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FORMAL PAPERS

Flight Instruction: The Challenge From Situated Cognition

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A primary claim from the field of situated cognition is that learning is ineffective if removed from the context in which the target skills must be deployed. This claim is inconsistent with many of the mainstream approaches to education and cognition. I describe what it means to be situated, and I outline the central issues raised in the literature on situated cognition and situated learning. The ideas outlined here have several implications for the conduct of flight instruction. The most pervasive implications are that current and potential training practices in aviation can create a breach between instruction and practice and can lead to the development of inert skills. A recurrent theme for situated cognition is that there is a self-organizing character to learning. If adequately supported by the design of the workspace and the structure of the training program, this self-organizing character of learning will limit the possibility of a breach between instruction and practice and will ensure development of robust skills. A further implication of the research reviewed here is that the role of aviation specialists in the design of systems and training programs has been too limited for it to be fully effective. I introduce the procedure of participatory design as an alternative approach that may ensure the effectiveness of flight training.

Over the past several years, a body of literature has emerged in which the claim is made that a proper treatment of cognition will heed its situated character. To be *situated* in this sense implies that cognitive activity is

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shaped by the context in which it is undertaken. The further claim is that mainstream cognitive science fails to capture many essential features of human learning because it treats cognition as a decontextualized activity. Situated cognition offers a stream of research and thought that is viewed by its adherents as an approach that captures the more substantive aspects of human cognition. In that our contemporary approach to aviation psychology draws on the ideas of mainstream cognitive science, it may be a useful exercise to examine this challenge.

From one perspective, it may appear that situated cognition offers nothing that differs in any meaningful way from what is already available in mainstream cognitive science (Vera & Simon, 1993a, 1993b). From another perspective, it may appear that these ideas, although worthy, are already well known and well accepted (Palincsar, 1989; Wineburg, 1989). Adherents to situated cognition object to each of these views (Brown, Collins, & Duguid, 1989a; Greeno & Moore, 1993; Suchman, 1993). In this review, I tacitly accept the claim that situated cognition offers an alternative to mainstream cognitive science and to standard educational practice. I glean several observations on learning and instruction from the situated cognition literature and draw out their implications for aviation psychology. I put aside, for the present at least, the additionally important task of judging whether or not situated cognition constitutes a radical reconceptualization of human cognition and educational practice.

ORIENTATION

A pervasive theme within situated cognition is that individuals structure their behavior by adapting to their situation (or context or environment). This is largely a self-organizing process in which explicit instruction, although having an important supportive role, cannot serve to fully (or even predominantly) shape behavior. It is through this self-organizing process that robust and generalizable behavior emerges. One implication of this claim is that both the workspace and the instructional procedures must be structured to facilitate learning. Failure to provide a supportive workspace and a supportive learning environment will lead to development of inert or brittle skills.

Sarter and Woods (1992, 1994) noted that even experienced pilots exhibit inert knowledge during execution of some procedures in modern-day glass cockpits. They argued that many commercial pilots who transition to these new-style cockpits learn how their systems operate but do not learn how to operate their systems. The problem of inert knowledge is particularly evident in pilots' responses to abnormal, time-critical events. Errors in the operation of glass-cockpit aircraft appear to be of a different nature to errors made in older-style cockpits. At least some of these errors suggest that not all pilots fully appreciate the effects that subtle interactions within automated systems have on the performance of the aircraft they fly.

Such failures have already been implicated in at least three accidents that have resulted in loss of life and of aircraft. The destruction of an Airbus A320 in 1988 during the airshow at Busle-Mulhouse airport in France was a stunning development in what was intended to be a festive occasion (Casey, 1993). The losses of China Airlines Flight 140 in Nagoya, Japan (Thurber, 1994) and of American Eagle Flight 4184 in Indiana (*NTSB Reporter,* 1994) were two of the more serious aviation accidents in 1994. Failure of the pilot to appreciate how automatic systems were affecting aircraft performance is thought to be a major contributor to each of these accidents. This review is motivated by the possibility that these accidents are partially due to our failure to heed lessons to be drawn from situated cognition, and that continued failure to heed those lessons could result in further accidents of this type.

SITUATED LEARNING

The situated view advances two distinctions about learning. The first is that skills and knowledge developed within standard educational practice are inert; that is, they do not transfer well from educational to applied or real-life settings. A primary goal of education is to develop robust and generalizable skills. However, standard educational programs often fail to do this because instruction is decontextualized. The second claim is that there is a breach between education and practice. Skills learned in formal education may appear to be relevant to the everyday practice, but they are in fact quite different from the skills normally employed.

Inert Versus Robust Skills

Current educational practice is guided by the assumption that activity and context are not critical to learning.[1] From this perspective, learning leads to the development of context-free cognitive skills that can be applied readily

[1]Several observations are drawn within the literature on situated cognition on standard educational practice and on mainstream approaches to cognition. It is difficult, however, to identify literature that fairly represents that standard view. Claims and beliefs attributed to the standard view are generally not stated explicitly in authoritative treatments of that view. It is possible that the adherents to the standard view will find these attributions at variance with their own attitudes. Nevertheless, the standard view of cognition, as with any other view of a scientific thrust, is based on assumptions that are rarely examined. These assumptions shape styles of thought and generate dominant modes of activity. In assessing the following argument, it is unfortunate, but possibly inevitable, that the only explicit statements about some central attitudes and beliefs of the standard view come from its critics, and we are left with the need to judge whether those statements are fair reflections of attitudes that pervade an often discordant body of literature.

across a broad range of contexts. A primary goal is the development of powerful and generalizable skills that can be deployed outside the educational setting. From the situated perspective, achievement of that goal is defeated specifically by the use of a strategy intended to achieve it. Lave (1988) and Brown et al. (1989b) argued that the removal of education from arenas of practice produces knowledge that is sterile. The resulting skills are brittle or inert; that is, they are error prone and cannot be deployed easily or effectively in practical settings. The only way to build robust, generalizable skills is by active exercise of those skills in arenas of practice typical of situations in which they will be used.

The situated critique of decontextualized learning is, to a large extent, posed as a commentary on the practices of mainstream cognitive science (Brown et al., 1989b; Lave, 1988). Issues of context have been de-emphasized within cognitive psychology (Gardner, 1985), and some have argued that cognitive theory cannot take account of contextual effects (Katz & Fodor, 1963). Johnson-Laird (1983, p. 224) argued that understanding of words learned in context will be vague and incomplete. This is in direct contrast to the situated view espoused by Brown et al. (1989b), who argued that the process of learning words in the context of ordinary communication is rapid and successful, whereas the process of learning words out of context is not.

