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AN INTELLIGENT POSITION-SPECIFIC TRAINING SYSTEM FOR MISSION OPERATIONS

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I. INTRODUCTION

During a Spacelab mission, approximately 19 payload ground controller positions provide operations support for Spacelab experiments. Each ground controller position provides a specific type of operations support. For example, the crew interface coordinator (CIC) position manages air-to-ground voice communication between the payload crew on the orbiter and the payload operations team on the ground. Since each ground controller position provides a specific type of support, ground controllers need both generic and position-specific ground controller training.

Although Marshall Space Flight Center's (MSFC's) ground controller training program provides very good generic training, position-specific training can be improved by adding position-specific training systems. MSFC's current training program does not contain any position-specific training systems. However, ground controllers need position-specific training systems which meet all of the following criteria:

- Provide training on position-specific knowledge
- Provide training on position-specific subjects and skills one at a time
- Provide training on integrating position-specific skills and knowledge
- Provide a training tool that is available 24 hours a day
- Provide an interactive training environment.

The purpose of this report is to describe a generic syllabus for position-specific training systems, describe a system design for position-specific training systems, describe a process for developing position-specific training systems, and describe the MacCIC intelligent position-specific training system prototype developed during this research project. The report is arranged as follows:

- Section II discusses how MSFC conducts ground controller training today and why MSFC needs position-specific training systems
- Section III discusses the objectives for this research project
- Section IV discusses the approach used to meet the research objectives
- Section V describes a generic syllabus for position-specific training systems
- Section VI discusses the range of possible system designs for position-specific training systems

- Section VII describes a process for developing position-specific training systems
- Section VIII describes the position-specific training system prototype developed during this research project
- Section IX discusses lessons learned during this research project.

II. BACKGROUND ON MISSION OPERATIONS TRAINING

MSFC's ground controller training program provides very good generic ground controller training; however, the program only provides a limited amount of position-specific training. MSFC's Spacelab ground controller training program is comprised of mission-independent training, mission simulations, and line-organization training.

A. Mission-Independent Training

Mission-independent training provides an overview of payload operations and does not provide position-specific training. Mission-independent training is provided through paper workbooks and classroom briefings. Paper workbooks provide general information and address a very broad audience. An example of a mission-independent training workbook topic is "Control Center Operations." This workbook provides the trainee with general information about mission management, flight rule changes, and payload operations team responsibilities. The classroom briefings provide specific information and also address a very broad audience. An example of a classroom briefing topic is "Experiment Power Distribution System." During this briefing, the trainee is presented with an overview of the experiment power distribution system and an overview of how experiment power distribution system failures affect payload operations. Although a few of the workbooks and classroom briefings describe position-specific responsibilities, mission-independent training does not provide position-specific training.

B. Mission Simulations

A mission simulation is a practice session for a mission. During a mission simulation, ground controllers practice position-specific skills; however, mission simulations are very expensive and they do not provide a first-time learning environment. Mission simulations are expensive because they require the following resources:

- Mission Simulation Planning Team
- Mission Simulation Participants (approximately 200)
  - ground controllers
  - orbiter payload crew (or surrogates)
  - scientists (or surrogates) who have experiments on board the orbiter
- Facility (Huntsville Operations Support Center)
  - facility costs (computers, power, water, etc.)
  - facility personnel.

Mission simulations do not provide a first-time learning environment because ground controllers are expected to perform position-specific skills and apply position-specific knowledge which they already possess. Therefore, although mission simulations provide an opportunity for ground controllers to practice position-specific skills, they are not appropriate for training new ground controllers.

C. Line-Organization Training

Ground controllers belong to different organizations within MSFC's Mission Operations Laboratory, and each organization provides some type of line-organization training. Line-organization training does focus on position-specific training; however, each organization provides line-organization training in a different way. Some organizations provide line-organization training through hands-on exercises, while others provide line-organization training through classroom briefings. Although line-organization training provides position-specific training, trainees sometimes miss important knowledge or skills for the following reasons:

- Line-organization training is usually provided verbally
- Line-organization training is not standardized—training depends on who is doing the teaching
- Line-organization training is not available 24 hours a day or even regularly scheduled
- Line-organization training is not structured—trainees get pieces of information, not the whole picture
- Line-organization training is affected by personnel changes—people leave the organization taking core knowledge with them.

D. Summary

Although MSFC's Spacelab ground controller training program provides very good generic training, ground controllers gain position-specific knowledge in a very nonstructured way. MSFC's ground controller training program needs a position-specific training system.

III. RESEARCH OBJECTIVES

The research project discussed in this report had the following research objectives:

(1) Utilize techniques in artificial intelligence supplemented by state-of-the-art technology in hardware and software to develop an intelligent position-specific training system for the CIC Payload Operations Control Center (POCC) cadre position

(2) Create a generic syllabus for position-specific training systems

(3) Create and document a process for developing position-specific training systems

(4) Specify a system design for position-specific training systems.

IV. RESEARCH APPROACH

The project team's approach to meet the research objectives covered in section III included the following two elements:

- Create a position-specific training system for one of the payload ground controller positions (CIC position)
- Start with an existing development process instead of creating a new development process.

By creating an intelligent position-specific training system, the project team could evaluate all aspects of developing these types of systems. The most important part of this approach was that the team could evaluate the entire process, uncover problem areas, and find solutions to the problems during the process. The second part of the approach was to adopt an existing development process instead of starting from scratch. Since one of the project objectives included using the techniques of artificial intelligence, the project team used an existing expert system development process. Although intelligent training systems are quite different from expert systems, the process to develop either type of system is very similar. The expert system-development process adopted was found in the book entitled "Knowledge Acquisition: Principles and Guidelines" written by Karen McGraw and Karan Harbison-Briggs. This process provided a solid foundation throughout the project. The approach used by the project team to meet the project objectives was very successful.

V. A GENERIC SYLLABUS FOR POSITION-SPECIFIC TRAINING SYSTEMS

This section describes the generic syllabus for a position-specific training system. (An example of using this generic syllabus for a specific ground controller position-specific training system can be found in section VIII.) The generic syllabus for a position-specific training system includes three main components: "Teach me about," "Practice," and "Scenarios." "Teach me about" provides a library of position-specific knowledge. "Practice" provides training on position-specific knowledge and skills one topic at a time. "Scenarios" provides training on integrating position-specific knowledge and skills.

A. "Teach Me About"

The purpose of the "Teach me about" component is to allow the trainee to investigate position-specific knowledge as if they were in a library. "Teach me about" should not provide any tutoring. "Teach me about" should contain all the position-specific knowledge the ground controller will need to perform his/her job during a mission. As a minimum, "Teach me about" should contain a payload operations overview and a position-specific overview. The payload operations overview should contain general information about payload operations onboard the orbiter and on the ground. Section VIII discusses this in more detail. The position-specific overview should contain as a minimum the following elements:

- Interfaces
- Inputs/outputs

- Tools
- Decision making
- On-console flow of events
- Voice protocol
- Miscellaneous.

