLAY	11	15.11829703	1.37439064	1.70	0.0797
Error	133	107.49208558	0.80821117		
Corrected Total	170	231.89795897			

TIME TO DOCK

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
SESSION	11	178.26970824	16.20633711	3.87	0.0001
DISPLAY	1	121.04590033	121.04590033	28.91	0.0001
SUBJECT	14	215.55246661	15.39660476	3.68	0.0001
SESSION*DISPLAY	11	75.68631837	6.88057440	1.64	0.0936
Error	133	556.83682301	4.18674303		
Corrected Total	170	1147.39121656			

COMMODITIES IN VISITED SOLAR SYSTEMS

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
SESSION	11	738728.4148	67157.1286	8.44	0.0001
DISPLAY	1	169331.4636	169331.4636	21.28	0.0001
SUBJECT	15	1067153.4404	71143.5627	8.94	0.0001
SESSION*DISPLAY	11	153681.1526	13971.0139	1.76	0.0664
Error	153	1217397.5595	7956.8468		
Corrected Total	191	3346292.0309			

EMPTY SOLAR SYSTEMS VISITED

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
SESSION	11	20.93229167	1.90293561	2.10	0.0232
DISPLAY	1	2.29687500	2.29687500	2.54	0.1133
SUBJECT	15	29.61979167	1.97465278	2.18	0.0091
SESSION*DISPLAY	11	17.01562500	1.54687500	1.71	0.0762
Error	153	138.50520833	0.90526280		
Corrected Total	191	208.36979167			

ERRORS IN DETERMINING STAR CRUISER MODE

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
SESSION	11	0.15430967	0.01402815	2.06	0.0263
DISPLAY	1	0.05105024	0.05105024	7.51	0.0069
SUBJECT	15	0.30097185	0.02006479	2.95	0.0004
SESSION*DISPLAY	11	0.15152666	0.01377515	2.03	0.0295
Error	153	1.04070271	0.00680198		
Corrected Total	191	1.69856113			

MATH SESSIONS

OVERALL SCORE

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
CONDITION	1	41812389.06	41812389.06	2.05	0.1598
DISPLAY	1	112503145.56	112503145.56	5.51	0.0236
SUBJECT	15	969599260.00	64639950.67	3.16	0.0016
SESSION (CONDITION)	2	77091470.31	38545735.16	1.89	0.1639
CONDITION*DISPLAY	1	43573201.00	43573201.00	2.13	0.1514
Error	43	878474404.1	20429637.3		
Corrected Total	63	2123053870.0			

SELECT WRONG TOOL

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
CONDITION	1	0.01562500	0.01562500	1.00	0.3229
DISPLAY	1	0.01562500	0.01562500	1.00	0.3229
SUBJECT	15	0.23437500	0.01562500	1.00	0.4726
SESSION (CONDITION)	2	0.03125000	0.01562500	1.00	0.3763
CONDITION*DISPLAY	1	0.01562500	0.01562500	1.00	0.3229
Error	43	0.67187500	0.01562500		
Corrected Total	63	0.98437500			

SELECTION ACTION ERROR

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
CONDITION	1	5.06250000	5.06250000	1.43	0.2388
DISPLAY	1	4.00000000	4.00000000	1.13	0.2943
SUBJECT	15	59.43750000	3.96250000	1.12	0.3711
SESSION (CONDITION)	2	3.12500000	1.56250000	0.44	0.6467
CONDITION*DISPLAY	1	6.25000000	6.25000000	1.76	0.1914
Error	43	152.56250000	3.54796512		
Corrected Total	63	230.43750000			

DEPLOYMENT / RETRIEVAL ERROR

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
CONDITION	1	118.2656250	118.2656250	99999.99	0.0001
DISPLAY	1	2613.7656250	2613.7656250	99999.99	0.0001
SUBJECT	15	8970.9843750	598.0656250	99999.99	0.0001
SESSION (CONDITION)	2	120.1562500	60.0781250	99999.99	0.0001
CONDITION*DISPLAY	1	50.7656250	50.7656250	99999.99	0.0001
Error	43	0.000000	0.000000		
Corrected Total	63	11414.234375			