Support for the situated claim regarding the fragility of procedures learned in school emerges from observations that some students exhibit a high standard of work-related performance even where their in-school performance with subjects that appear relevant to their work is poor. Lave (1988) considered the use of mathematics in nonschool settings. Her study was partially motivated by the observation that students who perform routine mathematical calculations in part-time employment cannot function at an equivalent mathematical level in school. She drew on a report from Herndon (1971) to illustrate her case. Herndon's observations were on some of his own junior high school students who performed poorly on school mathematics but who performed well on arithmetic activities outside the classroom. One example is of a student who had regular employment as a scorer for a bowling league. The work demanded fast, accurate, and complicated arithmetic. This student performed his work-related arithmetic activities at a level far above that of his in-school arithmetic achievement.

The situated view does not imply, however, that specific skills can be acquired only in the context in which they are used. The consequence of such a claim would be a denial of generalization or transfer. The debate is more accurately seen as one about learning conditions that promote transfer. From a standard educational perspective, the development of generalizable skills is enhanced by removal of peripheral, contextual details. In contrast, the situated view suggests that development of generalizable skills is enhanced by grounding instruction in a range of rich contexts that are representative of those that support standard practice[2] (Brown et al., 1989b).

Breach Between Education and Practice

A further claim of the situated view is that formal education fails to teach the right strategies; a failure that is referred to as a "breach between education and practice." The work of Jordan (1989) offered a sobering example of how the best of educational intentions can go awry. She documented attempts by the Mexican Ministry of Health to upgrade the skills of traditional birth attendants (i.e., village midwives). A special course was developed and taught by practitioners of the standard biomedical model of health care. Although the midwives who participated in these courses were influenced in the terminology they subsequently used during discussion of birth problems, they did not translate the technical skills they had been taught into practice. The basis of the problem appears to lie essentially in the gulf between the foundational knowledge of those who had acquired this expertise under the framework of the standard biomedical model, and those who had acquired it in a setting of indigenous medical practice. The standard biomedical skills could not easily be deployed (and in fact had little relevance) within the village settings in which the midwives practiced.

A fundamental assumption underlying current educational practice is that of cross-situational cognitive continuity. For example, a widely used activity such as arithmetic should be applied in a relatively uniform manner across different settings because of durable and generalizable arithmetic skills taught during formal schooling. Work in situated cognition suggests otherwise: that there are many useful variations on arithmetic strategies (Lave, 1988; Saxe, 1990), most of which are not taught in school. Lave (1988) noted that we generally know little about arithmetic procedures employed on the job or in everyday activities. When examined, these procedures are seen to be rather different from those taught in school.

An illuminating example is drawn from Carraher, Carraher, and Schlieman (1983), who examined arithmetic practices of street vendors of grade school ages. One 12-year-old, when asked for 10 coconuts, used base three arithmetic to calculate the total price. For this particular problem, the use of base-three arithmetic may seem puzzling. A base ten arithmetic would be

[2]Issues of context are of central concern in some contemporary work on skill acquisition and transfer (e.g., Singley & Anderson, 1989). Many cognitive scientists now recognize that training with general, context-free skills does not lead to robust transfer. Considerable uncertainty remains about how to promote transfer. Despite Lave's (1988) assertion to the contrary, the concern within situated cognition regarding inert skills is shared by many who follow the standard approach to cognition. Thus, this criticism from situated theorists is one that many will find objectionable when framed as a critique of all cognitive research.

more consistent with procedures taught in school and would require fewer steps. However, Lave (1988) proposed that arithmetic practice is shaped by setting and that this is an example of how contingencies of practice have encouraged development of strategies tailored to the range of tasks faced by these street vendors.

By reference to the work of Carraher et al. (1983) with street vendors, of Scribner and Fahrmeier (1982) with dairy packers, and of her own work with grocery shoppers, Lave (1988) argued that the evolution of arithmetic strategies is guided by the organization of work. Street vendors and grocery shoppers develop robust (error-resistant) and cognitively economical mathematical procedures shaped specifically by the requirements of their tasks. A base three arithmetic most likely evolves for certain commercial activities because it supports reliable and economical calculation across the common numerical range of items sold in that situation. It may not support economical calculations involving large numbers, but that is not a concern for these street vendors. Where it is essential to deal with large numbers, other relatively economical and robust procedures may evolve (Saxe, 1990).

The avoidance of arithmetic complexities is pervasive (Lave, 1988). Grocery shoppers are inventive in generating expedient solutions to best-buy problems. For example, a common procedure for ascertaining price per unit weight of meat is to search through the available packages to find one that is near whole units in weight. By this means the arithmetic for a best-buy problem is simplified considerably. Weight watchers who are taught to measure and calculate food portions by arithmetic manipulation of standard weights and volumes typically replace those strategies over time with simple and expedient solutions specific to their own kitchens. Street vendors generate arithmetic systems with nonstandard bases that simplify the calculations used in the sale of specific products. The strategies that evolve are both robust and economical in terms of cognitive effort. These are valid forms of arithmetic, but they do differ from arithmetic forms taught in school.

These observations suggest that there is a breach between formal instruction of arithmetic and practice of arithmetic in everyday life. To the extent that it is difficult for individuals to generalize spontaneously from one arithmetic form to another, it would be difficult for them to employ school mathematics in support of activity in general life. If school mathematics cannot be deployed effectively to support common activities, it should not be surprising that the procedures of standard arithmetic are used rather infrequently for tasks that require high levels of accuracy.

Nevertheless, formal instruction cannot be dismissed as entirely irrelevant. In a study of Brazilian street vendors, Saxe (1990) showed that school arithmetic can influence the procedures used for calculations surrounding decisions regarding wholesale purchasing and retail price setting. The street vendors considered in the study were boys ranging in age from 6 to 15 years. The counting and partitioning procedures used by younger boys and by boys of all ages with little or no formal schooling did not resemble the procedures of school arithmetic, but older boys with formal schooling did appropriate some elements of school arithmetic for their purchasing and selling calculations.

It was evident, however, that for those with formal schooling, the spontaneous transfer of school-taught arithmetic strategies was neither immediate nor complete. Boys who demonstrated use of school arithmetic in their calculations had been involved in street selling for several years. Saxe (1990) concluded that considerable experience with the task was needed before relevant strategies could be appropriated spontaneously from formal schooling. Thus, transfer from school arithmetic to the practice of street marketing, or to any other domain of practice, is unlikely to be immediate. Presumably, appropriation of knowledge and skills from formal schooling will be partial and will emerge gradually as practitioners become increasingly aware of the needs of their job and of the possibilities for implementing efficiencies or useful variations from other domains of knowledge.

COGNITIVE ANTHROPOLOGY

The claim that situated learning is more powerful than minimally contextualized learning has been supported primarily by anthropology's ethnographic methodologies. Situated cognition is predominantly aimed at observing and describing the cognitive strategies typically employed in various settings. In contrast, experimental and modeling methodologies dominate the practice of cognitive science. Although viewed as multidisciplinary, with anthropology as one of the subdisciplines, cognitive science remains largely analytical and empirical. Although few would deny the need for some description of normal cognitive activity in the early stages of a scientific program, the standard empirical and analytical approaches devote only cursory and nonsystematic effort to it.

