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Effective Computer Based Training in Aviation: an Evaluation of the NASA In-Flight Icing Program

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Effective aviation training must provide pilots with the knowledge and skills they need to make appropriate operational decisions and to implement those decisions. Pilots must not only learn information, they must be able to retrieve that information and apply it effectively in the operational environment. In this paper, we report an evaluation of a computer-based training (CBT) program designed to impart factual knowledge and to enhance pilots' abilities to make appropriate operational decisions regarding in-flight icing. To accomplish these goals, the educational design of the CBT relied heavily on current work in cognitive science on learning and decision-making. To evaluate the effectiveness of this approach, an experiment was conducted. Professional pilots' factual knowledge of icing and decisions in operational situations were evaluated. Then the participants received one of three educational products: the original CBT including interactive exercises, a CBT lacking the interactive exercises, or an icing text. After completing this training, the pilots' factual knowledge and operational decisions were again evaluated. In addition, subjective evaluations of the materials and evaluations of the pilots' previous training experience were obtained. Results indicate that the pilots learned more from the CBT and rated it more highly than the other materials and their previous training. This suggests that computer-based training based on current knowledge of learning and decision-making can be unusually effective and that the effort required to produce these products is justified.

Introduction

Aviation training should be designed to provide pilots and other aviation professionals with the knowledge and skills they need to make appropriate operational decisions and to implement those decisions. To accomplish these tasks, the educational design on which the training is based must take into account not only what must be learned, but also the operational environment in which the knowledge will need to be retrieved and applied. Pilots must learn the relevant declarative and procedural knowledge and the cues that will allow them to retrieve this information in the operational environment together with the necessary decision-making skills.

Essentially, declarative knowledge is the things we know and to which we have conscious access. These are the facts that we can state directly using words or images (e.g., the number of gears on a bicycle). Declarative knowledge can be conceptualized as facts or propositions imbedded in schema or mental models (Rumelhart, 1980; Schank & Abelson, 1977). Learning declarative knowledge involves both obtaining facts and building the schema that relate these facts to each other. A major task in learning new fields is developing appropriate schema of the new domains. If a learner develops appropriate schema, new facts can be easily related to each other as they are learned. Related information is clustered together at appropriate points in the framework. When any part of a cluster is cued, nearby information will be "activated" as well, making it more likely that relevant information will be quickly and accurately recalled when needed. Schema are continually modified as individuals gain knowledge and experience in a domain. Research on expertise suggests that many of the advantages that experts display can be traced to their well-developed mental representations of their domain of expertise (Chi, Glaser, & Farr, 1988).

Procedural knowledge (Anderson, 1987) is the things we know how to do and to which we may have only limited conscious access (e.g., how to balance on a bicycle). Because procedural knowledge usually cannot be consciously accessed, it is hard to change. It is also very resilient to loss. One can frequently remember how to perform a physical skill for years, but facts and figures are often quickly forgotten if they are not regularly used or rehearsed. Procedural knowledge can be conceptualized as sets of "if-then" statements that govern actions (such as, if the bicycle leans to the left then shift weight to the right). When a set of conditions is encountered, the individual is primed to take the learned action – whether that be seeking more information, considering certain options, or pushing a button. Procedural knowledge tends to build with practical experience. But that experience can also be provided in training.

Any area of skilled performance requires both types of knowledge. To effectively build both declarative and procedural knowledge, a training program must be designed to help students learn facts, build appropriate schema, and apply what they have learned. Pilots must learn a great deal about a host of topics (e.g., aircraft systems, weather, federal regulations, etc.). They must be able to retrieve this information, and they must learn how to use this information to make good operational decisions.

In complex domains, like aviation, decision-making cannot be reduced to simple procedures. Often, there are too many factors and too many possible interactions between the factors to consider. Time is often limited and reality unclear. In these circumstances, experienced decision-makers learn to use different strategies in different situations and to change strategies when they find that one does not work. Effective decision training cannot be reduced to teaching simple mnemonics. It is not clear how to best train operational decision-making. However, the existing literature suggests that decision-making can be improved by teaching individuals to selectively attend to the environmental cues that are most useful for discriminating between potential problems, teaching appropriate solutions to those problems, providing retrieval cues for those solutions, and providing practice making decisions in the operational environment

Traditional pilot training programs separate the teaching of declarative and procedural knowledge. Pilots are expected to learn large bodies of facts on their own or in classrooms. However, they are taught the skills that they need to know to operate aircraft in simulators and on training flights. Furthermore, the knowledge and skills necessary to make good operational decisions are learned (if at all) through experience or through mentoring on-the-job by more experienced pilots. This highly segregated training makes aviation training more difficult than it needs to be and can cause pilots to have difficulties in remembering, integrating, and using what they learn.

