THE EFFECT OF FUNCTIONAL DISPLAY INFORMATION ON THE ACQUISITION AND TRANSFER OF NOVICE PILOTING KNOWLEDGE

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Carl F. Smith
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Committee:

Director

Department Chairperson
Program Director
Dean, College of Humanities and Social Sciences

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By

Carl F. Smith
Master of Arts
George Mason University, 2004

Director: Deborah A. Boehm-Davis, Professor
Department of Psychology

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George Mason University
Fairfax, VA
DEDICATION

This is dedicated to the two people who made this paper possible.

To Debbie, whose unwavering patience and generous guidance were the driving force in my own professional development.

To Dhvani – you have changed how I approach my life and my work. You constantly lead by example, and in doing so, have shown me how to better myself.
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ABSTRACT

THE EFFECT OF FUNCTIONAL DISPLAY INFORMATION ON THE ACQUISITION AND TRANSFER OF NOVICE PILOTING KNOWLEDGE

Carl F. Smith, PhD
George Mason University, 2008
Dissertation Director: Dr. Deborah A. Boehm-Davis

Prior studies using an aviation display with functional properties have shown improvements in performance and knowledge, suggesting that functional interface design may be used to improve flight training. To improve training, however, the knowledge and performance benefits observed with a functional display must generalize to a standard flight display. This study evaluates whether the knowledge and performance benefits observed with a functional aviation display (Oz) can transfer to a conventional Cessna display. Thirty-two novices were trained in one of four display conditions (Oz-Oz/Oz-Conv/Conv-Oz/Conv-Conv). Results indicate that novices initially trained on the Oz display showed improved knowledge and performance compared to novices trained on a conventional display. Novices who trained on the Oz display and then transferred to
a conventional display showed decreased knowledge and performance compared to
novices using the Oz display only, but displayed improved knowledge and flight
performance compared to novices who trained only on a conventional display.
Implications for the use of functional displays in flight training are discussed.
INTRODUCTION

One of the central challenges for student pilots is acquiring the knowledge and skills necessary to effectively pilot an aircraft. Federal aviation regulation section 61 (FAA, 2007) suggests that 40 total hours of flight time is the minimum sufficient amount of experience required to obtain private pilot certification. However, many private pilot instruction programs report that the time actually required for pilot certification ranges between 50 and 70 flight hours (AOPA, 2007). The discrepancy between the minimum hours required for certification and the actual hours required to pass certification suggests that current training regimes may benefit from improvements to flight training. This requires identifying methods that can support students in gaining equal or greater competency in less time.

Using flight simulation for training

One promising method is the use of pc-based flight simulators to provide novices with greater opportunities to practice newly acquired skills. For example, the Navy currently provides its student pilots with copies of Microsoft Flight Simulator for practice (Williams, 2005). By providing a simulated environment within which novices can explore new skills, novices are given extra time to practice common procedures and
commands. However, simulations are typically used to augment current training procedures; thus, they do not mitigate the time required to gain basic competency.

An alternative possibility is the use of new displays, which have shown some potential for improving training. The availability of relatively low-cost personal computers that can render realistic displays and environments allows for the easy and widespread implementation of pc-based displays not currently used in flight training. This provides an opportunity for novel displays, whose presentation may improve novices’ understanding of the aircraft and its constraints.

*Improving Training with Functional Interface Design*

In proposing new displays for training purposes a central question emerges - what information should a display present to improve pilots’ knowledge and skill acquisition? One approach to answering this question is the application of functional interface design theory, which proposes that presenting abstract, high level functional system information to users can improve skill and knowledge acquisition (Lintern, Waite, and Talleur, 1999). This approach emphasizes the Skills-Rules-Knowledge (SRK) framework (Rasmussen, 1985). The SRK framework is decomposed into three behavior types. Skill based behavior (SBB) consists of parallel, perceptual-motor control based on environmental signals. Rule-based behavior (RBB) directly associates perceptual signs and appropriate actions or goals. In contrast, knowledge based behavior (KBB) consists of slower, serial analytic problem solving based on symbolic problem representation (Dinadis & Vicente, 1999).
Following this framework, several assumptions can be made. First, displays that visually present the constraints of a required analytic process should support faster and more accurate performance on time-pressured tasks. Second, displays that provide a direct, perceptual association between a cue on the display and its meaning (RBB) should support more rapid diagnoses and responses to system state. Third, actions requiring KBB should be slower and more error prone than identical tasks communicated directly by the display. Finally, providing explicit and accurate visualizations of deep system functioning should allow novices to better develop an accurate and comprehensive mental model of system functioning and the effect of their actions on system performance.

