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REENGINEERING PILOT TRAINING ACADEMICS: IMPROVING INFORMATION FLOW AMONG TRAINING PROCESSES

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This paper describes how learning theory and the principles of business process reengineering can be used to guide efforts for improving training by implementing information technology (IT) tools and adjusting training processs to exploit new capabilities.

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PREFACE

This report documents a paper that was presented at The Aviation Psychology Conference which was held in Columbus OH from 27 April to 1 May 1997. This research was conducted under Work Unit 1123-B2-17, Intelligent Tools and Instructional Simulations (ITTS). The Laboratory Principal Investigator was Dr Joseph S. Mattoon.

This effort is part of an Armstrong Laboratory, Human Resources Directorate, Aircrew Training Research Division (AL/HRA) program to help identify existing and emerging electronic tools that improve the performance/productivity of adult students and new personnel in science and engineering occupations.

REENGINEERING PILOT TRAINING ACADEMICS: IMPROVING INFORMATION FLOW AMONG TRAINING PROCESSES

The need for improving the way information technology (IT) is implemented in training is evident from the lack of measurable positive impacts on student learning and performance that can be unequivocally attributed to IT. IT affords many new training capabilities, including the potential to accelerate learning, but many training processes are based on older models of education that do not account for today's technology. This paper describes how learning theory and the principles of business process reengineering can be used to guide efforts for improving training by implementing IT tools and adjusting training processes to exploit new capabilities.

PROBLEMS ARISING FROM MISCONCEPTIONS OF IT

The cost, time, and effort associated with acquisition and implementation of IT is tremendous, so it is important to implement a plan that will ensure an acceptable return on technology investments. To date, there is evidence that most planning for implementation of IT has focused on technical issues while neglecting the human dimension (Klay, Yu, & Chen, 1991)—the behavioral and psychological factors that determine human information needs and cognitive performance. After examining several aircrew training programs, Nullmeyer, Bruce, and Rockway (1991) concluded that a properly designed and implemented information system is essential to the cost-effective operation of Air Force training programs. However, they were unable to identify any systems that have fully accomplished this goal and found that the failure of IT in training was at least partially due to the lack of focus on user information needs and behavior. Costs associated with computer technology investment have risen in the last three decades to levels that exceed $300 billion, but increases in productivity that are attributable to IT are rare (Davenport & Short, 1990; Dué, 1993; 1994; and Landauer, 1995). Increases in technology spending for K-12 schools have been substantial (Bulkeley, 1995), but have not been followed by the expected improvements in student learning and performance (Clark, 1983; 1994). This disappointing history is partially the result of unrealistic expectations concerning IT's effect on learning and some misconceptions of how and when IT should be acquired and implemented.

Education and business communities scramble to procure the newest computers, multimedia, and network systems, but it is now apparent that IT alone is not a solution to learning and performance improvement. The ability of people to use information effectively and efficiently depends on how it is accessed, the form of the information (e.g., pictorial versus symbolic), and the recipient's interaction with it in the course of learning or accomplishing tasks. Human performance on tasks that are predominately cognitive in nature (e.g., decision making and learning) depends on the degree that information flow matches the needs and abilities of users. The misconception that IT

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somehow improves the information it carries has resulted in hasty conversions of printed instructional material to computer-assisted instruction (CAI), but this has frequently resulted in instruction that is even less effective than the original material (Landauer, 1995). The ratio of development time to hours of instruction for conventional CAI is approximately 300:1 at best (Muraida & Spector, 1993) and can range much higher (1,000:1 or more) for more sophisticated training software, so converting older materials to an IT-based format should be restricted to high-payoff areas where gains in training effectiveness and efficiency are sure to exceed the cost of conversions. Another common misconception is that increased access to information via computer networks will improve learning. Yet, studies have found that students' learning can be hindered rather than facilitated by access to larger volumes of information due to inadequate navigation functions (Gay, Trumbull, & Mazur, 1991). Tapscott (1996) reports that a high volume of data is available via the Internet, but most of this data is unstructured and has a low level of utility for learning or other applications. Consequently, increasing access to information may reduce rather than increase the quality of information flow and prevent learners from exploiting IT capabilities.

