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INTELLIGENT TUTORING SYSTEMS FOR SPACE APPLICATIONS

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ABSTRACT

Artificial Intelligence has been used in many space applications. Intelligent tutoring systems (ITSs) have only recently been developed for assisting training of space operations and skills. In this paper, an ITS at Southwest Research Institute is described as an example of an ITS application for space operations, specifically, training console operations at mission control. A distinction is made between critical skills and knowledge versus routine skills. Other ITSs for space are also discussed and future training requirements and potential ITS solutions are described.

INTRODUCTION

There are many applications of expert systems technology to the space shuttle (27, 32) and Space Station Freedom (7, 8) and of artificial intelligence in general to space systems (10, 11, 12, 16, 21, 25, 26). The following is a representative list of potential and existing space application systems from various publications. Notice that there are three intelligent trainers or tutoring systems in this list.

Attitude control for spacecraft
Autonomous flight control for a Mars Balloon
Autonomous maintenance of platforms
Autonomous navigation and guidance for rovers
Autonomous rendezvous and docking for a space vehicle
Computer vision for automated rovers
Diagnosing spacecraft problems
EVA Retriever
Fault diagnosis of electrical power systems for Space Station
Flight Telerobotic Servicer
Hubble Space Telescope planning and scheduling
Intelligent interface for satellite operations
Intelligent trainer for shuttle flight controllers

Intelligent tutoring system for shuttle diagnosis
Liquid Oxygen Expert System
Mars Rover Sample Return
Mission planning
Mission Telemetry System Monitor
Radar tracker scheduling for shuttle and satellites
Satellite scheduling and control
Scheduling and planning for ground control systems
Shuttle Main Engine Test Evaluator
Spacecraft communications configuration optimization
Spacecraft operations scheduling
Space Shuttle Payload Integration
Special Purpose Dexterous Manipulator (Canada — for Station)
Venus Orbit Planner

An intelligent tutoring system (ITS) is a training system implemented on a computer, as in computer-based training. However, such systems also include some AI-based techniques that allow them to be more adaptive and responsive to a student's needs, making them appear smart. ITSs can be divided into four main modules: an intelligent interface, an instructional expert, a domain expert, and a student model (2, 19). The instruction module can be thought of as the center point which receives information from the other modules as in Figure 1. The domain expert module contains a representation of the knowledge or skill to be trained. It may also be associated with a simulator that allows a student to explore the domain. The student module is similar to the expert module except it usually is an empty shell or structure of the knowledge or skill to be trained. It is then filled with what the student learns and knows with respect to the domain based on the interactions that student has with the ITS. The instructional module is a representation of the knowledge and skill of teaching the subject matter of the expert module. The intelligent interface is the method of communication between the student and the ITS. An interface is intelligent in what is communicated to the student based on the student's response and history with the system. Knowledge-based system techniques can be used in any of these four modules in order to implement the "intelligence."

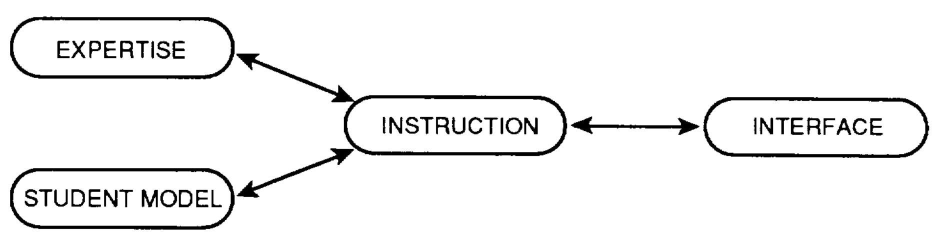

Figure 1. ITS Structure

As life becomes more complex and faster paced, there will be an increased demand for readily available, individualized, effective teaching and training sources. For example, on the average, the next generation of workers will change jobs more than five times and 95% of all jobs will involve information handling that will be highly computerized (3). At Johnson Space Center, the training for Space Shuttle missions was beginning to fall behind schedule before the Challenger accident in 1986. As NASA gears up to full capability of Shuttle flights, the demand on training will be resumed. Much of the training at NASA is one-on-one, human-to-human instruction with full-scale simulations. The training time that requires human instructors needs to be reduced. ITSs can fulfill some of the new training requirements, inside and outside of NASA, so that human teachers can spend more time on personalizing instruction for the more exceptional cases.