Several studies support the claims of functional interface design theory. One line of research has used the Oz display to illustrate the benefits of displaying functional information in aviation (Figure 1) (Still and Temme, 2004). The Oz display is a general aviation display designed to replace the standard six-dial display in instrument flight rules (IFR) conditions. Oz integrates several graphic elements to provide a visualization of the functional relationship between various system elements as they interact along the drag curve. The drag curve can be visualized as an abstract, functional relationship between thrust (power), drag, and airspeed; this relationship specifies the amount of thrust required to maintain a given airspeed given the amount of drag associated with the airspeed (Brandt, 2004).
Conventional flight displays do not communicate the relationship between these properties, though the physical information for both power and airspeed are available on the display. Unlike conventional flight displays, the Oz display (Figure 1) depicts a graphic visualization of the drag curve. A colored vertical line uses one color (green) to communicate the amount of power being used and another color (blue) to communicate the amount of power available. The same vertical line’s position on a horizontal axis communicates current airspeed, with increasing airspeed moving outwards towards the edges of the bent wings/drag curve. The intersection of the green area of the vertical line with the bent wings provides a graphic visualization of the optimal power setting needed to maintain current airspeed. Using this graphic, a pilot can directly perceive the most efficient and effective power setting for a given airspeed by matching the amount of power used (the green vertical line) to the amount of power required (the bent wings) (Figure 1.) (Smith et al., 2004).

The results of a series of studies using the Oz display suggest that visual communication of the functional relationship between power and airspeed improves both performance and knowledge of power maintenance (Smith et al., 2004, Smith and Boehm-Davis, 2005, Smith, Fadden, & Boehm-Davis, 2005). Three main findings have emerged from this line of research. First, Oz use improves and standardizes power maintenance. Second, Oz use improves understanding and knowledge of power maintenance. Finally, both aforementioned benefits appear to be moderated by the importance of power management when performing the maneuver.
Oz use improves and standardizes power maintenance. Experts and novices have shown improvements in power maintenance when flying the Oz display. Smith et al. (2004) tested a group of experienced pilots on a conventional Cessna display and the Oz display. When using the Oz display, pilots showed significantly fewer deviations from optimal power settings, as well as less variability in power use between pilots (Figure 2), even in higher workload conditions (Smith, Fadden, & Boehm-Davis, 2005). Novices using the Oz display also showed increased accuracy and consistent performance with power (Figure 4) (Smith and Boehm-Davis, 2005a) comparable with the expert results observed in Smith et al. (2004), and Smith et al (2005a). This suggests that performance is improved with the functional graphic regardless of experience level.

Oz use improves understanding and knowledge of power use. Smith and Boehm-Davis (2005b) tested novices’ knowledge before and after flight training with the Oz display. Immediately after classroom training, novices showed no significant difference in knowledge as a function of display type. Following six hours of flight training, novices trained on the Oz display were significantly more accurate in answering questions about the effect of power on aircraft state. Novices trained on the Oz display were also significantly better at predicting future system state when provided with current airspeed and power settings (Smith & Boehm-Davis, 2005b). These results indicate that training with a functional display (such as Oz) may lead to a greater understanding of functional system components.
Oz benefits are moderated by the importance of power management to the flight task. In each of the aforementioned studies (Smith et. al, 2004, Smith and Boehm-Davis 2005a, Smith and Boehm-Davis, 2005b, Smith et al. 2005), a predictable pattern of performance and knowledge results emerged. Maneuvers that required detailed maintenance of power to perform the task correctly – for example, maintaining airspeed while flying straight and level, climbing, or turning – showed significant performance and knowledge benefits when using the Oz display. Conversely, maneuvers that can be performed accurately without the regular maintenance of power – for example, increasing airspeed rapidly, ascending while turning (or any maneuver that requires near-maximum power), or descending - all failed to show significant knowledge or performance differences for power management. This lack of an effect for maneuvers that do not require regular, direct reference to the power-airspeed relationship can be interpreted as an indication that communication of the functional relationship is driving the performance and knowledge benefits, rather than some other artifact of the display design.