REENGINEERING TO SUPPORT PILOT LEARNING PROCESSES

Business process reengineering (BPR) was created specifically for improving business processes using IT (Hammer & Champy, 1993), so I have revised the principles to focus on training processes (Mattoon, 1996a). Training process reengineering can produce several benefits: (1) eliminate redundant tasks (e.g., repetitive lectures); (2) combine training activities to boost support of student learning (e.g., integrate content information with dynamic practice); (3) augment performance measurement (e.g., automate speed and accuracy assessment); (4) expand information flow (e.g., distribute student performance information across training components); and (5) clarify concepts (e.g., animation or simulation to demonstrate abstract phenomena). These training capabilities should be employed in coordination with the student's natural learning processes.

Pilot Training and Learning Processes

While *training processes* refer to overt activities (e.g., delivering instruction), *learning processes* are covert (internal to the learner) mental functions. Training processes can be reengineered as needed, but learning processes can only be supported according to the natural characteristics and limitations of human cognition and memory. The manner in which IT is applied to training processes can potentially improve training effectiveness (i.e., quality, usefulness, or longevity of knowledge) and efficiency (i.e., reduction in the training time and resources expended to accomplish performance objectives; ratio of output to input). Since information is a primary component of learning and cognition, improvements depend on training information flow—the

characteristics and qualities of instructional information that is passed on to students; student performance information that is generated during practice activities; and students' interaction with the information. I have defined three general learning processes that are relevant to pilot training—**acquisition of declarative knowledge, acquisition of component skills, and integration of knowledge and skills**—and some IT-based training tools that can support these processes better than conventional training methods and materials.

Process 1: Acquisition of Declarative Knowledge.

Both primary and advanced training programs require that a substantial amount of the student's time and effort be spent on declarative knowledge development. This process involves the memorization of certain "factual information (knowing what)," and is distinguished from skill development which requires "compilation of declarative knowledge into functional units . . . (knowing how)" that can be applied to a specific task domain (Alexander & Judy, 1988, p. 376). Declarative knowledge enables the learner to recognize and/or recall certain facts, rules, concepts, or sequences of steps in procedures, but it does not ensure understanding or even that the information will be retained long enough for practical purposes (Gagné & White, 1978). Instructor pilots (IPs) indicate that one of the major challenges in pilot training is ensuring that student pilots understand dynamic, three-dimensional flight concepts in the classroom before training in the aircraft (Mattison, Farnum, & Rokke, 1996; Mattoon, 1996b). The old saw "use it or lose it" describes a second challenge which student pilots must overcome in academics training. The time delays between courses and the opportunity to practice in the aircraft or simulator often result in the need to "re-acquire" information during flying training that was previously learned in the classroom.

Declarative knowledge is assessed during academics training, but verbal tests (e.g., multiple-choice) only ensure that student pilots have temporarily acquired certain aspects of the content material and do little to verify understanding or retention. Most academics training is physically and temporally separated from dynamic practice activities. Applications of IT that promote a closer working relationship between study and practice should augment the mutually supportive relationship among knowledge and skills.

Process 2: Acquisition of Component Skills.

Skill refers to the ability to use knowledge to perform physical and/or mental tasks and is acquired through the process of compiling declarative knowledge into functional units via practice (Anderson, 1987). The skills associated with Air Force piloting training consist of a complex of interdependent component skills that enable pilots to control their aircraft and execute a variety of other dynamic tasks to accomplish mission goals. It is not uncommon for such complex skills to require hundreds of hours of practice to master (Schneider, 1985). Many component skills are critical for executing complex tasks and are therefore important prerequisites for effective flying training in

the aircraft or simulator. Since flying training involves substantial costs, greater training efficiency may be accomplished by ensuring that student pilots master component skills using low-cost, "part-task" practice systems before beginning "whole-task" practice (flying training) (Gray & Edwards, 1991; Mattoon, 1994). Frederiksen and White (1989) demonstrated that prior mastery of component skills via part-task practice can accelerate development of complex skill, improve the learner's ability to use strategy, and even increase understanding and retention of domain knowledge.

Instructional simulations delivered on microcomputers can provide part-task practice on critical elements of flying and mission tasks such as tactical decision making, mission planning, and weapons deployment (Mattoon, 1996a). At a fraction of the costs associated with flight simulator training, academics could implement instructional simulation training to help student pilots master component skills. This approach would provide a scaffold between academics and flying training to enable student pilots to improve their speed and accuracy on required procedures and tasks before attempting to perform them within the complexities of the flight environment.

Process 3: Integration of Knowledge and Skills.