THE PRESENT

There are ITSs for a multitude of applications (13, 20, 31) including aircraft (1, 18, 23, 24) and space systems (4, 5, 14, 22, 30). However, ITSs are still very much in the research stage and used on a small scale. They are only beginning to be available to large groups of students (29).

Most of the areas of application for ITSs that already exist or that are being researched for space systems are in the environment of spacecraft command and control. For example, at Southwest Research Institute an ITS for training how to operate a console in the Mission Control Center at NASA's Johnson Space Center is under development (6). Currently, the ITS trains the operations for the Manual Select Keyboard (MSK). The MSK is used for initializing the console for the different phases of any mission such as ascent, orbit, and descent of the space shuttle. The initialization includes skills of formatting light panels and selecting video displays. Although the tutor would be useful in training new flight controllers in the use of the console, its main use is for research into the effectiveness of ITSs in the training of high performance skills. The training of high performance skills is a major issue with which NASA must constantly contend.

The console tutor runs on an Apollo Domain 4000 with a color monitor and is written in C, CLIPS, and GPR. The tutor provides a low-physical-fidelity, high-cognitive-fidelity training environment. Figure 2 shows what the student sees when interfacing with the tutor. The top half of the screen is a depiction of a control center console. Each of the sections or components on the console can be selected in the figure by clicking the mouse when the pointer is on the desired component. The component then appears on a larger scale in the bottom left-hand portion of the screen. In the figure, the MSK has been selected. The bottom right-hand side of the screen contains the text for information, instructions and feedback. The text that appears in the figure is information for training an overview of the system. The console tutor trains five levels of familiarity with the MSK: an overview of the MSK components, an overview of the procedure, example exercises for demonstration and accuracy training, example exercises for speed training, and exercises for automatizing the process. The tutor has been built with the purpose of training the MSK operation to the point where the operator can do the procedure automatically. This means that the console operator will be able to perform MSK manipulation while processing something else such as holding a conversation or responding to other auditory inputs. For training such automaticity in a skill, the tutor must provide a secondary task for the student to perform while he or she is performing the primary task of MSK manipulation. In this case, the secondary task is the recognition of a pattern of beeps and the response of hitting the corresponding function key. Advancement through the tutoring system and "graduation" depend upon performance accuracy and speed in some cases. The tutor will remediate and even return to the beginning of the training if required, based on the student's performance.