Functional interface design and the transfer of training

Although this research shows that both performance and knowledge benefits are associated with Oz display use, the Oz display is not the standard display most pilots will regularly fly. The true measure of a displays’ effectiveness for training is whether observed knowledge and performance benefits generalize beyond the training display itself. To see whether benefits extend beyond training with the Oz display, two questions
must be answered. First, do performance and knowledge improvements acquired during use of the Oz display to conventional flight display use? Second, if performance and knowledge benefits do transfer, is the amount of improvement significantly greater than training on a conventional display alone?

So why should functional display use improve knowledge acquisition beyond learning on a conventional display? One possibility is that a functional display’s use of visual form to communicate flight principles should free up cognitive resources for greater reflection on the information being trained, which should in turn improve the amount and quality of knowledge available to transfer (Lintern et al, 1999, Smith, 2007).

Current Study

If functional display use does allow for improved acquisition and transfer of general flight knowledge, then novices flying a functional display prior to using a conventional display should show improved flight performance and knowledge compared to novices trained only on a conventional display. To evaluate whether performance and knowledge improvements acquired during Oz display use will transfer and provide significant benefit over training with a conventional flight display, four groups of novices were each trained on different sequences of displays.

One group was trained only on the Oz display, while another group was trained only on a conventional Cessna display. These groups provided baselines for comparison with each transfer condition. To estimate the potential of transfer from Oz to a conventional Cessna display, a third group was trained on the Oz display, and then
retrained on a conventional Cessna display. Finally, a fourth group began on a conventional display, and then transferred to the Oz display.

Following training on the specified display, novices performed a series of flight maneuvers that required either regular or minimal power management. Performance results and open-ended responses were captured to replicate and extend earlier findings (Smith et al., 2004, Smith and Boehm-Davis, 2005, and Smith, 2007). To better evaluate underlying system knowledge, concept mapping (Novak, 1990) was used.

Concept mapping (Novak, 1990) is a descriptive knowledge elicitation methodology that can capture quantitative changes in knowledge over time, as well as specify the areas in which knowledge changes. Concept mapping has several methodological advantages over the previously used forms of knowledge elicitation. First, concept mapping allows for greater detail of the underlying knowledge components. Open-ended questions (Christofferson, Vicente, and 1998; Smith and Boehm-Davis, 2005) provide an indirect assessment of underlying concepts; this can create limitations in what conclusions can be intuited from the data. For example, the open-ended evaluations used in Smith and Boehm-Davis (2005b) showed differences in content knowledge, but did not explicitly identify how or when this knowledge changed. To address this issue, this study elicited novice knowledge using concept maps (Novak, 1990) over the course of training.

Second, concept maps also provide specific measures of declarative and procedural knowledge that can be scoped to directly assess the underlying knowledge
structure of interest. Third, concept mapping allows for the measurement of trends in knowledge acquisition over time. As concept maps allow for detailed quantification of both what is known and how it is integrated, the quantification of concepts and relationships provides a robust method for measuring changes in the participants’ knowledge structure over the course of the session.

Finally, concept maps allow for the isolation and identification of specific areas of the knowledge structure which functional displays have most affected. For example, earlier examination of the Oz display (Smith and Boehm-Davis, 2005) indicated that novices using a functional display were better able to plan, predict, and identify the effect of power usage on flight behavior. The 2005 findings, however, only allow for observing a difference in overall accuracy. This does not identify the exact aspects of participants’ underlying knowledge that were altered during training with a specific display. Using concept maps, the exact areas of knowledge that are altered by functional display use can be isolated and identified. This allows a direct observation of the changes in the underlying knowledge structure during functional display use.

Given this approach, the following findings were hypothesized. First, novices initially trained only on the Oz display will show the greatest amount of power management knowledge and performance. Second, novices trained only on a conventional Cessna display will show the least knowledge and performance benefits related to power management overall. Finally, novices initially trained on the Oz display and then transferred to a conventional display will show greater knowledge and
performance benefits for power management over the course of the study than novices trained only on a conventional display.
METHOD

Participants.

Participants were 32 undergraduate students (20 males and 12 females), ranging in age from 18-34 years (M=20.6, SD=3.2). None of the participants had any prior flight training or piloting experience, including flight-based video games or simulations. All participants reported normal or corrected-to-normal vision, and none were colorblind. All participants were compensated with course credit and $90 for completion of the study.