Experienced fighter pilots are able to distribute their attention and cognitive resources among several events and/or tasks such as aircraft control and maneuvering, management of weapons systems, navigation, and radio communications. This level of expertise is needed to maintain situation awareness during Air Force missions—be continuously aware of the state of the mission; monitor potential threats and execute countermeasures; and know how to respond accordingly to achieve mission objectives. The ability to perform in a highly complex mission environment is developed through the integration of individual knowledge and skills and the ability to perform with a team that may include many people performing many tasks to achieve a common goal.

Recent advancements in network IT now make it possible to generate a "synthetic battle space" in which multiple "players" (e.g., pilots and ground-forces personnel) practice various missions together in the same manner that they would work together during an actual combat mission. This capability is referred to as joint distributed mission training (DMT) and represents the future of advanced military training (Carroll, 1996). DMT usually refers to a large coordinated effort that links many simulators and communications systems together that are physically located at different sites throughout the U.S. or overseas. However, there is no reason that a smaller version of DMT could not be implemented using microcomputers that are located at the same site or linked from remote sites via local- or wide-area networks. Certain portions of a joint DMT environment could be assembled using microcomputers, although the simulation would be limited to two-dimensional displays with fidelity limited to specific mission elements. Pilots could practice mission planning, various mission-oriented flight procedures, and coordinated deployment of forces in small teams that participate via a distributed instructional simulation. Such training exercises could take place at the same training site, or students could participate remotely from different training sites.

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By using low-cost, microcomputer-based simulations, pilot training programs could reap some of the benefits of DMT in academics. The value of such training would be realized by enabling students to develop prerequisite team skills to boost the effectiveness of full-mission training in a DMT environment. Without this part-task scaffold, DMT engagements may be disrupted by confused participants and mismatched levels of ability among trainees. Disruptions to DMT are costly and waste valuable resources (Bell & Clasen, 1996). Since mission readiness is the terminal goal of Air Force pilot training, beginning mission-oriented training early with low-cost DMT systems may increase the overall efficiency of pilot training.

TECHNOLOGY INFUSION AND COMPRESSION OF TRAINING PROCESSES

The purpose of identifying the student pilot's learning processes and designing training activities around these processes is to strengthen cognitive links between knowledge and skills. Certain IT capabilities can be rallied to accomplish this goal, but training processes may need adjustment to take full advantage of the new capabilities. A gradual "infusion" of technology and incremental adjustments in processes may be preferable to immediate, major changes when implementing IT (Davenport & Short, 1990). Reengineering training processes will drive two types of changes: (1) "Horizontal compression" of processes will integrate separate components and activities to improve information flow and support multiple learning processes; and (2) "Vertical compression" of the management structure will result in greater authority and responsibility delegated to instructors and students so they can take full advantage of IT tools.

Technology Infusion

Technology infusion connotes a smooth blending of new technologies and methods within an existing training program versus radical changes which would interrupt or even temporarily shut down training operations. The infusion approach may incorporate several parallel efforts for designing and implementing prototype systems, adjusting training activities, and teaching instructors how to use new IT. To minimize disruption of training and validate new training tools as they are implemented, I recommend a user-centered reengineering team. Such a team operates at or near the training program site and consists of program administrators, instructors, training specialists, and engineers. IPs are key team members of such efforts, because they usually have a good understanding of student pilot learning problems. IPs who are enthusiastic about proposed solutions can also become "champions" of the reengineering effort and help gain the support of program staff and decision makers. To exemplify the IT infusion process, one component of a current effort to reengineer F-16 pilot training academics is described below:

1. Several structured interviews with IPs who teach F-16 basic fighter maneuvering (BFM) revealed a need to create dynamic, visual depictions of BFM maneuvers for the purpose of improving student pilots' understanding of three-dimensional maneuvering concepts and to enable them to practice recognizing visual cues and making maneuvering decisions during BFM engagements. To address these needs, the Basic Fighter Maneuvering Vision (BFMV) training package was proposed.

2. An IP who teaches BFM academics and flying training agreed to join the R&D team which consisted of Air Force training specialists, instructional designers, computer programmers, and graphics and animation artists. BFMV was planned to consist of three components: (a) Individualized instruction will be delivered by laptop computer and provide F-16 student pilots with a CAI-based introduction to BFM objectives, concepts, and instructional simulation practice on BFM visual cue recognition and decision-making; (b) Interactive classroom presentations will enable the IP to demonstrate specific BFM elements and concepts in the classroom on a large-screen computer display; and (c) A briefing tool will enable the IP to visually demonstrate specific BFM maneuvers prior to flying training sorties with student pilots.