Figure 1 shows the CIC position-specific overview.

1. Interfaces. Interfaces should cover all the interaction that this ground controller position will have with other payload operations personnel. This may include other ground controller positions, principle investigators, public affairs, or the orbiter crew.

2. Inputs/Outputs. Inputs/outputs should cover all the information that the ground controller position receives as well as all information which the ground controller position must produce. An example of an input is a flight note. An example of an output is a shift report.

3. Tools. Tools should cover all the tools that the ground controller will utilize during a mission. Tools include items such as a log book, real-time displays, position-specific software, and the AOS/LOS clock and groundtrack display.

4. Decision Making. Decision making should cover the types of decisions that the ground controller will be required to make during a mission. This topic is very position-specific.

5. On-Console Flow of Events. On-console flow of events should provide a flow chart showing what happens from the time the ground controller enters the payload operations control center to begin a shift until the ground controller hands over to the next shift. The purpose of this element is provide new ground controllers with some sense of what they can expect and what they should be doing. Often new ground controllers feel very awkward because they do not know what to expect or exactly what they are supposed to do on-console. Most of the time, this occurs because they only have bits and pieces of information to work with and do not have an overall understanding of their responsibilities.

6. Voice Protocol. Voice protocol should cover the important concepts about voice protocol that every ground controller is required to know. Since voice protocol is covered in a mission-independent training class, only the highlights need to be covered.

7. Miscellaneous. Miscellaneous should cover any topics that belong in the position-specific overview but do not fit in any of the categories listed above. An example of a miscellaneous item would be space classroom or space adaptation syndrome.

As was mentioned earlier, the purpose of "Teach me about" is to provide the trainee with a library of information. The trainee should be free to investigate the topics in "Teach me about" in any order they would like.

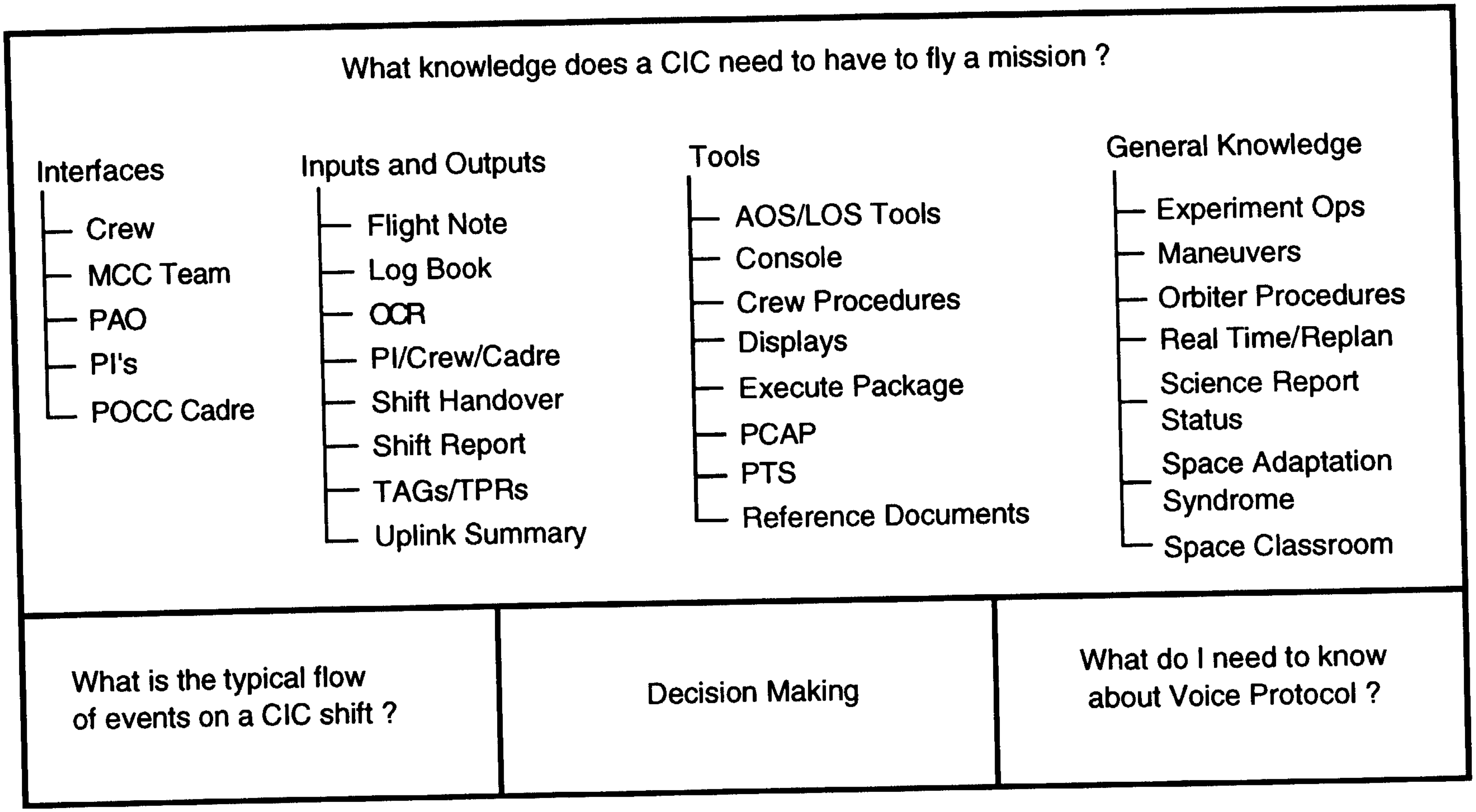

Figure 1. MacCIC training system—CIC overview screen.

B. "Practice"

The purpose of the "Practice" component is to allow the trainee to practice what they have learned one topic at a time. "Practice" contains two major elements. The first element is question and answer. The question and answer element should allow the trainee to practice how much he/she knows about the topic. The second element should include a variety of unique exercises related to the topic. For example, if the training topic is flight notes, there should be several exercises which allow the trainee to practice evaluating and responding to a flight note. The combination of question and answer and unique exercises should allow the trainee to test how much he/she knows about a topic and practice position-specific skills for the specific topic.

C. "Scenarios"

The purpose of the "Scenarios" component is to allow the trainee to practice integrating all position-specific knowledge and skills at one time. "Scenarios" should strive to simulate the decision-making process that occurs during a mission.

D. Summary

Intelligent position-specific training systems should contain components for "Teach me about," "Practice," and "Scenarios."

VI. SYSTEM DESIGN CHOICES FOR POSITION-SPECIFIC TRAINING SYSTEMS

The system design for a position-specific training system could be based on computer-assisted instruction (CAI), intelligent computer-assisted instruction (ICAI), or an intelligent tutoring system (ITS). This section provides a short discussion on each type of system and then explains why an ICAI system is the most suitable type of system for the position-specific training systems.