In traditional training programs, if psychology is considered at all, only the cognitive psychology of learning is considered. This can lead to educational designs that excel at teaching information that can be retrieved in the learning environment but that fail to provide students with the ability to retrieve and use their knowledge when they need it in an operational context outside of the classroom.

In this paper, we describe the evaluation of a training program that was explicitly designed to integrate declarative and procedural knowledge, connect this knowledge with the pilots' existing aviation schema, provide retrieval cues, and provide practice making operational decisions. In the educational design, we explicitly considered when and how pilots would need to be able to retrieve and use their knowledge of icing. Cues that are expected to be present in the operational environment were embedded in the training to boost the user's ability to retrieve their icing knowledge when it was needed. In addition, we explicitly taught and demonstrated how to use information about icing in making pre-flight and in-flight decisions. As often as possible we also provided the users with opportunities to practice these skills in exercises and situated questions. These issues are discussed in more detail elsewhere (Mauro & Barshi 2003; 2006). In this paper, we report an evaluation of this training product.

Method

Overview

To evaluate the effectiveness of our educational design, we recruited professional pilots and randomly assigned them to receive a training program based on the principles described above or traditional training materials. The pilots' declarative and procedural knowledge and domain relevant decision-making was measured before and after they completed their training. Differences between the pilots' knowledge before and after completing the training program provided measures of learning.

Materials

Training Materials. In response to the continuing loss of aircraft in icing-related accidents, the Icing Branch of the National Aeronautics and Space Administration (NASA) at Glenn Research Center developed a series of training products designed to teach pilots about ground and in-flight icing.[1] The most recent installments in this series are computer-based training programs based on the educational design described above. We chose one of these programs -- *A Pilot's Guide to In-flight Icing* (NASA Glenn Research Center, 2002) -- for use in this study. This CBT was designed to be used by pilots without instructor intervention.

The pilots participating in this study received either a CD version of *A Pilot's Guide to In-Flight Icing* or Perkins & Reike's (2001) text on in-flight icing. Several other training materials were considered for

[1] See aircrafticing.grc.nasa.gov for a description of these products.

this study. These included proprietary materials and texts by Lankford (2000) and Newton (1991). The selected text was chosen because it provided the closest match to the CD in topic coverage and intended audience. It is also widely available throughout the aviation community.

Questionnaires. Four on-line questionnaires were developed: a measure of the pilots' prior experience and icing training (Experience and Knowledge Survey), two parallel tests of the pilots' icing knowledge (Icing Knowledge Questionnaires) and an evaluation of the training material (Training Material Survey). The knowledge questionnaires were designed to provide two similar – but not identical – tests of the participants' icing knowledge. These tests measured the participants' knowledge of icing and ability to utilize this knowledge in practical situations using scenario-based items whenever possible. The questions covered a variety of topics including visual identification of ice types and severity, interpretation of icing weather products, effects of icing on aircraft performance and handling, pre-flight planning, in-flight operations in icing conditions, and coping with icing emergencies.

Procedure

Pilots were recruited through flyers placed at a regional airline base and through announcements in recurrent airline training classes and paid $80 to participate in this study. Participants were first asked to complete two questionnaires on the research website – one version of the Icing Knowledge Questionnaire and the Experience and Knowledge survey. Once these questionnaires were completed, the participants were randomly assigned to receive either the icing text or a CD containing *A Pilots Guide to In-Flight Icing.* To mimic the way that we anticipate most pilots outside the study would use the training materials, we allowed the participants to take as much time as they wished to complete the training. The pilots were instructed to contact the research staff once they had completed the training. Once they did so, they were sent a password that allowed them to complete two additional questionnaires – a different version of the Icing Knowledge Questionnaire and the Training Material Survey.