TOOLS OUT OF COMMISSION

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
CONDITION	1	1.56250000	1.56250000	4.03	0.0511
DISPLAY	1	1.56250000	1.56250000	4.03	0.0511
SUBJECT	15	7.93750000	0.52916667	1.36	0.2090
SESSION (CONDITION)	2	0.62500000	0.31250000	0.81	0.4536
CONDITION*DISPLAY	1	0.06250000	0.06250000	0.16	0.6902
Error	43	16.68750000	0.38808140		
Corrected Total	63	28.43750000			

UTILIZATION OF STAR CRUISER CAPACITY

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
CONDITION	1	0.33012410	0.33012410	1.34	0.2535
DISPLAY	1	0.15413968	0.15413968	0.63	0.4332
SUBJECT	14	2.00210688	0.14300763	0.58	0.8626
SESSION (CONDITION)	2	0.73730791	0.36865395	1.50	0.2357
CONDITION*DISPLAY	1	0.12192239	0.12192239	0.50	0.4854
Error	39	9.58531392	0.24577728		
Corrected Total	58	12.93091488			

TIME TO ORBIT

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
CONDITION	1	2437283.159	2437283.159	0.96	0.3320
DISPLAY	1	2624262.397	2624262.397	1.04	0.3143
SUBJECT	14	34793577.226	2485255.516	0.98	0.4871
SESSION (CONDITION)	2	4941814.223	2470907.112	0.98	0.3850
CONDITION*DISPLAY	1	2660093.108	2660093.108	1.05	0.3110
Error	43	108850984.765	2531418.250		
Corrected Total	62	156308014.879			

THRUSTS TO ORBIT

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
CONDITION	1	0.9978095	0.9978095	0.07	0.7866
DISPLAY	1	623.8406137	623.8406137	46.38	0.0001
SUBJECT	14	1168.7984024	83.4856002	6.21	0.0001
SESSION (CONDITION)	2	18.2776636	9.1388318	0.68	0.5122
CONDITION*DISPLAY	1	3.8632106	3.8632106	0.29	0.5948
Error	43	578.3309866	13.4495578		
Corrected Total	62	2394.1086865			

THRUSTS TO DOCK

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
CONDITION	1	1.47545356	1.47545356	1.73	0.1962
DISPLAY	1	4.15715456	4.15715456	4.87	0.0332
SUBJECT	14	26.84398722	1.91742766	2.25	0.0234
SESSION (CONDITION)	2	4.42280703	2.21140352	2.59	0.0877
CONDITION*DISPLAY	1	0.12259250	0.12259250	0.14	0.7067
Error	39	33.27760568	0.85327194		
Corrected Total	58	70.29960056			

TIME TO DOCK

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
CONDITION	1	6646.034909	6646.034909	0.98	0.3282
DISPLAY	1	5533.948720	5533.948720	0.82	0.3718
SUBJECT	14	84829.871344	6059.276525	0.89	0.5715
SESSION (CONDITION)	2	13138.854150	6569.427075	0.97	0.3884
CONDITION*DISPLAY	1	6574.348874	6574.348874	0.97	0.3308
Error	39	264387.93399	6779.17779		
Corrected Total	58	381110.99199			

COMMODITIES IN VISITED SOLAR SYSTEMS

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
CONDITION	1	113296.85518	113296.85518	13.77	0.0006
DISPLAY	1	166221.35287	166221.35287	20.20	0.0001
SUBJECT	15	934012.62614	62267.50841	7.57	0.0001
SESSION (CONDITION)	2	178538.36599	89269.18300	10.85	0.0002
CONDITION*DISPLAY	1	13098.83652	13098.83652	1.59	0.2139
Error	43	353921.8951	8230.7417		
Corrected Total	63	1759089.9318			