A. Computer-Assisted Instruction

CAI has been around since the early 1960's and basically uses the computer as a tool to assist in instruction or training. The goal of CAI was to "build instructional programs that incorporate well-prepared course material in lessons that are optimized for each student" (ref. 4, p. 225). Barr and Feigenbaum explain that "early programs were either electronic 'page-turners,' which printed prepared text, or drill-and-practice monitors, which printed problems and responded to the student's solutions using prestored answers and remedial comments" (ref. 4, p. 225). Since CAI is based on prestored answers, this type of system does not provide a very rich training environment. For example, the training system cannot change the training environment based on the student's responses. However, the advantage of this type of system is that it is very easy to develop. The developers can decide on the list of topics and exercises to provide and code the material in a very straight-forward manner.

B. Intelligent Computer-Assisted Instruction

Barr and Feigenbaum explain that "in the intelligent CAI (ICAI) programs of the 1970's, course material was represented independently of teaching procedures, so that problems and remedial comments could be generated differently for each student"(ref. 4, p. 125). ICAI is a step above CAI since it provides the capability to adapt to the student. However, due to this added capability, it is somewhat more difficult to develop than a CAI system. ICAI systems eventually evolved into what is now referred to as an intelligent tutoring system. In some material, the terms ICAI and ITS are still used interchangeably. In this report, a strong distinction is made between an ICAI system which incorporates a small amount of intelligence and an ITS which incorporates a very significant amount of intelligence.

C. Intelligent Tutoring Systems

The jump from an ICAI system to an ITS is really quite extreme. Most ITS's are still used in university laboratories and have not made it out into industry. This is because they are very complex, and most of the components of an ITS are still under study. An ITS consists of three main components: an expert module, a student module, and a teacher module. The expert module contains knowledge about the subject matter. The student module contains knowledge about the student including what the student understands and what the student does not understand. The teacher module contains knowledge about teaching, controls the interaction with the student, and evaluates the student's progress. At present, there are many different ideas about how the three modules should interact and the specific design of each module. Besides these factors, there are several other areas of research in the ITS field such as the environment module and the human-computer interface. The environment module is an important area of study and refers to "that part of the system specifying or supporting the activities that the student does and the methods available to the student to do those activities"(ref 5, p. 109). The human-computer interface provides the capability for the user and the system to communicate. The human-computer interface for an ITS is "inherently complex because the users of these systems are by definition working with concepts they do not understand well" (ref. 5, p. 143) and, therefore, can greatly enhance or harm the effectiveness of an ITS. In general, ITS's are very complex, very difficult to develop, and need a lot more work before they can be mass produced.

D. Recommendation for Position-Specific Training System Design

The ICAI system design represents the most economical and robust solution for the position-specific training systems. Technology is available to develop an ICAI system in a straight-forward manner. The ICAI system will provide better training than a CAI system, but will not require the enormous amount of manpower and research necessary to develop an ITS.

E. Summary

Although there are several different system designs available for the position-specific training systems, the research completed during this project indicates that an ICAI design would be the most beneficial.

VII. A GENERIC METHODOLOGY FOR DEVELOPING POSITION-SPECIFIC TRAINING SYSTEMS

The development process presented in this section is a generic development process that can be used for developing any position-specific training system. As was discussed in section III, this process was adapted from the expert system development process presented by Karen McGraw and Karan Harbison-Briggs in their book entitled "Knowledge Acquisition: Principles and Guidelines." Figure 2 shows each phase in the development process.

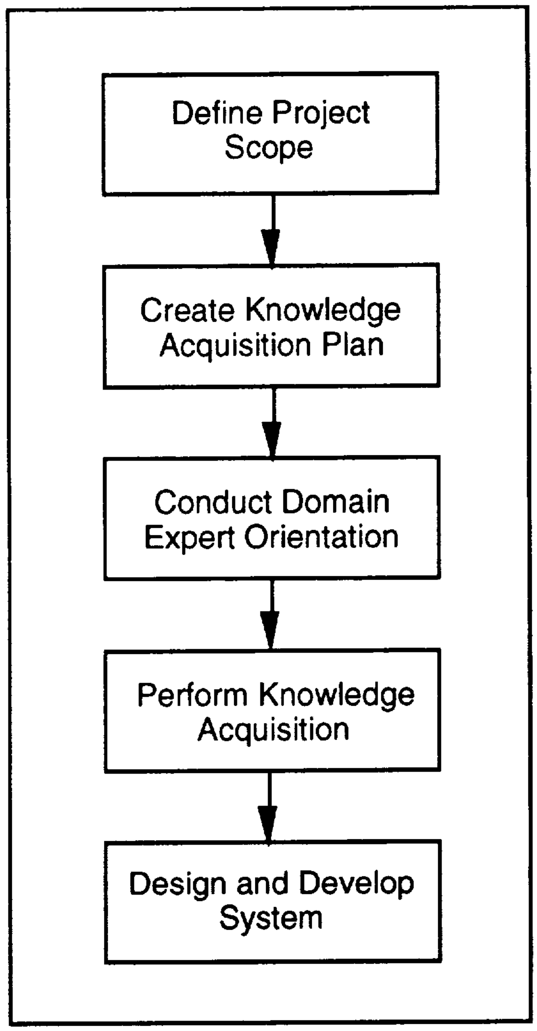

Figure 2. Position-specific training system development process.

A. Define Project Scope

During phase 1, the project team should define the project scope. The project scope defines what the position-specific training system will teach. Since the position-specific training system targets a specific ground controller position, the project team members should be people who are experts on that specific ground controller position. For example, if the position-specific training system will train CIC's, the project team should consist of people who have flown Spacelab missions as CIC's. People who are experts in a particular subject, or domain, are called domain experts. Therefore, the project team should be made up of domain experts in the particular ground controller position domain. The following developmental strategies can be used to define the project scope:

- Brainstorming sessions
- Building a concept dictionary
- Creating a cognitive map.

1. Brainstorming Sessions. The first project team meetings should be brainstorming sessions. During the brainstorming sessions, the team should identify goals for the position-specific training system. The brainstorming sessions should drive out the general requirements for the training system. It is likely that the goals discussed during the brainstorming sessions will also identify specific hardware and software requirements. For example, suppose the team identifies a goal to teach voice communication protocol. This goal requires that the hardware and software support the capability to manipulate audio. Therefore, audio manipulation is a requirement on both the hardware and software tools needed to develop the position-specific training system.

2. Building a Concept Dictionary. Following the brainstorming sessions, the project team should create a concept dictionary. The concept dictionary "...provides a mechanism to visualize an abstraction of the primary concepts in a domain and the terminology used to label them" (ref. 2, pp. 136–137). The project team should perform the following steps to create the concept dictionary. Each team member should:

(1) Create a list containing every acronym, term, or phrase used in the domain

(2) Group similar or related terms together

(3) Label each group of terms.