Subjects

Fifty-four pilots participated in this study. Approximately half (53.7%) had Airline Transport Pilot (ATP) certificates, the remainder held Commercial Pilot certificates with an instrument rating. Nearly all of the pilots (52) were employed by an airline. One was a charter pilot and another worked as a corporate pilot. The pilots had been flying for an average of 13 years (sd=6.3; range 4.5 – 34 years). On the average, the pilots had logged just over 5,000 hours of flight time (Mean=5213, sd=3756; range 950-18,000). These pilots (mostly from the Northwest) reported spending an average of 16% of their flying time in icing conditions with an average of 5.5% of the time in actual icing. Although accurate statistics on exposure are difficult to obtain, these figures suggest that the pilots in this study had considerable experience with icing conditions.

Results & Discussion

Prior Icing Knowledge

As a group, the pilots believed that they knew a considerable amount about icing; 29.7% believed that they knew a "large" or "very large" amount about icing. Only three pilots admitted to knowing only a "little" or "very little" about icing. However, the participants were somewhat less sanguine about their knowledge of icing physics and meteorology (see Table 1).

Table 1. Pilot self-evaluation of icing knowledge

	Icing Topic			
Amount	**Physics**	**Wx**	**Ops**	**Overall**
Very large			1.9%	1.9%
Large	14.8%	11.1%	35.2%	27.8%
Moderate	48.1%	72.2%	55.6%	64.8%
Little	33.3%	13.0%	5.6%	3.7%
Very little	3.7%	3.7%	1.9%	1.9%

Note: N=54 in all columns.
Ops: Icing Operations; Wx: Meteorology

The participants' knowledge of icing came from many sources. These included both formal training in certification courses and airline ground schools and informal education from books, magazines, videos, and other pilots. Over 90% of the pilots reported learning about icing from personal experience. Seventy-seven percent reported learning about icing from other pilots. Seventy-four percent reported learning about icing from materials that they sought out on their own outside of any formal educational setting. Pilots were much less likely to name more formal sources of icing education. Only 64.8% of the pilots named initial airline ground school as a source of icing information – and this was the most often named source of formal training in icing.

Of these various sources, the pilots reported learning the most from their own experience; 53.7% of the pilots reported learning a "large" or "very large" amount about icing from their own experience (see Table 2). Other pilots (20.4%), college courses (18.6%), and materials obtained on their own (14.9%) were the next most frequently endorsed sources of "large" or "very large" amounts of icing knowledge. Neither federal certification courses nor airline initial or recurrent training provided much icing training. Most pilots reported receiving "little", "very little", or no training about icing in primary ground school (90.8%), commercial/instrument ground school (76%), initial airline training (63%), or recurrent airline training (81.5%).

Table 2. Pilots' Evaluation of Sources of Icing Knowledge

	Amount Learned					
Source	**None**	**Very Little**	**Little**	**Moderate**	**Large**	**Very Large**
Primary Training	13.0	51.9	25.9	7.4	1.9	0.0
Commercial Train.	13.0	11.1	51.9	18.5	5.6	0.0
College	22.2	11.1	16.7	31.5	13.0	5.6
Initial Airline	7.4	16.7	38.9	33.3	3.7	0.0
Recurrent Airline	20.4	25.9	35.2	11.1	7.4	0.0
Company Materials	14.8	18.5	29.6	31.5	5.6	0.0
Own Materials	3.7	7.4	29.6	44.4	13.0	1.9
Other Pilots	3.7	3.7	31.5	40.7	14.8	5.6
Experience	0.0	1.9	11.1	33.3	37.0	16.7
Other	64.8	18.5	7.4	3.7	1.9	3.7

Note: Entries are % of pilots endorsing response.

This is a very dangerous situation. It reflects a system in which the training about one of the most hazardous aviation weather phenomena is left almost entirely to the individual pilot. It is particularly disturbing that personal experience is the source of so much icing knowledge. Experience may be an excellent teacher, but it is also a very fickle one. From any single experience or small set of experiences, one can learn the wrong things. For example, one may attribute surviving a dangerous icing encounter to the characteristics of the aircraft or one's own piloting skill instead of to transient weather phenomena and come away from the experience believing that icing is a minor nuisance instead of a dangerous threat. Indeed, the results of the knowledge tests (see below) indicate that many pilots think that they know more about icing than they actually do.