Ethnography

Lave (1988) provided a strong critique of research that was undertaken with little regard for the contextual realities of normal human activity (also see Hutchins, 1991). Even considerable research on grocery shopping, which would seem relevant to everyday human activity, is faulted because the form of the experimentation has not heeded the pervasive realities of the situation. A common assumption that shoppers rely on standard arithmetic procedures to generate best-buy decisions is false. The apparent problem is that research has not been preceded by comprehensive descriptive efforts to support formulation of experimental scenarios that accurately reflect the exigencies of grocery shopping behavior. Lave's own descriptions, derived via her ethnographic methodology, offer evidence of the precarious assumptions underlying the bulk of the previous research.

Although not commonly characterized as situated cognition, the work of Klein and Calderwood (1991) provided a similar contrast in the area of decision making. Their use of ethnography reveals the limitations of a huge body of research on formal decision making, the bulk of which has indicated that decision makers are biased, that they are not efficient at selecting optimum solutions from the many that are available, and that they are not sensitive to disconfirming evidence regarding an incorrect decision. These observations had been derived primarily from testing college students with abstract artificial problems.

Klein and Calderwood (1991) argued that the formal decision-making research does not provide insights about the processes of experts working in natural, time-critical scenarios. Such experts are neither biased nor insensitive to disconfirming evidence. More significantly, the assumption that decision makers are not efficient at contrasting options is irrelevant, because experts do not employ that procedure to make effective decisions regarding time-critical events. Instead they assess a situation, select a strategy that seems to satisfy requirements, and then mentally simulate the use of that strategy. If consequences are not satisfactory, they seek another solution and mentally simulate that. They proceed with action when the results of the mental simulation indicate a satisfactory outcome. This is a serial procedure for examining options, whereas an assumption underlying the formal decision-making research is that options are assessed concurrently or in parallel.

The message to be taken from Lave's (1988) work on grocery shopping and Klein and Calderwood's (1991) work on decision making is that ethnographic methods often will generate insights about strategies that are not evident from rational analysis. Lorenz (1988/1991) noted:

> It is regarded as modern to set experimentation above observation (no matter how assumption-free) and to see quantification as a more important source of understanding than description. We tend to forget that description is the foundation of all science. (p. 7)

Of course, many cognitive scientists become introspective about their own behavior and the behavior of their acquaintances as they formulate a research paradigm. We may think that such an approach offers an adequate descriptive precursor to an empirical program because scientists are expert decision makers in at least some domains, and most are experienced grocery shoppers. The ethnographic work on shopping and decision making suggests that many assumptions about cognitive strategies derived from casual observation or introspection are false and that research based on these assumptions is irrelevant.

Rational Analysis

It may seem puzzling that those who are familiar with these types of tasks can be so wrong about central strategies. Much of the fault can be attributed to a pervasive maneuver in cognitive science of drawing a foundational assumption regarding the nature of human cognition from preconceived ideas. For example, Rips (1988) based his extensive analysis of deductive principles as central components of thinking primarily on his own intuitions about the nature of thought. Johnson-Laird (1983) motivated his interest in deductive inference primarily from arguments that syllogistic and propositional reasoning are inadequate to explain what is known about cognitive processes, apparently without thought that there may be other strategies that circumvent the need for deductive, syllogistic, or propositional reasoning. Sternberg (1988) developed a comprehensive model of intelligence from a rational analysis of how the information-processing model needs to be extended, again apparently without thought that the information processing model may be seriously misguided (cf. Kugler, 1986).

The maneuver is outlined explicitly by Singley and Anderson (1989), who argued that "human behavior can be predicted from a rational analysis of the task if one takes into account the basic information processing capabilities under which the person operates" (p. 275). The central problem here is that theoretical developments and subsequent empirical research and interpretation of data are based on unsupported and possibly flawed assumptions about the fundamental nature of cognition. Within mainstream cognitive science, it is unusual to find experimentation that is based on comprehensive descriptions of behavior as it unfolds in naturally complex situations.

TRAINING FOR SITUATED ACTION

It is via the use of the ethnographic method that adherents to the situated view seek to understand how learning and instruction may build robust, generalizable skills relevant to practice. The studies that have been undertaken in this area suggest a number of concerns for training.

Legitimate Peripheral Participation

Lave and Wenger (1991) argued that many applied skills are learned in apprentice style relationships situated within ongoing work activities. Apprentices are permitted to participate initially in peripheral activities of practice and, as they become more skilled, in more central activities. Lave and Wenger (1991) illustrated their view by drawing on Goody's (1989) description of tailor's apprentices in West Africa. These apprentices are involved in rich opportunities to observe and assist masters and other apprentices as they learn the trade of tailoring throughout a 5-year period. Each apprentice moves from the production of simple, inexpensive garments to the production of more complex, expensive garments. Within garment types, they progress from simple tasks in which errors can be corrected (e.g., marking out patterns) to more complex and final tasks (e.g., cutting and sewing) where errors are costly. Throughout, they have opportunities to observe the production of a variety of complete garments.

Also instructive is the study by Hutchins (1992) of the training of Naval quartermasters. Apprentice quartermasters are taught skills associated with plotting a ship's position. This is a distributed task that requires integration of information from several quartermasters at different positions on a ship. Apprentices begin with limited duties, such as working one piece of equipment at one station. They move to more complete involvement at each station as they become more experienced, and they also progress through each of the stations throughout their training. Communication and coordination with other stations are learned, as well as the technical skills for operating equipment. Apprentices' activities are monitored closely by experienced personnel throughout the year of training.

The observations by Jordan (1989) of the development of midwifery skills in Mexican villages are also of interest. On the way to becoming a midwife, women are peripherally involved with birth-related activities, first as children and then as young adults. They help in a variety of ways, with that help becoming more central to the main activity of assisting with labor and birth as they gain experience. Thus, their skills are acquired informally via situated experience. In addition, they are often present when experienced midwives trade stories about difficult births and other significant aspects of the work. In all of these examples, beginners are accorded a legitimate role in the activities of interest and are encouraged by those according them this legitimacy to progress from peripheral to more central involvement.

Preferred Modes of Learning

It would be a mistake to think of these apprenticeships exclusively as exemplifying transmission of knowledge from master to student. With West African tailors, an apprentice's master provides only one of several opportunities to learn. Other senior apprentices and master tailors provide opportunities for observation, interaction, and discussion that substantially enrich the apprentice's learning situation. For village midwives, storytelling by experienced practitioners about problems and challenges they have faced is a dominant mode of transferring information. In contrast, the formal course developed by the Mexican Ministry of Health for midwives emphasized a lecture format that differed markedly to the situated activity and storytelling modes of learning to which these women were culturally attuned.