Experimental Design.

A repeated-measures mixed design was used, with display presentation between subjects and trials as a within subject variable. A trial was defined as a set of 8 maneuvers (listed in Table 1). This yielded a 2 (Transfer/No Transfer) X 2(Conventional/Oz) X 6 (Trials) design. On the first and third trials, participants received verbal feedback from the experimenter during performance of the maneuvers (Table 2). On all other trials, no experimenter feedback was provided (Table 2). Of the 8 maneuvers performed, six required regular power management and two required minimal power management (Table 1).
Eighteen concept maps were collected for each participant, with three concept maps collected at six time points over the course of the experiment. Three concept maps were completed immediately after classroom training, but prior to any actual flight training, and then completed again after the third trial of the experiment. Another set of three concept maps were completed immediately after all flight sessions had been completed for a particular display (Table 3). Concept maps were presented for three maneuvers total; two maneuvers required regular power management (straight and level flight, and turning) and one maneuver did not require regular power maintenance (descending). After completion of the flight sessions, Post-tests, and concept maps, participants were retrained on either the same or the other display. The same procedure was repeated using the second display, as seen in Table 3.

Apparatus.

An Elite iGATE Personal Computer Aided Training Device (PCATD) driven by a PC running Microsoft Flight Simulator 2002 was used to simulate the flight environment. The simulator was configured to run as a Cessna 172D flying over the Dade County Airfield (KDCD). The OZ display was run by the same PC, and covered the six central dials of a conventional Cessna instrument panel (see Figure 1). Flight performance data produced by Microsoft Flight Simulator 2002 were broadcast on a local network to a second personal computer for data collection. A third personal computer was used for all pre-tests, post-tests, and concept maps. The TPL-KATS software used for the completion and analysis of concept maps was provided by University of Central Florida’s
Team Performance Laboratory (TPL, 2007). Prior to training, participants were given a demographic questionnaire and a packet of slides to follow during flight training.

Procedure.

After signing a consent form, participants were presented with a short questionnaire requesting demographic information. Once the questionnaire was completed, participants were seated in front of a computer monitor and presented with a printed packet of flight information excerpted from Microsoft Flight Simulator 2002’s Training Module. Participants then listened to a lecture detailing the basic principles of flight and an introduction to the instrument panel. Principles and maneuvers that were not readily understood by the participants were demonstrated by the flight instructor on the simulator. Following the training session, participants were presented with a short written pre-test (consisting of a mix of open-ended and completion questions), and were instructed on how to use the concept mapping software. For clarity, an example concept map was performed with the instructor. The time required to complete the each session was approximately two hours.

To begin the second training session, the participant was seated at the simulator and familiarized with its controls. When operating the conventional display, participants were presented with a reference power table for the simulated Cessna. Participants were then instructed to perform a series of maneuvers. Participants received specific instructions on the objective of each maneuver, and were told to fly as accurately as possible. As the maneuver was initiated, the experimenter manually marked the data
using a data harvester program developed on site. Each maneuver ended when the participant leveled off within 10 feet of the target altitude and 3 degrees of the target heading, or at the end of 2 minutes of flight time. After each maneuver was completed, the aircraft was adjusted by the experimenter to the position required for the next maneuver.

A complete “trial” consisted of a total of 8 maneuvers. After the first trial, participants were excused for a short break, followed by another trial of 8 maneuvers. Order of maneuvers was counterbalanced across participants and trials. For each trial involving experimenter feedback, the experimenter monitored the performance of the novice and offered in-session guidance based on the principles taught in the instruction session. To ensure consistency and avoid bias, guidance was limited to a series of phrases directly related to the material initially taught to the novices (Table 2). After the first trial of the second session (the midway point of the experiment, and the end of any instructor assistance), participants filled out a second concept map. After two sessions were completed, the following session was performed by the participant without assistance from the instructor. After the participant had completed all flight sessions, the final concept map was completed. Following the concept maps, participants were given a series of open-ended questions, where each question specifically requested an explanation of the procedures the participant followed to complete a given maneuver (See Appendices H & I for examples of post-tests for each display). Following the post-tests, participants were randomly assigned to a second display condition – either the same
display the participant had first trained on, or the display not initially used. The
procedure was then replicated for the second display, followed by a debriefing session.
RESULTS & DISCUSSION