Table 3. Evaluation of Training Materials

	Training Material	
Question	**Text**	**CD**
How much did you learn?	3.1 (.49)	3.5 * (.61)
How much would the professional pilot learn?	3.4 (.82)	4.2 *** (.65)
How important was what you learned?	3.6 (.88)	4.1 ** (.56)
How does this compare to other materials?	3.5 (.76)	4.4 *** (.56)

Note: * indicates means are significantly different at $p<.05$ on the 5 point scale; ** indicates $p<.01$; *** indicates $p<.001$. Std. Deviations in parentheses.

Subjective Evaluation of Icing Training Materials

The participants preferred the CD to the icing text on all of the subjective general measures of the training materials (see Table 3). The pilots who received the CD reported that they learned more than did the pilots who received the icing text ($F(1,52)=5.54$, $p=.022$). Fifty-two percent of the pilots who received the CD reported that they had learned a "large" or "very large" amount compared to 20% of the pilots who received the text. Compared to the pilots who received the icing text, the pilots who received the CD also reported that the typical professional pilot would learn more from the material they used ($F(1,52)=16.97$, $p<.001$). Eighty-eight percent of the pilots who received the CD reported that the typical professional pilot would learn a "large" or "very large" amount from the CD compared to 50% who felt that way about the text. Ninety percent of the pilots who received the CD responded that what they had learned was "very" important or "extremely" important compared to 65% of the pilots who used the text ($F(1,52)=7.82$, $p=.007$). Finally, 97% of the pilots who had used the CD reported that the training they had received was "better" or "much better" than the other aviation training they had received. Only 55% of the pilots who received the text had the same response ($F(1,52)=27.13$, $p<.001$).

The CD was also rated more highly than the text on all of the specific subjective measures of training material quality ($\lambda=.458$, $F(6,47)=9.25$, $p<.001$; see Table 4). Most of the pilots (85.3%) who received the CD rated the overall quality as "very good" or "excellent", compared to only 15% of the pilots who received the booklet. The majority of the pilots who received the CD also rated the content (91.3%), clarity (79.4%), organization (76.5%), appearance (79.4%), and ease of use of the CD (76.4%) as "very good" or "excellent". Although the icing text was not rated as highly, it received relatively high marks. A large proportion of the pilots who received the text rated the content (80%), clarity (50%) organization (70%), appearance (75%) and ease of use (75%) as "good" or "very good", though few (2 pilots on content, 1 on appearance) rated it as "excellent" on any scale.

Table 4. Measures of Training Material Quality

	Training Material			
	Text		**CD**	
Criterion	**Mean**	**SD**	**Mean**	**SD**
Overall Quality	4.90	(.72)	6.18	(.67)
Content	5.45	(.94)	6.24	(.61)
Clarity	4.20	(1.28)	6.03	(.76)
Organization	4.85	(.81)	6.18	(.87)
Appearance	5.15	(.93)	6.18	(.76)
Ease of use	4.90	(1.37)	6.12	(.84)

Note: Differences between materials on all measures are significant at p<.001 on the 7 point scales.

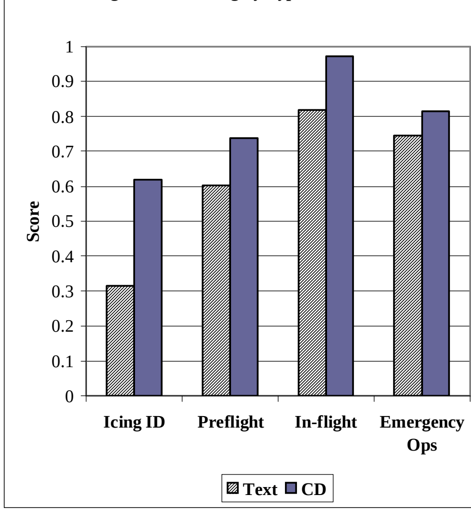
On the average, pilots took longer to complete the CD (3:21) than the text (1:58; F(1,52)=13.71, p<.001). However, the range was considerable (CD: 1:45-6:00, sd=1:28; text: 0:30-5:00, sd=1:03).