Denial of Legitimate Peripheral Participation

Lave and Wenger (1991) are not enamored of apprenticeships as learning situations, but instead of certain characteristics that are often found in apprentice programs. Some apprenticeships do not work well because these characteristics are absent. Lave and Wenger discuss butcher's apprentices in modern supermarkets, who are often set apart in the workplace from experienced butchers. An emphasis on cost reduction has the new apprentice performing menial tasks from which graduation is not by virtue of developing skill but at the employer's convenience. With no legitimate access to experienced practitioners of the trade and no natural progression from peripheral to central activities, this exploitive relationship limits opportunities for learning. Early tasks are not, in the main, relevant to an apprentice's progression toward developing the skills of a master butcher. Apprentices are thus denied situated exposure to the central activities of master butchers. Absent in this situation are the dominant features of effective apprenticeships: cultural legitimacy conferred on the student and timely progression from peripheral (but relevant) to more central activities.

Breach Between Instruction and Practice

Use of formal schooling to supplement knowledge raises the possibility of a breach between instruction and practice. Nowhere is this more evident than in Jordan's (1989) study of the instructional program imposed on village midwives. Of the many problems with this program, a significant one was the failure of the instructional staff, steeped as they were in the standard biomedical model, to appreciate the knowledge already available to their students. In addition, the instructional staff failed to understand the constraints imposed by the context in which these traditional birth attendants had first learned their craft and in which they continued to practice.

Lave and Wenger (1991) noted that formal schooling to supplement training of butcher's apprentices devotes considerable time to instruction of outdated skills; for example, an emphasis on cuts of meat that are no longer popular. Hutchins (1992) noted that some experienced quartermasters prefer to teach new ratings who have not been to navigational school. This negative opinion in regard to specialized schooling raises the possibility that much of what is taught in school is irrelevant, possibly because instructors themselves have become divorced from current practice or because the teaching of relevant skills poses a substantial challenge that most instructors are ill-prepared to face. Transfer of learning will be minimal when school curriculums focus on the development of knowledge and skills that are irrelevant to or even incompatible with practice.

Progressive Nature of Learning Transfer

The research of Saxe (1990) indicates that the breach between schooling and practice is not always absolute. Transfer between formal education and job-related activities is possible. However, the transfer of these skills is progressive rather than immediate. A pervasive attitude in the literature on transfer is that skill learned in one context (e.g., school) can be readily applied in different but relevant contexts. Saxe (1990) suggested otherwise:

Skills learned in one context will be appropriated gradually and then adapted to the new context as possibilities are recognized. In this regard, a skill may be seen in the same light as a new tool. For example, the purchase of a new woodworking tool may enhance the potential of the home carpenter, but that full potential will be realized only gradually as the home carpenter works with the new tool, learning to deploy its special capabilities and learning to adapt to its special limitations.

SITUATED LEARNING IN REVIEW

Important goals for training are to develop knowledge and skills that are both robust and relevant to practice. This review of situated cognition has revealed that training context and instructional content may subvert these goals. There are also indications in this review of procedures that may avoid these problems. It is evident that the nature of the operational environment is important. Even the most robust skills may not be appropriate for certain arenas of practice. Thus, design of a training program will need to consider the interplay between system design, instructional curriculum, and training strategies. In this section I consider how the observations drawn on situated learning in the previous section may relate to flight operations.

Breach Between Instruction and Practice

A breach between instruction and practice becomes possible when instructors and curriculum designers are separated from practice by virtue of their exclusive and extended involvement in training. In considering the possibility of such a breach, note that aviation has the benefit of a cadre of instructors who actively participate in flight (Telfer & Bent, 1992). Some commercial operators regularly cycle their training personnel through line-flying periods to keep them current with actual operations (Lautman & Gallimore, 1987). That strategy would seem to minimize the likelihood of a breach between instruction and practice.

The benefits of this may be seen in the work of Johnston (1992), in which a practitioner's experience contributed to the design of a simulator-based training program. In this training program, priority was given to reproduction of realistic operational settings for training rather than to high physical fidelity of training devices. The result was a learning environment that grounded instruction in a range of rich contexts that were representative of those found in standard practice. The possibility of a breach was reduced by careful assessment of the skills that were needed and by offering detailed assessments of how well students were prepared for the next phase of their training. The factors that have been missing from programs in which breaches between instruction and practice have been observed are assessment of requirements for instruction from the practitioners perspective and critical evaluation of the outcomes of the training.

In contrast, much simulator design work is undertaken with only peripheral guidance from active pilots. The work described by Thomas and Geltmacher (1993) on the development of visual displays for air combat simulators offers an example. It remains unclear whether these technological developments can contribute positively to training effectiveness. Nowhere in their description do Thomas and Geltmacher refer to the manner in which such a system might be used or how its training effectiveness might be evaluated. The implication of their description is that this is a problem for hardware development and visual science, but not for instructional science.

Training devices and instructional strategies can induce a special type of breach. For example, motion systems may enhance sensitivity to perceptual information that is not representative of that induced by aircraft motion, or to perceptual information that skilled pilots disregard (Lintern, 1989). Part-training strategies and manipulations of task difficulty may create tasks that differ in critical respects from the criterion task (Lintern & Gopher, 1978; Wightman & Lintern, 1985). Although these breaches between instruction and practice may be more subtle than those noted by Jordan (1989), they are equally invidious.

One possible value of situated instruction is that it forces relevance. Whereas formal instruction can focus on the simple or the superficial, situated instruction encourages instructors to emphasize relevant material. No instructor can be aware of all the skill elements that a student must learn during practice of a complex task. For example, not all of the perceptual skills needed for landing are known (Lintern, 1991; Lintern & Liu, 1991). Nevertheless, instructors must find a means of teaching those skills, and there is little possibility in landing instruction that a breach between instruction and practice could pass by unnoticed. In nonsituated instruction, material that is not explicitly known will often be missed. Although the long-term consequences will be negative, the short-term impact on course-related assessments may not. Furthermore, the failure in subsequent on-the-job performance may never by clearly linked to the failure of instruction.

Attentional Demand of Situated Learning

Jordan (1989) noted that the midwives of her study failed to assimilate the course material because they were not culturally attuned to the mode of classroom instruction so common in our society. She noted that the attention of the student midwives in that class would often drift. However, even in our own society, classroom formats permit (perhaps induce) a drift of attention. In some respects, aviation has a clear advantage over instruction for many other endeavors because it is a motivating and attention-demanding activity and because interactive instructional forms predominate. Nevertheless, instruction of flight theory and aircraft systems has generally followed standard educational practice in relying on a lecture format. Instruction in those areas may benefit considerably from a more interactive approach (Newburg, 1992; Telfer & Bent, 1992).

The standard classroom format may be only marginally effective because it limits opportunities for student participation and does not force students to engage the material actively. Even when students actively engage elements of a lecture course, they may focus on peripheral or even irrelevant details. Thus, students may generate a breach even where their instructor does not. In contrast, the consequences of failure to engage critical elements within situated instruction of flight skills or of any other high-level skill becomes apparent immediately and should force a correction of any breach between instruction and practice.