A concept dictionary "...is based on the notion that words may be grouped by common elements of reference into recognizable concepts" (ref. 2, p. 137). The project team should use the concept dictionary as a tool to define the project scope by identifying all the major concepts in the specific ground controller position domain. The concept dictionary provides an outline for the project scope. The information which follows are excerpts from three different concept dictionaries created by three different domain experts during development of the CIC position-specific training system prototype. Each of the domain experts grouped these terms together and labeled the terms in a category called communications. The domain experts did this individually and did not share information. These excerpts show how well the concept dictionary can extract domain concepts.

Excerpt from Crew Interface Coordinator Concept Dictionary

Domain Expert 1 COMM Terminology	Domain Expert 2 Voice Communications	Domain Expert 3 Communications
A/A	A/A	A/A
A/G	A/G	A/G
AOS	AOS	AOS
CH	COMM	CH
FM	CONF	COMM
ICOM	GDS	D/L
KSA	GN	DOMSAT
LOS	GSTDN	ECIO
PM	H/O	FOV
PN	ICMS	Hz
SSA	INTELSAT	ICOM
COMM	LOS	LOS
	MILA	Mbps
	MIPS	MHz
	NCC	RF
	SIM	SCIO
	WCCU	TV
	WSGT	uhf
	CH	VID

3. Creating a Cognitive Map. After defining the concept dictionary, the project team should create a cognitive map. A cognitive map is "... a domain expert's ideas concerning primary concepts and interrelationships in a domain" (ref. 2, p. 139). Although the concept dictionary provides an outline for the project scope, it does not provide enough information to create the training structure which is needed to complete the project scope. The training structure is the specific syllabus for the position-specific training system. By using the concept dictionary as a building block, the team can create the cognitive map which establishes interrelationships between all the concepts in the ground controller position domain. Figure 3 shows the cognitive map created for payload operations during development of the CIC position-specific training system prototype. Since the project team is comprised of domain experts, the cognitive map provides a mental model that can become the training structure for the position-specific training system. When the project scope definition is complete, the project team can move to the next step in the development process: creating the knowledge acquisition plan.

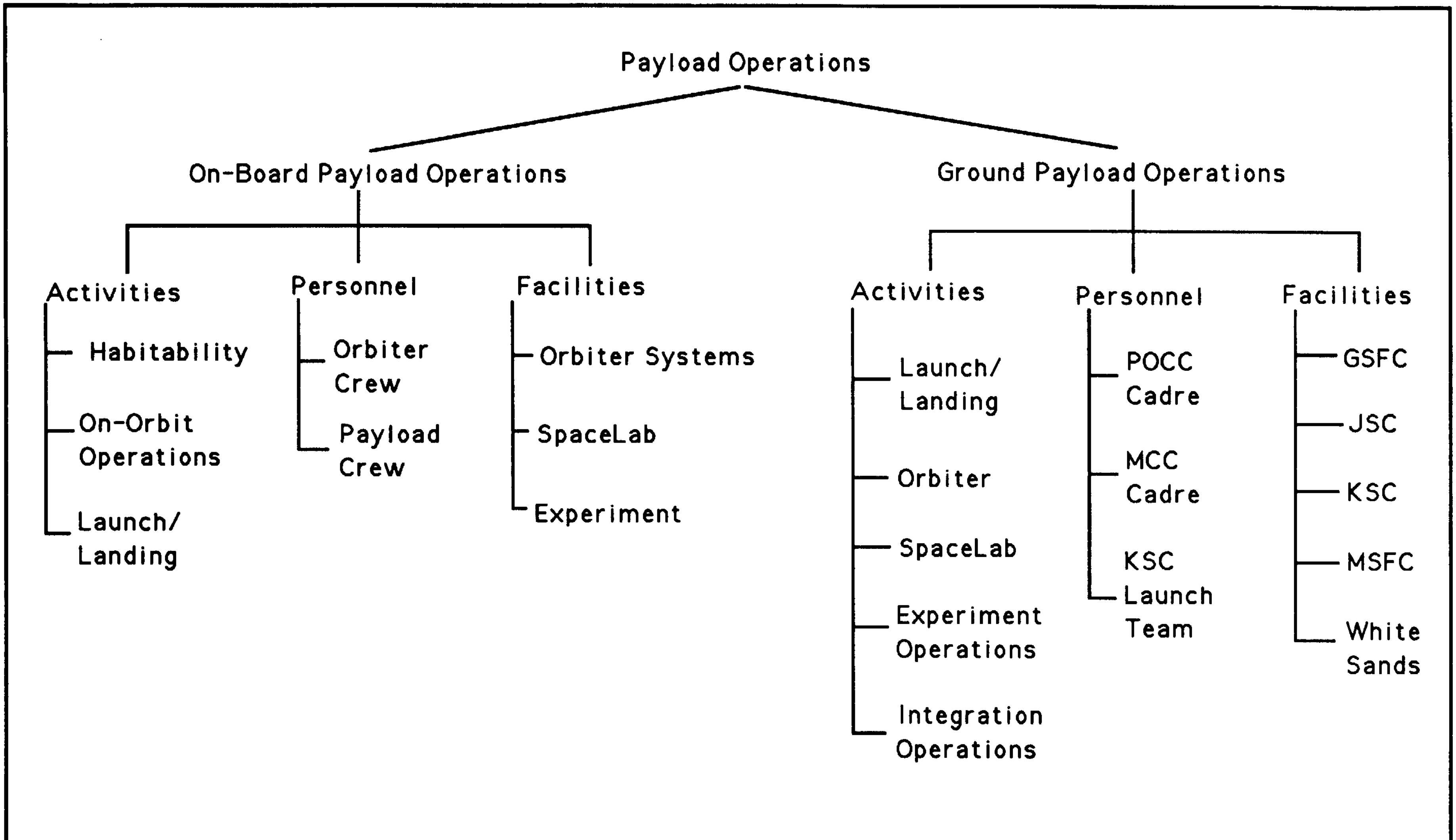

Figure 3. Cognitive map for payload operations.

B. Create Knowledge Acquisition Plan

After defining the project scope, the project team should write a knowledge acquisition plan. The knowledge acquisition plan should contain an entry for every training topic in the position-specific training system. The plan should also include a preliminary list of questions and information sources for acquiring the knowledge for each topic. The information sources usually range from documents to domain experts. The following is an excerpt from the knowledge acquisition plan written during this research project:

Launch/Landing

What on-board activities are associated with launch and landing?

Who performs these activities on-board?

What time do these activities take place? For example stowage, deorbit procedures, etc.

What ground activities are associated with launch and landing?

Who performs these activities on the ground?

Information Source: Domain experts and training materials.

There are two types of knowledge that need to be collected for a position-specific training system. The first type is the domain knowledge and the second type is pedagogical knowledge. For example, the CIC position-specific training system prototype provides training on flight notes. Therefore, the team had to collect domain knowledge about flight notes and domain knowledge about training new CIC's on handling flight notes. The knowledge acquisition plan should address both types of knowledge. The project team should use the knowledge acquisition plan as a guideline for collecting all the domain knowledge and pedagogical knowledge necessary for the position-specific training system.