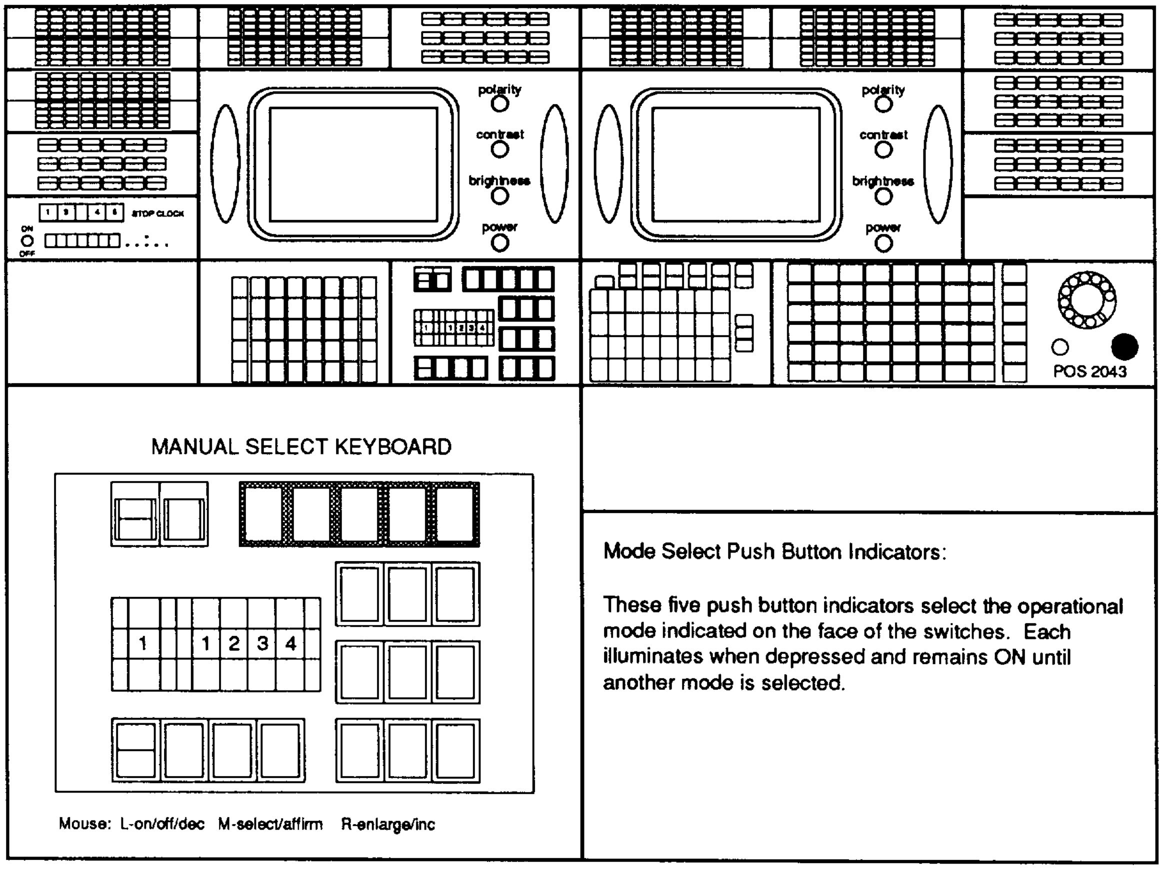

Figure 2. Grahical Interface of the console Tutor

The console tutor can be expanded to include all the operations of a console in mission control. Figure 3 shows a structure that the tutor can use in order to train all of the components and procedures required for console operations (5). This tutor would be a useful tool for the current console operators and training to become an operator. Those who have already become proficient on the console could use the system to refresh their skills or improve their speed. Currently, training new operators consists of many hours of one-on-one, on-the-job type instruction. Trainers of the console operators are in high demand. Some of the expensive one-on-one and full simulation time could be saved with a tutoring system such as the console operations tutor.

There are other ITSs for space application domains, such as the OM (orbital mechanics) tutor, and MITT for maintaining the space shuttle fuel cells (22). ITSSO (intelligent tutoring system for satellite operations) is an embedded training system for operators of ground control systems for near-earth unmanned scientific satellites (30). A prototype ITS is under development to assist in teaching the command and control language STOL (systems test and operations language) at NASA (4). The Payload-Assist Module Deploys/Intelligent Computer-Aiding Training system trains mission control center flight dynamics officers to deploy a satellite from the shuttle (14).