Irremedial Incompleteness of Instruction

Central to the situated view is the notion that verbal descriptions of behavior are necessarily incomplete (Suchman, 1987; Winograd & Flores, 1986; also see Lintern, 1992). Certainly, much of the skill associated with physical activity, and probably much associated with cognitive activity, relies on precise adjustments of dynamic task properties. Expert table tennis players can consistently time forehand drives within accuracies of less than 30 msec (Bootsma & van Wieringen, 1990). Such accuracies are difficult to comprehend. A table tennis instructor may advise a student to strike the ball earlier or later, but that instructor could not specify the timing within the accuracies that players can achieve. Nor could a student respond appropriately to such instructions. Dynamic properties of a skill must be tuned by dynamic action, and that would seem to demand something close to situated practice.

The principle of irremedial incompleteness suggests that flight students should have opportunities to practice skills with interactive, real-time devices. Simulators offer the potential to do that, but the simulations must be represented at the required level. Instruction of control skills will require a different style of simulation than instruction of navigational skills. Whatever the nature of the target task, these simulations will be fully effective only if they permit practice with dynamic properties that flight students find most difficult to tune during normal instruction. On the other hand, attempts to correct operator or pilot behavior by promulgation of instructions or by development of standard operating procedures are seen as misguided from the situated perspective (Lintern, 1992). Verbal statements can support change but are not sufficient on their own to guide learning or to specify action (Suchman, 1987).

In contrast to recommendations that flow from these views on irremedial incompleteness, instructional system development (ISD) is based on the assumption that all skill and knowledge requirements can be documented in sufficient detail to provide the essential syllabus (e.g., Long, Freedman, Walker, & Thode, 1982; Longridge & Boothe, 1991; Oneal, 1990). However, overly detailed feedback as encouraged by ISD may overwhelm a student and may divert learning effort from critical task properties that are not amenable to description. This points to a potential problem with the Federal Aviation Adminstration's Advanced Qualification Program (AQP) as outlined by Longridge (1992). Instructional requirements and criteria for evaluation are derived from a rational task analysis. Such an analysis should identify some important skills and may therefore offer a reason to modify an emphasis or to adjust content of instruction, but it could not identify all knowledge and skills that must be covered.

Stories as Surrogate Situations

Although anecdotes and stories are often viewed as an important supplement to the formal content of an instructional program (e.g., Telfer & Bent, 1992), their status in the learning process remains unspecified. From the situated perspective, stories emerge as a natural and potentially powerful mode of instruction—as, for example, in the experiential development of village midwives (Jordan, 1989) or in the education of crew members responsible for flight-deck operations aboard an aircraft carrier (Rochlin, La Porte, & Roberts, 1987).

In formal instruction, stories or jokes are often used with the intent of arousing interest within a lecture format that otherwise works against maintenance of attention. Nevertheless, stories appear to have a role beyond that of arousing attention. More likely, they serve to sensitize others to situational possibilities for circumstances that they have not personally experienced. In that situations are always different, listeners would have to relate some of a story's generalities to their own experiential knowledge, and must then be able to appropriate those generalities into their own behavioral repertoire at some future time. This might be characterized as a form of surrogate situated learning or as a form of vicarious learning.

Pilots have to learn many things that cannot be experienced during training and stories may offer an important means for aviators to exchange that knowledge. In the U.S. Navy, *Approach* magazine offers a forum for aircrew members to tell their stories about aviation incidents. Each issue of the magazine typically contains several stories of one or two pages that describe an event, the actions of the flight crew, and the outcomes. These stories generally carry a message about safety; that is, about the importance of activities such as preparations for the flight, practice of emergency procedures, and communications with others. Stories abound in aviation, and many aviators are known informally at least for their storytelling skills. It would be remiss of us to view this as an entertaining but otherwise unimportant activity. Stories may have a crucial role in maintenance of aviation safety, not so much because they raise the level of interest and attention, but because they promote a form of indirect situated learning.

Learning as a Self-Organizing Process

A dominant theme for situated cognition is the self-organizing[3] character of uninstructed learning in which robust and economical forms of knowledge are shaped through continued experience with the demands and constraints of a situation. Lave's (1988) account stresses the manner in which street vendors, weight watchers, and grocery shoppers structure their own strategies in response to situational exigencies. Thus, learning is less often a process of knowledge transfer from teacher to student than it is a process in which students develop their own ways of interacting within the instructional environment. The transfer of knowledge via instruction is a contrasting theme that dominates the contemporary approach to science, technology, and education (Edelman, 1987, 1992; Reed, 1989).[4] Attempts to shape behavior with an instruction set (e.g., formal knowledge from teacher to student) can generate fragile knowledge that is not well tuned to task-related exigencies (Kugler & Lintern, 1995).

The contrast approximates Perrow's (1983) distinction between design and operating logic. In Perrow's terms, *designers* are attracted to elegant, state-of-the-art solutions for problems identified by formal analysis (e.g., Thomas & Geltmacher, 1993) whereas *operators* prefer established, simple, and trusted procedures. Nowhere are the problems with design logic more apparent within aviation than in the development of the new automated cockpit. The solutions are elegant and have many quantifiable benefits relating to production, maintenance, and reliability. The new strategies required for control (Billings, 1991), however, have been developed based on a rational analysis of equipment capabilities and task requirements. Many of these strategies demand a high level of cognitive effort (Sarter & Woods, 1992) and some require a work pace that approaches the estimated limits of human perceptual-motor ability (Casner, 1994). It is a sobering indictment of this technological enterprise that experienced pilots occasionally switch features off in times of difficulty and return to older, more trusted strategies.

Older style cockpits conform more closely to the demands of operating logic. Hutchins' (1991) description of activity in the cockpit of the DC–9 aircraft reveals how pilots can use the structure of their workplace to develop

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[3]Self-organization and the related concepts of dynamical systems and chaos have emerged as key topics in the agenda of the physical and biological sciences (e.g., Glieck, 1987; Prigogine & Stengers, 1984; Yates, 1987). The methods of the study of self-organizations and the insights that have evolved cut across many disciplines. Although the use of the term *self-organization* within situated cognition does not carry the same technical implications, the similarities in global organization described in both areas is striking. Elsewhere, Peter Kugler and I have made preliminary statements about the potential connection between these two areas (Kugler & Lintern, 1995).

[4]Edelman (1987, 1992) and Reed (1989) are critics of the instructionist approach. Edelman supports a contrasting selectionist view and Reed an ecological view, both of which are partially consistent with themes that pervade situated cognition.

robust and cognitively economical strategies for critical tasks. For example, a common requirement is to determine a landing approach speed by incrementing the minimum safe operating speed (Vref) by 5 knots. In preference to an arithmetic strategy, many pilots ascertain the approach speed by exploiting the fact that the mechanical speed bugs on the air speed indicator span a 10-knot interval at their base. Thus, the pointer of the speed bug indicates the desired approach speed when the lower edge is placed at Vref. It is this sort of strategy that can be discovered and refined by situated practice.