C. Conduct Domain Expert Orientation Meeting

After creating the knowledge acquisition plan, the project team lead should conduct a domain expert orientation meeting. This meeting introduces new domain experts to the project goals and activities. Although the project team is made up of domain experts, there will usually be other domain experts who participate in the development process. The domain expert orientation meeting addresses the new domain experts. The purpose of this meeting is to "... help domain experts understand what the team is attempting to build, what their role in the program will be, and what they can expect from 'knowledge acquisition'" (ref. 2, pp. 88–89). The following is an example of some of the topics addressed during the domain expert orientation meeting conducted during this research project:

- Introduction to artificial intelligence
- Introduction to intelligent training systems

- Functional goals of the CIC position-specific training system
- Knowledge acquisition for the CIC position-specific training system.

D. Perform Knowledge Acquisition

After the domain expert orientation meeting, the project team should begin conducting knowledge acquisition sessions. Knowledge acquisition is the "process of extracting, transforming, and transferring expertise from a knowledge source..." (ref 2, p. 344). At this stage in the project, the project team personnel usually expands. The original team members continue to serve as domain experts and new members join the project team to serve as knowledge engineers. A knowledge engineer is an individual who "...works with domain experts to acquire, structure, and translate domain knowledge..." (ref. 2, p. 345). For each knowledge acquisition session, the knowledge engineer should perform the following steps:

- Pre-knowledge acquisition activity
- Knowledge acquisition session
- Post-knowledge acquisition activity.

As was discussed above, there are two types of knowledge that need to be collected for a position-specific training system. The knowledge acquisition sessions are used for collecting both types of knowledge.

1. Pre-Knowledge Acquisition Activity. The knowledge engineer should prepare for a knowledge acquisition session by contacting the domain expert to schedule a session, researching the session topic, and preparing a pre-knowledge acquisition session form. The pre-knowledge acquisition session form should include as a minimum the date, place, time, and purpose of the knowledge acquisition session. The knowledge engineer should also list preliminary questions for the domain expert to begin thinking about before the session. Both the knowledge engineer and the domain expert use the information in the pre-knowledge acquisition session form to prepare for the knowledge acquisition session.

2. Knowledge Acquisition Session. There are many different techniques that can be used to perform knowledge acquisition. Karen McGraw and Karan Harbison-Briggs[2] provide an excellent discussion on using the interview as a knowledge acquisition technique. During this research project, the knowledge engineers used several knowledge acquisition techniques including:

- Reviewing available documentation
- Conducting interviews with domain experts
- Communicating with domain experts through electronic mail
- Observing mission simulations.

However, since most of the knowledge ground controllers possess is obtained through on-console experience, interviews are usually the most beneficial. Many times interviews are the only appropriate technique available to acquire certain pieces of knowledge. Therefore, the knowledge engineering team should be prepared to spend a significant amount of time interviewing domain experts. The knowledge acquisition sessions should be recorded on video or audio tape in order to store all the knowledge discussed during the session. The knowledge engineers should utilize these tapes when they prepare the post-knowledge acquisition session notes. Knowledge acquisition sessions conducted as an interview with a domain expert should not last longer than 2 hours. The knowledge engineering team found that interviews which lasted longer than 2 hours tended to lose focus.

3. Post-Knowledge Acquisition Activity. After conducting a knowledge acquisition session, the knowledge engineer should perform the following steps:

- Document the session results on a post-knowledge acquisition session form
- Send the results to the domain expert for review
- Incorporate any comments or modifications made by the domain expert
- Submit the post-knowledge acquisition form to the project team.

When the project team receives a post-knowledge acquisition form, the team should determine if the knowledge acquisition session goals were met and whether further sessions will be necessary. The project team must be comprised of domain experts in order to make these determinations.

E. Design and Develop System

Once the team has collected all the domain knowledge for the position-specific training system, the team can move into the design and develop system phase. The manner in which the team performs this phase depends on which system design is selected. Section VI describes a range of system designs which are applicable to a position-specific training system. The information which follows is based on the research conducted during this research project. Therefore, this information should be carefully evaluated before a team decides this is the best route to follow. If the team decides to adopt the type of system design recommended in this report, the following steps should be performed during this phase:

- Layout and detail the overall design concept
- Design and develop the user interface for each topic
- Design and develop the knowledge base for each topic
- Connect the user interface and the knowledge base.

1. Layout and Detail the Overall Design Concept. The very first step the team should perform in the design and develop system phase is to layout and detail the overall design concept. The overall design concept should be based on the generic syllabus presented in section V of this report and the cognitive maps which were created when the team defined the project scope. The generic syllabus presented in section V provides the foundation for the layout of the system's user interface. The team can start with this layout and then modify the parts which will be specific to the particular position-specific training system they are developing. For example, figure 1 shows the layout for the CIC overview screen which is the position-specific overview screen in "Teach me about." If the team is building a system for the data management coordinator (DMC) position, they can begin by using the CIC overview screen as the starting point, and then modify it so that it contains information specific to the DMC position. Once modified the screen can be used as the DMC overview screen. During this part of the design and develop phase, the team should evaluate each of the three areas of the generic syllabus and define the specific information each area should contain based on the specific ground controller position. As soon as the team completes the layout and detail of the overall design concept step, they can then move on to design and development tasks for each of the individual topics.

2. Design and Develop the User Interface for Each Topic. The first step in the design and develop phase for a specific topic focuses on the user interface design. The team should use the process shown in figure 4 to design and develop the user interface. First, one of the team members should create a user interface design for the topic. The design should be based on the preliminary user interface design concepts created during the definition of the overall design concept. The development team member should submit the design to the project team. Once the project team approves the design, the developer should create a software prototype of the design. Once the prototype is complete, the team should ask potential users to evaluate the design. The users should include both experienced ground controllers and ground controller trainees. The project team and users should work together to revise the design. After incorporating the revisions, the developer should create the final version.

3. Design and Develop the Knowledge Base for Each Topic. During this step in the design and develop phase, the project team should transform the knowledge collected in the knowledge acquisition sessions into facts and rules. These facts and rules, which represent the domain knowledge, are then stored in the knowledge base. This step in the design and develop phase will be guided by the overall system design defined during the layout and detail for the overall design concept.

4. Connect the User Interface and the Knowledge Base. During the last step in the design and develop phase for a particular topic, the developer connects the user interface and the knowledge base. This step is really a clean-up step since the developer has usually added bits and pieces of code to connect the user interface and knowledge base throughout the two previous steps. Although the previous steps were presented as individual steps, they are really very tightly integrated.

F. Summary

The methodology presented in this section can be used as a model to create other ground controller position-specific training systems. Steps 1 through 4 can be applied to any type of position-specific training system which is developed. As was stated earlier, step 5 may need to be modified based on the type of system design which is selected for the position-specific training system. Although each position-specific training system will contain different domain knowledge, the process to develop a position-specific training system is generic.