EMPTY SOLAR SYSTEMS VISITED

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
CONDITION	1	3.51562500	3.51562500	8.55	0.0055
DISPLAY	1	0.01562500	0.01562500	0.04	0.8463
SUBJECT	15	6.73437500	0.44895833	1.09	0.3911
SESSION (CONDITION)	2	1.53125000	0.76562500	1.86	0.1675
CONDITION*DISPLAY	1	0.01562500	0.01562500	0.04	0.8463
Error	43	17.67187500	0.41097384		
Corrected Total	63	29.48437500			

ERRORS IN DETERMINING STAR CRUISER MODE

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
CONDITION	1	0.00078267	0.00078267	0.17	0.6811
DISPLAY	1	0.00000142	0.00000142	0.00	0.9860
SUBJECT	15	0.06679947	0.00445330	0.97	0.4971
SESSION (CONDITION)	2	0.00833615	0.00416808	0.91	0.4095
CONDITION*DISPLAY	1	0.00238237	0.00238237	0.52	0.4743
Error	43	0.19660095	0.00457212		
Corrected Total	63	0.27490303			

TRANSFER SESSIONS

OVERALL SCORE

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
CONDITION	1	97088998.89	97088998.89	3.81	0.0574
DISPLAY	1	21547003.52	21547003.52	0.85	0.3628
SUBJECT	15	585383172.61	39025544.84	1.53	0.1362
SESSION (CONDITION)	2	92482025.78	46241012.89	1.82	0.1749
CONDITION*DISPLAY	1	404655.02	404655.02	0.02	0.9003
Error	43	1094975280.55	25464541.41		
Corrected Total	63	1891881136.36			

SELECT WRONG TOOL

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
CONDITION	1	0.01562500	0.01562500	1.00	0.3229
DISPLAY	1	0.01562500	0.01562500	1.00	0.3229
SUBJECT	15	0.23437500	0.01562500	1.00	0.4726
SESSION (CONDITION)	2	0.03125000	0.01562500	1.00	0.3763
CONDITION*DISPLAY	1	0.01562500	0.01562500	1.00	0.3229
Error	43	0.67187500	0.01562500		
Corrected Total	63	0.98437500			

SELECTION ACTION ERROR

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
CONDITION	1	3.51562500	3.51562500	0.95	0.3352
DISPLAY	1	6.89062500	6.89062500	1.86	0.1796
SUBJECT	15	58.98437500	3.93229167	1.06	0.4167
SESSION (CONDITION)	2	3.15625000	1.57812500	0.43	0.6556
CONDITION*DISPLAY	1	3.51562500	3.51562500	0.95	0.3352
Error	43	159.17187500	3.70167151		
Corrected Total	63	235.23437500			

DEPLOYMENT / RETRIEVAL ERROR

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
CONDITION	1	14.0625000	14.0625000	0.20	0.6579
DISPLAY	1	729.0000000	729.0000000	10.31	0.0025
SUBJECT	15	3712.5000000	247.5000000	3.50	0.0006
SESSION (CONDITION)	2	176.5625000	88.2812500	1.25	0.2972
CONDITION*DISPLAY	1	976.5625000	976.5625000	13.81	0.0006
Error	43	3041.3125000	70.7281977		
Corrected Total	63	8650.0000000			

TOOLS OUT OF COMMISSION

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
CONDITION	1	0.14062500	0.14062500	0.37	0.5472
DISPLAY	1	0.39062500	0.39062500	1.02	0.3175
SUBJECT	15	8.73437500	0.58229167	1.52	0.1390
SESSION (CONDITION)	2	1.65625000	0.82812500	2.17	0.1267
CONDITION*DISPLAY	1	0.14062500	0.14062500	0.37	0.5472
Error	43	16.42187500	0.38190407		
Corrected Total	63	27.48437500			

UTILIZATION OF STAR CRUISER CAPACITY

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
CONDITION	1	0.00352547	0.00352547	0.02	0.8961
DISPLAY	1	0.06454589	0.06454589	0.32	0.5771
SUBJECT	14	3.16092843	0.22578060	1.11	0.3825
SESSION (CONDITION)	2	0.77702948	0.38851474	1.90	0.1625
CONDITION*DISPLAY	1	0.21246067	0.21246067	1.04	0.3139
Error	40	8.16849239	0.20421231		
Corrected Total	59	12.38698233			