Knowledge Test Performance

The pilots did not differ in their performance on the icing knowledge test before receiving the icing training materials (t(41)=.838, n.s.). However, after completing the training materials, pilots who received the CD, scored higher on the post-test than did pilots who completed the booklet (Booklet Mean=.641, CD Mean .759; t(41)=5.11, p<.001). Indeed, pilots who completed the icing training text did not show any overall improvement in performance (t(17)=1.32, n.s.), whereas pilots who completed the CD demonstrated marked improvement (t(24)=7.10, p<.001)

Although the groups did not differ on the subtest pre-tests (λ=.694, F(15,34)=.694, n.s.), the pilots who completed the CD demonstrated higher scores on the post-test subtests (λ=.368, F(15,28)=3.211, p=.004) than did the pilots who completed the icing text. These differences were significantly higher on all of the different categories (icing identification, preflight planning, in-flight, and emergency operations) and remained so when differences on the pre-test were taken into account through analysis of covariance (see Figure 1).

Figure 1. Learning by Type of Material



To test the efficacy of practice through "virtual experience", half of the pilots who received a CD received one from which the pre-flight planning exercises had been removed. Pilots who received the CD that included the exercises demonstrated significantly higher post-test scores on the measures of decision-making in pre-flight planning than did pilots who received the CD from which the exercises had been deleted (F(1,40)=4.141, MSe=.093 p=.049). This suggests that the inclusion of the interactive exercises had the intended effect of increasing the pilots' pre-flight planning skills. No other differences between these groups were anticipated or found and so their scores were combined for the analyses reported above.

General Discussion

The pilots who participated in this study were not a random sample of the aviation community. The participants were mostly experienced professional pilots who had substantial experience with actual icing conditions. They believed themselves to be well versed in icing issues. Nevertheless, as a group they failed to answer correctly many questions on the icing knowledge pre-test. These included not only questions about icing physics and meteorology, but also questions about icing operations and the identification and recovery from ice-induced emergencies. These results indicate that the need for pilot training in icing remains unsatisfied. Although many of these pilots sought out training materials on their own, these materials did not teach them all that they needed to know. But because there are no clear standards for training in this area, what was missing remained unclear. As one participant put it, "Until I saw the CD, I didn't know how much about icing I didn't know."

This result underscores two potential problems. First, because they are unaware of their lack of knowledge, many pilots may fail to seek out information and continue to fly with a false sense of security. Even an aggressive "marketing" campaign may fail to succeed in attracting the attention of these pilots if it does not first lead them to realize that there are operationally important things that they do not know. Second, one should not plan education campaigns entirely around what pilots or airline managers think they need. They may not know what they need to know and they do not know what they do not know.

Our effort to address these needs appears to have been successful. The pilots who received *A Pilot's Guide to In-flight Icing* demonstrated significantly greater declarative and procedural learning and improved decision-making compared to pilots who received the icing text. However, this learning came at a cost. On the average, pilots took considerably longer to complete the CD than to complete the text. This result may have been caused by several different factors. One reason that the pilots may have taken longer with the CD was that it contained more material. The CD was designed to repeat the same information in different ways, to illustrate points completely, and to integrate the knowledge within the operational context. Another reason that the CD may have taken longer to complete was that it might have been more enjoyable. This hypothesis is supported by the pilots' subjective evaluations. When education is regimented, the attractiveness of the teaching material is often considered of little importance. The students must either learn the material in the time and manner allotted, or fail and be expelled from the school or the airline. However, people will spend more time learning and will learn more when they enjoy the process. Of course, if an airline were paying for the pilots' training time, managers might question whether time could be saved while providing the same level of learning. This remains an open question. It may be possible to shorten the training material. However, when we deleted one component of the CD – the interactive exercises on preflight planning – we observed a significant drop in performance in that area. This suggests that it may be difficult to cut the training time without harming the results.

In sum, the results reported here demonstrate that by taking into account the principles of modern cognitive science in the design of training materials, highly effective educational products can be developed. In *A Pilot's Guide to In-Flight Icing*, NASA brought together substantial domain expertise in icing, flight operations, and human factors to develop superior training materials. In so doing, NASA is making a substantial improvement in aviation safety that justifies the development costs.

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