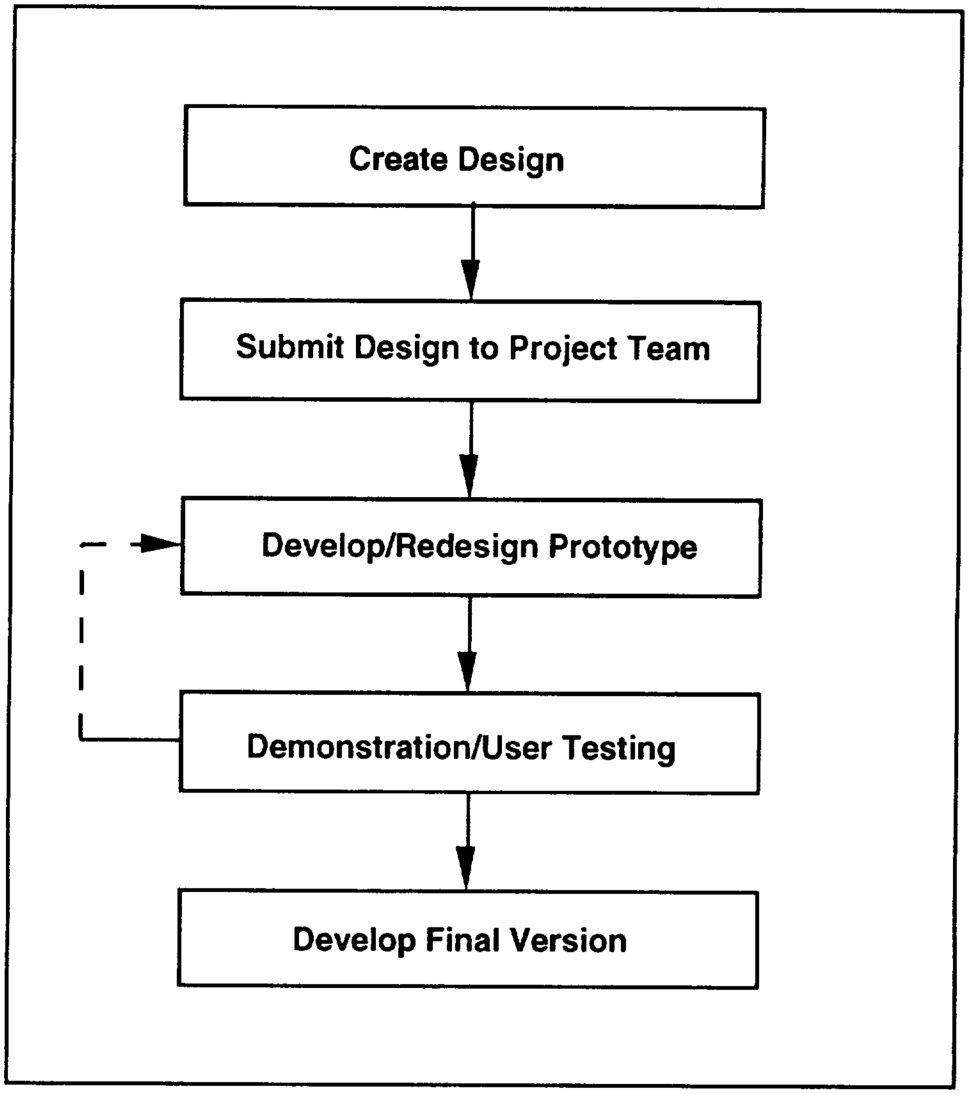

Figure 4. User interface design process.

VIII. MacCIC : AN INTELLIGENT POSITION-SPECIFIC TRAINING SYSTEM PROTOTYPE

MacCIC is an intelligent position-specific training system prototype for the CIC ground controller position. MacCIC has been under development throughout the course of this research project. A significant amount of the development time has been spent in the knowledge acquisition phase. MacCIC contains hooks for each major component that should be part of a position-specific training system. However, MacCIC is a prototype and will require a significant amount of work to make it a complete training system. MacCIC's training structure is based on the generic syllabus presented in section V of this report. Although MacCIC provides training for a specific ground controller position, many of MacCIC's elements are applicable to other ground controller position-specific training systems. Upon completion, MacCIC will meet all of the following criteria:

- Provide training on CIC specific knowledge
- Provide training on CIC specific knowledge and skills one topic at a time
- Provide training on integrating CIC specific knowledge and skills
- Provide a training tool that is available 24 hours a day
- Provide an interactive training environment.

A. MacCIC Training Structure

The MacCIC training structure has three major components: "Teach me about," "Practice," and "Scenarios." "Teach me about" provides a library of CIC specific knowledge. "Practice" provides training on CIC specific knowledge and skills one topic at a time. "Scenarios" provides training on integrating CIC specific knowledge and skills.

1. Teach Me About. "Teach me about" provides a library of information on a variety of topics. The trainee is free to investigate the information in any order and in any amount of detail. "Teach me about" provides information on the following topics:

- Payload operations overview
- Network communications
- Mission milestones
- Documentation
- CIC overview.

a. Payload Operations Overview. The payload operations overview provides information about activities, personnel, and facilities on the ground and onboard the orbiter during a spacelab mission. Most of the information provided in the payload operations overview is also provided in mission-independent training. However, MacCIC provides a concise presentation of the information that is pertinent to the CIC position.

b. Network Communications. Network communications provides information on ground and space network communications. CIC's need to understand this information in case network communications fail. The information presented specifically addresses types of failures that affect the CIC position. For example, network communications provides the trainee with information on tracking data relay satellite system (TDRSS) failures and provides information on how CIC's respond to TDRSS failures.

c. Mission Milestones. Mission milestones provides information on all the major pre-mission events that occur during the 3 years prior to a spacelab mission launch. These mission milestones include events such as the integrated payload design reviews, crew training, payload operations team training, and joint integrated simulations. Mission milestones includes a cartoon-story entitled "A day in the life of a principle investigator." The cartoon-story provides a step-by-step look at an entire Spacelab mission. The story begins with the principle investigator's proposal to NASA to fly an experiment onboard the space shuttle. The story ends with the process of distributing the mission science data after the orbiter lands. The mission milestone information provides a general introduction to the Spacelab program.

d. Documentation. Documentation provides information on all the mission documents a CIC should be familiar with. It includes a description of each document and the document's table of contents. When MacCIC displays the table of contents, it highlights the topics which are most important to the CIC. The mission documents addressed in the documentation section are as follows:

- Basic Flight Definition Document
- Data Flow and Data System Configuration
- Flight Definition Document
- Orbital Mechanics Analysis—Appendix A
- Generic Joint Operations Interface Procedures for Spacelab
- Integrated Training Plan
- Operations Control Handbook
- Operations and Integration Agreement
- Payload Crew Activity Plan
- Payload Flight Data File
- Payload Operations Checklist
- Payload Operations Control Center Configuration Requirements Document
- Payload Operations Control Center Integrated Requirements Document
- Payload Operations Guidelines (All Flights)
- Payload Operations Guidelines (Flight Supplement)
- Payload Operations Handbook (All Flights)
- Payload Operations Handbook (Flight Supplement)
- Space Shuttle Operational Flight Rules Annex
- Spacelab Verification Plan

- Space Transportation System Flight Data File
- Training Annex No. 7.

e. CIC Overview. The CIC overview presents a table of contents for all the CIC specific knowledge. It is the most important item in "Teach me about." New CIC's will spend most of their time studying the information provided through the CIC overview. Figure 1 shows the wide range of subjects addressed in the CIC overview. The CIC overview structure is generic and applies to all ground controller positions. For example, all ground controllers interface with other personnel, accept inputs, generate outputs, use position-specific tools, make decisions, and use voice protocol. Therefore, the CIC overview section is an example of a generic structure that can be used to represent any ground controller position environment.