Use of the speed bug in this manner may seem to be a peculiar and isolated strategy. However, the situated claim is that this sort of strategy pervades human activity. As a matter of course, we seek structure in our environment to support robust and cognitively economical strategies. Casner (1994) offers an account of how commercial pilots exploit their familiarity with specific routes to structure their use of automated systems for navigation and control. The design of a human–machine interface must be compatible with this considerable potential for human operators to structure their own behavior (Suchman, 1987). The considerable danger in the application of design logic is that supports for robust strategies will be designed out of a system. As in the case of speed-bug width in the DC–9, many supports for robust strategies are not specified as design requirements and would most likely be designed out of the system in any radical redesign effort. This would force pilots to discover new strategies. In a worst-case scenario, the application of design logic will produce a cockpit with no supports for robust strategies, and pilots will be forced to rely on the fragile, cognitively effortful strategies that have been generated via a rational task analysis and taught to them during formal training.

Progressive Nature of Transfer

The work of Saxe (1990) suggests that transfer of skills learned in training programs may not be immediate and complete, and that good transfer is achieved only after protracted situational experience. This is a troubling issue for aviation, in which it is unacceptable to have only partially competent pilots actively engaged in the practice of flying. At first glance it may seem that this issue should not concern us, because the safety record of aviation demonstrates that most pilots are at an acceptable level of competence. In addition, there is evidence that flight instruction is having a positive impact at least in the area of time-stressed decision making in flight (McKinney, 1993; Stokes, Kemper, & Marsh, 1992).

Nevertheless, any radical change in training procedures or technological developments that impose new demands on training may disrupt this process. Even the success of type transition with zero flight time does not preclude the possibility that pilots in transition may experience some initial awkwardness in adapting their new skills to contextual subtleties not experienced in training. This may not always be revealed in a single flight with a check pilot. In stressful circumstances, such awkwardness could reveal itself in unfortunate ways. Especially where the new skills differ substantially from those required in previous aircraft, requirements such as en-route navigational changes may place excessive demands on skills not yet fully tuned to the new context.

Summary

Several independent features of learning have been identified from the analysis of ethnographic work described earlier and have been posed here as possibly central to the power of situated learning. Whether one, some, or all are important has not yet been established. At this stage, an empirical program appears necessary to further clarify the essential relationships. However, all have one thing in common: Instead of emphasizing the instructor as the source of knowledge, they shift focus to the self-organizing potential of a learner as shaped by the structuring power of the situation. Although an instructor's role as coach or critic (i.e., a structuring resource) may remain important, the self-organizing character of learning is dominant. In addition, each of the independent features of learning that have been identified has implications for how we might proceed with the design of an instructional program that must, for reasons of cost or safety, be removed from the natural setting. It is these implications that seem relevant to any discussion of flight instruction.

Although the discussion has so far raised a number of concerns relevant to aviation, a solution may not be apparent. Direct application of strategies outlined in discussions of situated learning is unlikely to be appropriate in a multifaceted and technically complex environment such as aviation. However, one fundamental concern that emerges from this review is that our general approach to design of systems and training programs is flawed. Participatory design offers an alternative approach that is consistent with the situated perspective (Bødker, 1991). In the next section, I outline the rationale for participatory design.

PARTICIPATORY DESIGN

Within this review, I have occasionally expressed concern with the design of cockpits and flight training. It is important to realize that effective training relies as much on design of the human–machine interface as on a comprehensive curriculum and appropriate instructional techniques. One conclusion to be drawn from situated cognition is that practitioners are adept at discovering robust procedures for execution of critical tasks. However, it is possible to block such discoveries by designing a workspace that does not provide support for any robust strategies. Even where an appropriate workspace is available, an irrelevant curriculum or an ineffective learning environment may prevent development of robust strategies for operational activities.

From a human factors perspective, we might argue that these problems emerge through neglect of systematic task analyses. Adherents to situated cognition would find fault with that view. There was presumably some form of task analysis, albeit cursory, for the instructional program described by Jordan (1989). The problem here was that the instructional program was undertaken from the wrong perspective; that is, a rational analysis of the medical aspects of childbirth rather than a situational analysis of childbirth as it occurred within the context of a primitive village. Additionally, there is likely to be some concern with the type of task analyses normally undertaken within human factors. In contrast to the extended participatory observations undertaken by ethnographers, these tend to be based on relatively brief discussions, interviews and observations.

Anthropology is a discipline that takes a serious attitude to description. The insights generated about a range of normal human activities via ethnography are impressive. Nevertheless, direct transfer of the observational methods used by Jordan (1989) in her observations on village midwives, by Saxe (1990) in his observations on street vendors, or by Lave (1988) in her observations on grocery shoppers is unlikely to work for many of the issues found in our profession. Aviation is a complex and multifaceted business. Extended observations by ethnographers who lack aviation expertise (or even by those who have limited aviation qualifications) are unlikely to generate the required understandings of complex jobs such as air traffic control, air combat, or command of a commercial aircraft.

Within the framework of the situated argument, note that formal qualification is insufficient. It would not do, for example, to base design decisions for commercial aviation on the advice of pilots who have commercial licenses but no commercial experience. Nor would the advice of pilots with extensive but outdated commercial experience be adequate. In addition, it must be recognized that aviation is a multidimensional activity in which individuals with similar qualifications may have only limited knowledge of the specifics of each other's work activities. Thus currency and expertise on their own are not sufficient qualifications to advise on design issues. That currency and expertise must be specific to the context under study.

This raises a challenge for effective design. It is impractical to require, at least in general, that a design specialist also be a current and expert practitioner in the specific area to be targeted. The case described by Johnston (1992), in which design skills and relevant experiential knowledge reside with a single individual is and will remain unusual. Bødker (1991; see also Lintern, 1994) has proposed a participatory-design solution to this problem. Her approach is to co-opt active practitioners who are accorded a status equal to that of the engineers and human factors specialists on the design team. For complex design tasks, these practitioner may have to be in the design team for an extended period although they may be permitted (even required) to return periodically to their main work activity.

At first glance it may seem that the AQP is an exercise in participatory design. Task analyses accomplished by experienced and currently operational pilots (Longridge, 1992) are used to develop line operational simulations for training and for evaluation (FAA, 1990, 1991). However, this is not participatory design in the style outlined by Bødker (1991). Within the AQP, experienced practitioners are constrained by a framework imposed on them by instructional designers. The resulting line operational simulations may have the appearance of supporting situated practice, but if they are based on incomplete task descriptions they will not represent the realistic operational settings that should emerge from genuine participatory design. Most specifically, the self-organizing perspective suggests that designs and procedures for use must be developed situationally. Genuine participatory design would seem to call for a number of crews to engage in simulated exercises to discover how they could use the system effectively before design features were finalized and before procedures of use were formalized into instructional requirements.