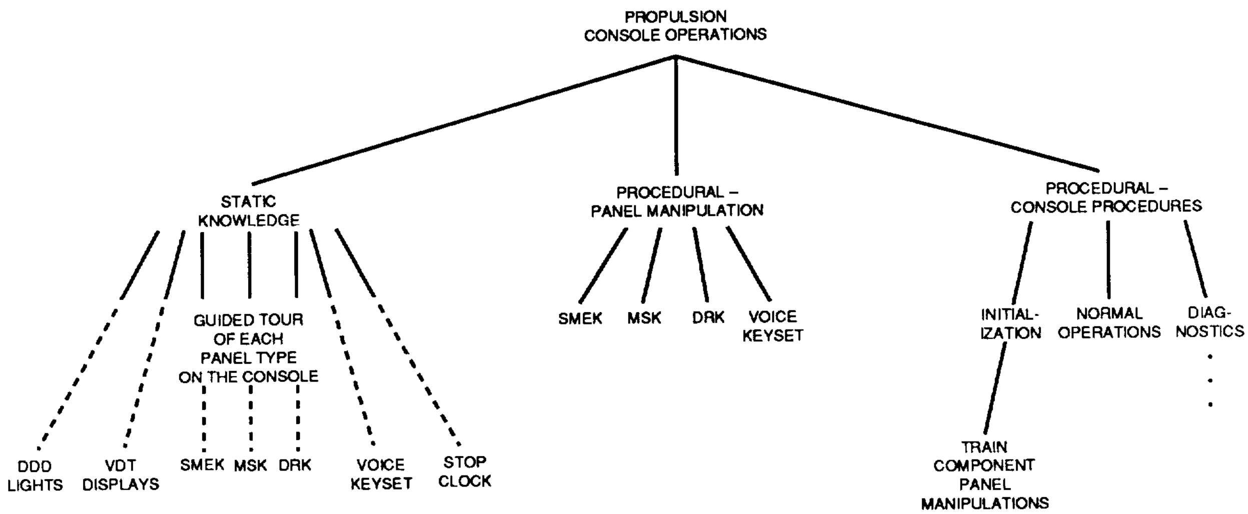

Figure 3. Top Level Overview of the Knowledge Needed to Train Console Operations

THE FUTURE

We expect to have a space station before the turn of the century, a lunar base shortly thereafter, and a manned mission to Mars after that. The President of the United States confirmed this in his speech of July 20, 1989, the 20th Anniversary of humanity first stepping onto the moon. The shuttle is the key to the station and the rest of our accomplishments in space right now. With the agressive shuttle flight schedule, training for missions will become overloaded using the current training methodologies that require extensive time, one-on-one training, and large, three-dimensional, full-fidelity simulators. Future training will need to be consolidated and made more effective while using less human and full-fidelity simulation intensive techniques. ITSs could be used to assist in training for many aspects of space related endeavors by lowering requirements for so much human intervention.

For example, the instructors to the astronauts work very closely with the astronauts many months before a mission. The astronauts train in the shuttle mission simulator in order to have experience with many different shuttle flight scenarios. The instructors using this system are inundated with data and information during a simulation. An ITS could be utilized to process the data and decide what is important and pertinent for the instructors' use in their decisions of what malfunctions to introduce into the simulation for the most effective training of the astronauts undergoing the training. The ITS could serve to train the instructors as well. The ITS could be written to be an intelligent interface for the instructors in viewing the current status of the simulation and to input malfunctions. It could be an advisor of malfunctions to help achieve a session's objectives, and it could be a record keeper for reporting the results of a session and tracking training objectives.

A payload specialist aboard the shuttle will use equipment and run experiments, all in an unfamiliar, weightless environment. ITSs can be coupled with simulations to assist in determining curricula, tracking and analyzing student performance, running individualized instruction and scenarios, and making recommendations to students. Finally, ITSs would be useful for embedded training in addition to training and retraining specialized equipment usage and repair.

One of the recommended applications of knowledge-based systems for the space station is onboard personnel training (9). In the Lunar Evolution Case Study of the Office of Exploration's Study Requirements Document, there is a requirement that autonomous, on-site crew training be available for all crew operated, safety critical systems (17). ITSs can fulfill these needs. The people who live and work on the station will have many skills and much knowledge. When the skills and knowledge are not utilized, they degrade over time. ITSs can be used for keeping skills and knowledge intact and fully accessible to the people staying on the station. A lunar city, long term voyage in space, and a Mars base have similar problems with respect to knowledge degredation from lack of use and would also benefit from ITSs in this way.

Skills and knowledge areas for living in and running space systems could be split into different categories of training such as those that are routine and those that are used in emergency situations. Routine tasks such as equipment maintenance and repair, facility cleaning, and food management may need to be handled in a different manner than tasks that are needed for life threatening circumstances such as structural or propulsion breakdowns. Paper, on-line manuals, or conventional computer-based training may be best for the routine tasks where time can be taken by the learner. On the other hand, an ITS with an interactive videodisc interface could be best suited for emergency-type tasks that need to be learned and used immediately. The ITS could be geared to the particular learner and the specific, required task and repair, so that the training can occur quickly. Having ITSs accessible could make an important difference in criticial situations.

One place to look for ITS applications is where expert systems have been built, such as the system for failure diagnosis on the space station (15). It is possible to build an ITS around an expert system (28). Smith, Fink, and Lusth present an approach to taking a specific expert system design and developing a tutoring system around it. The expert system design is called the Integrated Diagnostic Model where information about the domain is represented in two levels, the experiential and the functional. The experiential level contains information gained from the experience of working in the domain. The functional level contains information about the operation of the domain and how the physical devices work. The experiential part can be used as a tutor that can impart the overall behavior of a system to the student. The functional model can be used to teach a deeper, more detailed knowledge of a system. An instructional designer can choose between the two representations as is appropriate and most effective for each skill to be taught.

CONCLUSION

Intelligent tutoring systems need to continue to be developed and improved in order to come up to speed for future requirements, especially for space systems. NASA and other future-looking organizations should be very interested in ITS development for space applications and other training needs from manipulating and diagnosing complex systems to teaching language and computer literacy.

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