2. Practice. "Practice" allows the trainee to practice CIC specific knowledge and skills one topic at a time. For each topic, MacCIC provides both question and answer exercises and unique exercises which relate to the specific topic. During the practice exercises, MacCIC provides tutoring when necessary. "Practice" will eventually contain exercises for the following topics:

- AOS/LOS clock and groundtrack display
- Communications panel
- Console operations
- Crew procedures
- Enabling/disabling principle investigators on air to ground
- Flight notes
- Interfaces
- Joint operations procedures
- Making decisions
- Log book
- Operations change requests
- Payload crew activity plan
- Payload operations handbook procedures
- Real-time displays
- Shift handover
- Shift report

- TAG's/TPR's
- Uplink summary
- Voice protocol.

At this time, "Practice" contains one fully developed topic and partial entries for approximately half the others. The enabling/disabling principle investigators on air to ground topic has been completed. The other topics will be completed during the next year.

3. Scenarios. "Scenarios" provides a way for the trainee to practice making decisions which require integrated knowledge and skills. In a real mission environment, each ground controller must use all the domain knowledge and skills he or she possesses to make many important decisions. These decisions almost always require knowledge about many different topics. The purpose of the "Scenarios" section is to provide an environment which allows the trainee to practice making decisions using integrated skills and knowledge. Originally, the development team had planned to make this component a mini-simulation. However, the technology that would be required to emulate a simulation, as well as the complexity involved in developing a mini-simulator, did not allow the team to pursue this direction. Therefore, after much consideration, the team decided on the "Scenarios" component which tests the trainees capability to use integrated knowledge and skills to make decisions. At this time, the team has written many scenarios and plans to develop the software to support them during the next year.

B. MacCIC System Design

MacCIC's system design utilizes artificial intelligence which is "...the part of computer science concerned with designing intelligent computer systems, that is, systems that exhibit the characteristics we associate with intelligence in human behavior—understanding language, learning, reasoning, solving problems, and so on" (ref. 1, p. 2). The MacCIC system design provides a generic structure that can be used as a model for creating other ground controller position-specific training systems. As shown in figure 5, the MacCIC system design consists of three primary components: the user interface, the inference engine, and the knowledge base.

1. User Interface. The user interface accepts user input and presents system output to the trainee. MacCIC's user interface is a graphical user interface (GUI) which provides a way for the trainee to issue commands to the computer by using an input device (such as a mouse) to manipulate objects on the screen. Some of the common objects found in a GUI are windows, pull-down menus, and icons. MacCIC's user interface complies with Apple's Human Interface Guidelines graphical user interface style guide.

2. Inference Engine. The inference engine uses the knowledge in the knowledge base to evaluate the trainee's inputs and to make decisions about providing feedback to the trainee. The inference engine is provided by a commercial software product; however, the inference engine can be configured.

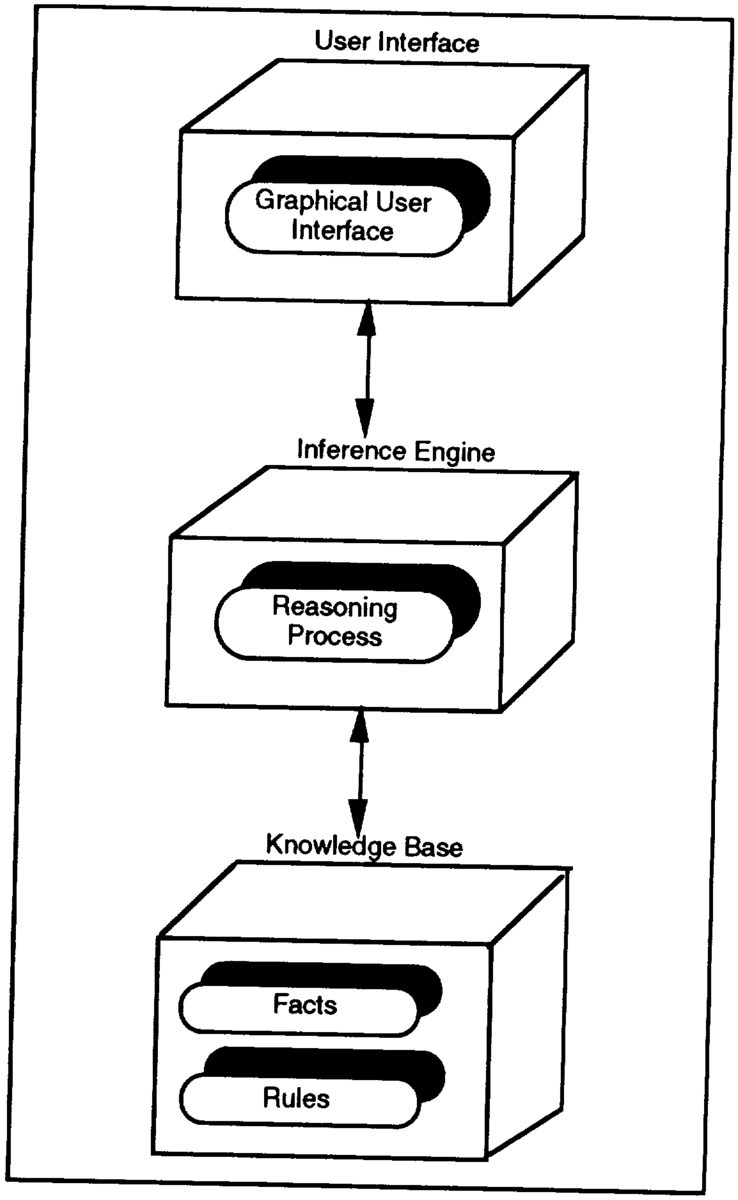

Figure 5. MacCIC system design (source: adapted from reference 3, p. 34).

3. Knowledge Base. The MacCIC knowledge base contains the following types of knowledge:

- Knowledge about the CIC position
- The trainee's knowledge about the CIC position
- Knowledge to evaluate the trainee's interactions with the MacCIC system.