TIME TO ORBIT

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
CONDITION	1	2473512.786	2473512.786	1.00	0.3236
DISPLAY	1	2501637.564	2501637.564	1.01	0.3209
SUBJECT	15	37199255.447	2479950.363	1.00	0.4728
SESSION (CONDITION)	2	4939453.107	2469726.554	1.00	0.3778
CONDITION*DISPLAY	1	2570495.717	2570495.717	1.04	0.3144
Error	43	106659701.478	2480458.174		
Corrected Total	63	156344056.099			

THRUSTS TO ORBIT

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
CONDITION	1	3.93550807	3.93550807	0.21	0.6515
DISPLAY	1	33.62524642	33.62524642	1.77	0.1907
SUBJECT	15	612.16721153	40.81114744	2.14	0.0258
SESSION (CONDITION)	2	13.30210528	6.65105264	0.35	0.7070
CONDITION*DISPLAY	1	434.95495644	434.95495644	22.86	0.0001
Error	43	818.1387324	19.0264821		
Corrected Total	63	1916.1237601			

THRUSTS TO DOCK

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
CONDITION	1	0.16540317	0.16540317	0.18	0.6763
DISPLAY	1	5.22633117	5.22633117	5.59	0.0230
SUBJECT	14	29.42121472	2.10151534	2.25	0.0228
SESSION (CONDITION)	2	1.85255800	0.92627900	0.99	0.3803
CONDITION*DISPLAY	1	0.06224565	0.06224565	0.07	0.7977
Error	40	37.40237432	0.93505936		
Corrected Total	59	74.13012703			

TIME TO DOCK

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
CONDITION	1	3388.22965	3388.22965	0.13	0.7190
DISPLAY	1	5784.08198	5784.08198	0.22	0.6385
SUBJECT	14	328306.93118	23450.49508	0.91	0.5571
SESSION (CONDITION)	2	56082.35302	28041.17651	1.09	0.3472
CONDITION*DISPLAY	1	60634.34333	60634.34333	2.35	0.1332
Error	40	1032443.83783	25811.09595		
Corrected Total	59	1486639.77699			

COMMODITIES IN VISITED SOLAR SYSTEMS

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
CONDITION	1	880.0670	880.0670	0.07	0.7945
DISPLAY	1	94546.2749	94546.2749	7.38	0.0095
SUBJECT	15	1052639.3280	70175.9552	5.48	0.0001
SESSION (CONDITION)	2	219348.9610	109674.4805	8.56	0.0007
CONDITION*DISPLAY	1	46082.7360	46082.7360	3.60	0.0646
Error	43	550973.0080	12813.3258		
Corrected Total	63	1964470.3749			

EMPTY SOLAR SYSTEMS VISITED

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
CONDITION	1	2.64062500	2.64062500	5.96	0.0188
DISPLAY	1	0.01562500	0.01562500	0.04	0.8519
SUBJECT	15	7.23437500	0.48229167	1.09	0.3941
SESSION (CONDITION)	2	1.53125000	0.76562500	1.73	0.1897
CONDITION*DISPLAY	1	0.01562500	0.01562500	0.04	0.8519
Error	43	19.04687500	0.44295058		
Corrected Total	63	30.48437500			

ERRORS IN DETERMINING STAR CRUISER MODE

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
CONDITION	1	0.02189534	0.02189534	2.43	0.1266
DISPLAY	1	0.00730525	0.00730525	0.81	0.3733
SUBJECT	15	0.12005687	0.00800379	0.89	0.5827
SESSION (CONDITION)	2	0.01791007	0.00895503	0.99	0.3790
CONDITION*DISPLAY	1	0.01771288	0.01771288	1.96	0.1684
Error	43	0.38803143	0.00902399		
Corrected Total	63	0.57291185			

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