Increased emphasis on the practitioner in the design process should not be permitted to relegate other professionals to minor roles. Human factors professionals have an important role to play although they must be armed with the appropriate tools. Ecological interface design, as outlined by Vicente and Rasmussen (1992), offers an approach that could strengthen our design effort considerably. Nevertheless, even a design approach as strong as this is only part of the solution. In the absence of participation from practitioners, implementation of an ecological interface design is unlikely to generate support for the robust behavior that is desired.

One activity within a multidisciplinary design team is for members from each area of expertise to educate members from other areas of expertise (Bødker, 1991). Conflicts and misunderstandings between various areas of expertise are likely but, in Bødker's view, it is in the resolution of such conflicts and misunderstandings that the possibilities for new design solutions emerge. Satisfactory resolution of contentious issues will depend on effective participation from all areas of expertise, which depend in turn upon all areas of expertise being accorded equal status in the design process.

In contrast, technological development of the modern cockpit has been driven largely by engineering versus operator concerns, and procedures for use have evolved through application of a rationalist philosophy. The result is an error-prone system that increases pilot workload at more difficult times and reduces it at less difficult times (Sarter & Woods, 1992). The self-organizing perspective of situated cognition finds much in this developmental process that is misguided. If such a system is to be imposed on commercial aviation, pilots who are actively and currently engaged in commercial activities must have a central role in its design and in the development of procedures for its use.

CONCLUSION

For Lave and Wenger (1991) the instructional method of choice is that of apprenticeship in a natural, on-the-job setting—an approach that would seem to guarantee a solid level of relevant learning and of transfer. As a general solution, such as approach would impose an unrealistic burden on education for a technological and complex society (Brown et al., 1989a). Flight training has, however, evolved from a tradition in which there has been an apprentice-style relationship between instructor and student, and much of the instructional work has been situated in flight. Nevertheless, pressures to economize and the introduction of new technologies into the cockpit are pushing flight training towards the instructional methods of contemporary education. The lesson to be drawn from situated cognition is that there are potential risks in such changes. In addition, current methods of training must be adapted to instructional requirements for modern, high-technology cockpits. One implication of the results from Sarter and Woods (1992, 1994) is that these adaptations have not been entirely successful.

A central issue for this review is whether the crucial elements of situated learning can be transported into a nonsituated instructional context. The analysis of the ethnographic research in situated cognition and situated learning undertaken in this article suggests that training can be effective even if removed from the context of actual flight. Nonsituated instruction must, however, incorporate a curriculum that encompasses the essential and challenging skills, offer opportunities for calibration of dynamic properties of skill, emphasize natural learning modes, provide extended practice that permits stable transfer of specific strategies to operational tasks, and support the self-organizing process of learning.

One concern for situated theorists is the reliance of cognitive science and standard educational practice on rational analysis. It is this approach that leads to unsupported (and often incorrect) assumptions about what students need to learn and how they learn. In place of rational analysis, the primary insights of situated cognition have emerged via an ethnographic methodology which is used to develop a detailed description of strategies used in natural or work settings and of how people learn in those settings. This approach can lay the foundation for an educational program that would avoid a breach between instruction and practice and development of brittle and nongeneralizable skills. Nevertheless, widespread application of ethnographic methods are unlikely to be as informative within aviation as in less technologically oriented activities. Participatory design is an alternative method of avoiding the types of problems identified in the situated cognition literature. This process of participatory design would accord aviation specialists a more substantive influence on design of systems and of training than has generally been the case within aviation human factors.

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REFERENCES

Billings, C. E. (1991). Human-centered aircraft automation: A concept and guidelines (NASA Tech. Memo. No. 103885). Moffett Field, CA: NASA Ames Research Center.

Bødker, S. (1991). *Through the interface: A human activity approach to user interface design.* Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Bootsma, R. J., & van Wieringen, P. C. W. (1990). Timing an attack forehand drive in table tennis. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 21–29.

Brown, J. S., Collins, A., & Duguid, P. (1989a). *Debating the situation. Educational Researcher, 18,* 10–12.

Brown, J. S., Collins, A., & Duguid, P. (1989b). Situated cognition and the culture of learning. *Educational Researcher, 18,* 32–41.

Carraher, T., Carraher, D., & Schlieman, A. (1983). *Mathematics in the streets and schools.* Unpublished manuscript, Universidade Federal de Pernambuco, Recife, Brazil.

Casey, S. (1993). *Set phasers on stun.* Santa Barbara, CA: Aegean.

Casner, S. M. (1994). Understanding the determinants of problem-solving behavior in a complex environment. *Human Factors, 36,* 580–596.

Edelman, G. M. (1987). *Neural Darwinism: The theory of neuronal group selection.* New York: Basic Books.

Edelman, G. (1992). *Bright air, brilliant fire.* New York: Basic Books.

Federal Aviation Administration. (1990). *Line operational simulations: Line-oriented flight training, special purpose operational training line operational evaluation* (Tech. Rep. No. AC 120–35B). Washington, DC: Author.

Federal Aviation Administration. (1991). Advanced qualification program (Tech. Rep. No. AC 120–54). Washington, DC: Author.

Gardner, H. (1985). *The mind's new science: A history of the cognitive revolution.* New York: Basic Books.

Glieck, J. (1987). *Chaos: Making a new science.* New York: Viking.

Goody, E. N. (1989). Learning, apprenticeship and the division of labor. In M. Coy (Ed.), *Apprenticeship: From theory to method and back again* (pp. 233–256). Albany, NY: SUNY Press.

Greeno, J. G., & Moore, J. L. (1993). Situativity and symbols: Response to Vera and Simon. *Cognitive Science, 17,* 49–59.

Herndon, J. (1971). *How to survive in your native land.* Cambridge, England: Cambridge University Press.

Hutchins, E. (1991). *How a cockpit remembers its speeds.* Unpublished manuscript, University of California, Distributed Cognition Laboratory, San Diego.

Hutchins, E. (1992). Learning to navigate. In S. Chaiklin & J. Lave (Eds.), *Understanding practice: Perspectives on activity and context* (pp. 35–63). New York: Cambridge University Press.

Johnson-Laird, P. N. (1983). *Mental models.* Cambridge, MA: Harvard University Press.

Johnston, N. (1992). The development and use of a generic nonnormal checklist with applications in *ab initio* and introductory advanced qualification programs. *The International Journal of Aviation Psychology, 2,* 323–337.

Jordan, B. (1989). Cosmopolitical obstetrics: Some insights from the training of traditional midwives. *Social Science Medicine, 28,* 925–944.

Katz, J. J., & Fodor, J. A. (1963). The structure of a semantic theory. *Language, 39,* 170–210.

Klein, G. A., & Calderwood, R. (1991). Decision models: Some lessons from the field. *IEEE Transactions on Systems, Man, and Cybernetics, 21,* 1018–1026.