The knowledge base contains the knowledge listed above in the form of facts and rules. A fact is simply a statement. An example of a fact is: a CIC can enable a principle investigator on air to ground. A rule is usually in the form of an if-then statement about facts. An example of a rule is: if the air-to-ground communication status is not good, then a CIC should not enable a principle investigator on air to ground. In general, MacCIC's system design is based on an interpretation of the type of ICAI systems described in section VI. Artificial intelligence provided a very good framework for creating the MacCIC system design.

C. MacCIC Hardware and Software Components

The MacCIC training system consists of the following hardware and software components:

Hardware:

- Apple Macintosh IIci with extended keyboard and mouse
  - 8 MB memory and 80 MB disk space
- RasterOps 19-in color monitor
- RasterOps 24XLTV video card
- Pioneer laserdisc player
- Pioneer VHS VCR
- Apple CD-ROM player
- 9-in television monitor.

The MacCIC training system has three major hardware components: the Apple Macintosh IIci, keyboard, and RasterOps monitor. Since CIC's use video to perform their jobs, the MacCIC training system uses Spacelab mission video during some of the training exercises. The Spacelab mission video includes a shuttle launch and landing, payload experiment video, and video of the orbiter payload crew performing experiment procedures. The MacCIC hardware components which provide this capability are: the VHS video-tape recorder, laserdisc player, RasterOps 24XLTV video card, and 9-in television monitor. Since training systems often need to motivate trainees in order to maintain interest, MacCIC enhances the training environment by providing a variety of sound effects and music through digitized audio and an Apple CD-ROM player.

Software:

- Silicon Beach's Supercard
- Neuron Data's NEXPERT OBJECT.

As mentioned in the system design section, the MacCIC system contains three major components: the user interface, the inference engine, and the knowledge base. The user interface was created using Silicon Beach's Supercard software. The inference engine and the software structure used to create the knowledge base were provided by Neuron Data's NEXPERT OBJECT software.

D. Summary

The MacCIC training structure and MacCIC system design are both generic and can be used as a model for creating other ground controller position-specific training systems. With its three major training structure components, MacCIC provides a framework for representing the ground controller environment. Each component can be modified in order to accommodate differences among ground controller positions. For instance, although the specific skills for a DMC position will differ from those of the CIC position, all position-specific training systems need to provide training and practice sessions on position-specific skills.

MacCIC's system design can also be used as a model for creating other position-specific training systems. If the ICAI system design is used, each position-specific training system will need a user interface, an inference engine, and a knowledge base for storing domain knowledge. Although MacCIC's hardware and software components could be used to create other position-specific training systems, each system may have unique requirements. Therefore, a position-specific training system developer should consider the overall system requirements and changes in technology before deciding what type of hardware and software components to use.

IX. LESSONS LEARNED

During this research project, there were many important lessons learned. Like many research projects, the lessons learned are important since they can have a large impact on the success or failure of continuing work in this area. The lessons learned were as follows:

(1) Domain experts must be assigned to the project and their time dedicated to the project or it will fail.

The knowledge that goes into a position-specific training system, regardless of the type of system design selected, is 100-percent dependent on the availability of domain experts to provide that knowledge. At least 90 percent of the knowledge which Spacelab ground controllers possess is not written down anywhere. Therefore, if management does not guarantee that several domain experts will participate in the development process, there will be nothing to develop. Spacelab ground controllers are like all domain experts: very busy. Therefore, the project should not be organized around the principle of using a domain expert's free time to provide knowledge. During this project, no domain experts were officially assigned to the project. Therefore, the project was dependent on borrowing what little time was available with domain experts. The only reason the project survived was because the project lead happened to be a domain expert. The moral of the story is: *do not attempt to build a position-specific training system unless management guarantees domain experts will participate.*

(2) The knowledge engineers who did not have a significant amount of knowledge about the domain often had trouble knowing when they had collected enough knowledge.

During the project, there were many people who served as knowledge engineers. The knowledge engineers each had a different range of domain expertise. Some knowledge engineers knew a little and some knew a lot. The knowledge engineers who had very little domain experience had a very hard time determining when they had collected enough knowledge about a topic. The project team solved this problem by setting up a process for the team lead to review all post-knowledge acquisition session material and determine if more knowledge acquisition sessions were required. This process worked out quite well.

(3) The knowledge acquisition plan should contain both domain knowledge and pedagogical knowledge.

The original knowledge acquisition plan only addressed the domain knowledge. For each subject, the knowledge acquisition plan should also address how the pedagogical knowledge for the subject will be acquired.

(4) The technology required to develop a simulation capability is not yet available.

The original proposal for this research project discussed the desire to create some type of stand-alone simulation capability. However, during the project scope definition phase, the team decided that the hardware and software must be widely available and inexpensive. Therefore, this precluded purchasing a high-powered workstation which would be capable of handling a simulation capability. However, even if the development platform had been a machine capable of handling a simulation capability, the complexity of developing this capability still would have prevented it. The requirements to simulate a control center environment include simulating audio, video, data, and people. The technology required to do this adequately does not exist at this time. However, the original intent behind the capability discussed in the project proposal was to reduce the need to use real mission simulations to provide basic position-specific skills. Therefore, by creating a stand-alone training system that would provide position-specific training, real mission simulations could be used to develop team work and mission-specific procedures. The project team feels that this objective has been met.

(5) Interviews with domain experts were identified to be the best knowledge acquisition technique available for the payload operations domain.

Although the knowledge engineers used many types of techniques to perform knowledge acquisition, they determined that interviews provided the most detailed information. When domain experts were asked to provide information through paper requests or electronic mail, most of the domain experts returned information that was very high-level. Therefore, the knowledge engineers had to rely on interviews in order to obtain the detailed knowledge they needed to develop the position-specific training system.

X. CONCLUSIONS

Since payload ground controllers acquire position-specific training in a nonstructured way, MSFC needs to provide a position-specific training system for each payload ground controller position. However, this can only be accomplished if management officially assigns domain experts and insures that they are available throughout the development process. The generic syllabus, system design, and development process presented in this report can be used as a model for creating the rest of the position-specific training systems. By using intelligent position-specific training systems, MSFC can insure that all payload ground controllers receive position-specific training which is structured and standardized. Intelligent position-specific training systems also provide the capability to store domain knowledge which is often lost due to personnel changes. Although this report evaluated MSFC's spacelab ground controller training program, these recommendations should also be considered for the Space Station *Freedom* (S.S. *Freedom*) payload ground controller training program.

XI. RECOMMENDATIONS

Based on the research presented in this report, the following actions are recommended:

(1) Complete the MacCIC position-specific training system and then move MacCIC into the main-line training program.

(2) Prepare an evaluation procedure to test MacCIC's effectiveness as a position-specific training tool.

(3) Investigate the possibility of creating similar position-specific training systems for the other ground controller training positions. This will depend on the availability of domain experts to participate in the development process.

(4) Once the S.S. *Freedom* payload operations concept is well-defined and experienced domain experts are available, the S.S. *Freedom* program should investigate developing position-specific training systems.

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