3. As key elements of BFMV are designed, the IP is consulted to verify concurrence with existing F-16 training material and doctrine, check for accuracy and validity of the instructional material, and suggest changes in the content and proposed training methods.

4. On completion of an "alpha version" of BFMV, a representative group of IPs will evaluate and try out the training tool. This will ensure that students do not receive untested training and that useful criticism and suggestions for improvement can be solicited from a wide range of expertise prior to the student tryout.

5. A "beta version" of BFMV will be developed according to feedback by the IP subject-matter experts and will be used in the student tryout.

6. Data in the form of students' perceptions, opinions, performance on BFM practice, and subsequent performance in the simulator and aircraft will be used to identify potential improvements to BFMV.

The design and implementation of tools that can be immediately employed without radically changing existing training operations is the key to technology infusion. If BFMV is accepted into the F-16 syllabus, changes will eventually take place in the BFM training process, but these changes need not occur immediately to improve BFM training. For example, time spent on passive learning of BFM concepts may be gradually transferred to more active, participatory learning and practice via BFMV on the laptop computer. Also, the classroom and briefing room presentation tools may reduce the amount of time IPs spend teaching and reviewing BFM in the classroom, because they will not have to draw as many diagrams on the whiteboard to explain

BFM setups and maneuvers. The time saved may be used for individual practice or on other F-16 training tasks. The hardware and software were carefully chosen for compatibility with existing classroom presentation systems and student laptop computers, so no special installation expenses will be incurred if BFMV is accepted into the F-16 training syllabus. BFMV will require very little personnel training, because it was designed to accommodate the general teaching strategies and styles used by IPs who teach BFM in the F-16 program. Although training processes will change as more IT tools are implemented, processes can evolve gradually over several training cycles without disrupting the program.

Horizontal Compression

One of the major goals of reengineering is to combine or compress activities and resources in a way that improves training support of learning processes and reduces time and effort on training activities. Information flow across different phases of pilot training can improve the independent and collective effectiveness of training components. For example, the objective of implementing training tools like BFMV is to combine the acquisition of declarative knowledge with component skill development. BFM practice is currently available to student pilots only in whole-task form in the simulator or the aircraft, so it is difficult for pilots who are new to the F-16 to focus on BFM (a very complex set of skills in itself) in this context until they have gained some component skills.

A second IT-based tool that is being planned illustrates the horizontal compression of training information flow. Currently, information on student performance is somewhat sparse and in a form that is difficult for IPs to use to check individual student progress and proficiency. An electronic "proficiency profile" system will soon be proposed to synthesize performance information from academics testing, part-task practice, and IP ratings on student performance in the simulator and aircraft. The student proficiency profile will store the information on laptop computers or on a network system and will enable the individual student or IP to access the profile to guide ongoing learning and teaching efforts. The idea is to compress several sources of performance information across pilot training components to prescribe an optimal "mix" of training activities that matches each individual's strengths, weaknesses, and current level of knowledge and skill.

Vertical Compression

Vertical compression refers to a shift of decision-making authority downward in the management hierarchy so that both IPs and students play a more active part in controlling training resources and choosing the type, time, and place of training activities. The purpose is to enable students and IPs to take advantage of new IT capabilities and the increased level of flexibility in training that IT tools afford. For example, the implementation of BFMV would enable students to study and practice BFM on their own, with the instructor, or cooperatively in small groups. Vertical

compression is needed to give the IP additional latitude to assign specific part-task practice, simulator training, or flying sorties that meet individual training needs. Emphasis on individual training also places greater responsibility on students, because they must manage their training time independently rather than simply participating in scheduled courses.

The increased power and flexibility of new IT should eventually compress pilot training academics and simulator training into a unified ground-based training system. Most academics training can be managed and delivered by microcomputers, and flight simulators can now be designed as portable stand-alone or networked systems. Thus, knowledge acquisition, skill development, and team mission training could all be supported by a single learning center where students could move from one type of training to another as needed, and IPs could tutor individuals or set up team training exercises with minimal delay. The degree of flexibility of such a training system would increase the capability to support learning processes in parallel and as a function of individual progress rather than fragmenting training among separate courses, facilities, and training components.

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