Kugler, P. N. (1986). A morphological perspective on the origin and evolution of movement patterns. In M. Wade & H. T. A. Whiting (Eds.), *Motor development in children: Aspects of coordination and control* (pp. 459–525). Boston: Martinus Nijhoff.

Kugler, P. N., & Lintern, G. (1995). Risk management and the evolution of instability in large-scale, industrial systems. In J. M. Flach, P. A. Hancock, J. K. Caird, & K. J. Vicente (Eds.), *An ecological approach to human machine systems II: Local applications* (pp. 416–450). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Lautman, L. G., & Gallimore, P. L. (1987, April–June). Control of the crew caused accident. *Airliner,* pp. 1–7.

Lave, J. (1988). *Cognition in practice.* New York: Cambridge University Press.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation.* New York: Cambridge University Press.

Lintern, G. (1989). The learning strategies program: Concluding remarks. *Acta Psychologica, 71,* 301–309.

Lintern, G. (1991). Instructional strategies. In J. E. Morrison (Ed.), *Training for performance: Principles of applied human learning* (pp. 167–191). New York: Wiley.

Lintern, G. (1992). Risk management: The irremedial incompleteness of rules. In *Proceedings of the 1992 IEEE International Conference on Systems, Man, and Cybernetics* (Vol. 1, pp. 833–836). New York: IEEE.

Lintern, G. (1994). Review of *Through the interface: A human activity approach to user interface design* by Susanne Bødker. *The International Journal of Aviation Psychology, 4,* 97–102.

Lintern, G., & Gopher, D. (1978). Adaptive training of perceptual–motor skills: Issues, results, and future directions. *International Journal of Man–Machine Studies, 10,* 521–551.

Lintern, G., & Liu, Y. (1991). Explicit and implicit horizons for simulated landing approaches. *Human Factors, 33,* 401–417.

Long, K. T., Freedman, C., Walker, R. A., & Thode, W. F. (1982). *Instructional systems development for P–3 aircrew training* (Tech. Rep. No. NPRDC TR 82–51). San Diego, CA: Navy Personnel Research and Development Center.

Longridge, T. M. (1992). The advanced qualification program: Matching technology to training requirements. In *Proceedings of the Royal Aeronautical Society* (pp. 9.1–9.11). London: Royal Aeronautical Society.

Longridge, T. M., & Boothe, E. M. (1991). Training equipment implications of the FAA's new advanced qualification program. In *Proceedings of the Second Annual International Training Equipment Conference* (pp. 223–228). Maastricht, Netherlands: American Defense Preparedness Association.

Lorenz, K. (1991). *Here am I—Where are you?* New York: Harcourt Brace Jovanovich. (Original work published 1988)

McKinney, E. H. (1993). Flight leads and crisis decision-making. *Aviation, Space, and Environmental Medicine, 64,* 359–362.

Newburg, S. (1992). Goodbye to the lecture: Embracing interactive learning techniques. *Journal of Aviation/Aerospace Education & Research, 3,* 32–37.

NTSB Reporter. (1994). Flight accident: ATR72. White Plains, NY: Author.

Oneal, J. A. (1990). Integration of training systems and analyses. In H. R. Booher (Ed.), *Manprint: An approach to systems integration* (pp. 391–416). New York: Van Nostrand Reinhold.

Palincsar, A. S. (1989). Less charted waters. *Educational Researcher, 18*(4), 5–7.

Perrow, C. (1983). The organizational context of human factors engineering. *Administrative*

Science Quarterly, 28, 521–541.

Prigogine, I., & Stengers, I. (1984). *Order out of chaos.* New York: Bantam.

Reed, E. S. (1989). Neural regulation of adaptive behavior. *Ecological Psychology, 1,* 97–117.

Rips, L. J. (1988). Deduction. In R. J. Sternberg & E. E. Smith (Eds.), *The psychology of human thought* (pp. 116–152). New York: Cambridge University Press.

Rochlin, G. I., La Porte, T. R., & Roberts, K. H. (1987, Autumn). The self-designing high-reliability organization: Aircraft carrier flight operations at sea. *Naval War College Review,* pp. 76–90.

Sarter, N. B., & Woods, D. D. (1992). Pilot interaction with cockpit automation: Operational experiences with the flight management system. *The International Journal of Aviation Psychology, 2,* 303–321.

Sarter, N. B., & Woods, D. D. (1994). Pilot interaction with cockpit automation II: An experimental study of pilots' model and awareness of the flight management system. *The International Journal of Aviation Psychology, 4,* 1–28.

Saxe, G. B. (1990). *Culture and cognitive development: Studies in mathematical understanding.* Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Scribner, S., & Fahrmeier, E. (1982). Practical and theoretical arithmetic: Some preliminary findings. *Industrial Literacy Project,* (Working Paper No. 3). New York: City University of New York, Graduate and University Center.

Singley, M. K., & Anderson, J. R. (1989). *The transfer of cognitive skill.* Cambridge, MA: Harvard University Press.

Sternberg, R. J. (1988). Intelligence. In R. J. Sternberg & E. E. Smith (Eds.), *The psychology of human thought* (pp. 267–308). New York: Cambridge University Press.

Stokes, A. F., Kemper, K. L., & Marsh, R. (1992). *Time-stressed flight decision making: A study of expert and novice aviators* (Tech. Rep. No. ARL–93–1/INEL–93–1). Savoy: University of Illinois, Aviation Research Laboratory.

Suchman, L. A. (1987). *Plans and situated actions: The problem of human machine communication.* Cambridge, England: Cambridge University Press.

Suchman, L. (1993). Response to Vera and Simon's situated action: A symbolic interpretation. *Cognitive Science, 17,* 71–75.

Telfer, R., & Bent, J. (1992, Spring). Producing a workshop for training airline instructors. *The Journal of Aviation/Aerospace Education & Research,* (3), 31–38.

Thomas, M., & Geltmacher, H. (1993, April/May). C mbat simulator display development. *Information Display, 9*(4 & 5), 23–26.

Thurber, D. (1994). *Investigators say co-pilot battle computer before crash.* Associated Press.

Vera, A. H., & Simon, H. A. (1993a). Situated ion: A symbolic interpretation. *Cognitive Science, 17,* 7–48.

Vera, A. H., & Simon, H. A. (1993b). Situated a on: Reply to reviewers. *Cognitive Science, 17,* 77–86.

Vicente, K. J., & Rasmussen, J. (1992). Ecological interface design: Theoretical foundations. *IEEE Transactionsl on Systems, Man, and Cybernetics, 22,* 589–606.

Wightman, D. C., & Lintern, G. (1985). Part-task training for tracking and manual control. *Human Factors, 27,* 267–283.

Wineburg, S. S. (1989). Remembrance of theories past. *Educational Researcher, 18,* 7–10.

Winograd, T., & Flores, F. (1986). *Understanding computers and cognition: A new foundation for design.* Reading, MA: Addison-Wesley.

Yates, F. E. (Ed.). (1987). *Self-organization: The emergence of order.* New York: Plenum.