Overview of Data Reported

Three types of data are reported – questionnaires, flight performance, and concept mapping results. Questionnaire and concept mapping measures were provided both pre and post flight to assess whether novices trained with the Oz display showed knowledge improvements. Pre-test questionnaires specifically measured participants’ understanding of the displays used and the procedures required for proper operation of the aircraft, while post-test questionnaires focused on proper operation of the aircraft and the effect of power on system performance. Concept mapping was used to assess and directly compare novice system knowledge to expert system knowledge across transfer conditions. Performance measures were used to assess whether novices trained on the Oz display showed significantly reduced flight technical error from the maneuver’s optimal flight path. Both questionnaires and performance data served as a replication and extension of earlier work that showed knowledge and performance benefits with functional display use (Smith and Boehm-Davis, 2005, Smith, 2007).

Pre-test Results

Pre-tests were provided to assess novice knowledge directly after classroom training but prior to performing flight maneuvers. As each novice was exposed to two
displays, each novice performed two pre-tests – once after flight training, but prior to any flight (referred to as Pre-Test 1), and again after the second classroom session, but prior to any flight with the second display (referred to as Pre-Test 2). The pre-tests were designed to assess two characteristics prior to flight training – first, how well could novices understand and identify the elements of the display, and second, how well did novices understand the correct application of power in system use. For both question types, answers were coded for correct/incorrect answers; differences were compared between display conditions using a univariate ANOVA. Differences in accuracy across Pre-tests 1 and 2 were compared using a series of paired sample t-tests.

The pre-test findings suggest several trends. First, the display used for training affected knowledge of the functional relationship prior to any flight training. A significant univariate ANOVA of Pre-test 1 answers $F(3, 28) = 4.58, p=.01$ indicated that novices trained on a Conventional display ($M=3.0, SD=1.93$) scored significantly lower on Pre-Test 1 than novices trained on the Oz display in the Oz-Conventional display condition ($M=5.75, SD=.55$), ($p<.01$), and marginally lower than the Oz-Oz condition ($M=5.125, SD=.55$) ($p=.07$) (Figure 2).

After six hours of flight, however, there were no significant differences in pre-test accuracy between the four display conditions for power-related questions. A paired samples t-test across transfer conditions indicated a significant increase in correct answers overall between times 1 and 2 ($M=-.84, SD=2.23$) $t(31) = -2.14, p=.04$. However, post-hoc analysis of the transfer conditions showed that the only significant

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performance improvements occurred in the Conventional-Conventional display condition between pre-tests 1 (M=3.0, SD=1.93) and 2 (M=5.63, SD=2.07) $t(7) = -4.93, p=.01$, with no other display conditions showing significant improvements between pre-tests. Though the result was not significant, the Oz-Conventional condition was the only condition to show a decrease in correct responses between the two pre-tests (Figure 2). This suggests the possibility of negative transfer of power knowledge upon initial exposure to the Oz display.

Second, conventional display use showed greater accuracy in identifying display elements, suggesting that the individual elements of the conventional display were easier for novices to correctly identify than the integrated elements of the Oz display. Novices trained in the Conventional-Conventional display condition correctly identified significantly more display elements than all other groups on pre-test 1: $t(25.8)=-2.58$, $p=.02$, and pre-test 2: $t(28)=-2.48$, $p=.02$ (Figure 3), suggesting that it is significantly easier to identify separate display elements on a conventional Cessna display than extract single elements from the series of highly integrated geometric forms used in the Oz display.

Six hours of flight experience generally improved novices’ ability to identify display elements on the display the novices used. In both conditions where participants retrained on the same display, there was a marginal improvement from pre-test 1 to pre-test 2 (Conventional-Conventional: Time 1, M=10.63, SD=1.50, Time 2, M=14.00, SD=4.28, $t(7) = -3.37$, $p=.07$), (Oz-Oz: Time 1, M=6.88, SD=3.98, Time 2, M=10.88, SD=3.98, $t(7) = -3.88$, $p=.01$).
SD=6.06) \( t(7) = -2.24, p=.06 \) (Figure 3). However, both conditions that involved transferring between displays (Oz-Conventional and Conventional-Oz) showed no significant improvements between Pre-test 1 and 2. Though it was not significant, only novices who initially flew a Conventional display and transferred to the Oz display showed a decrease in correct responses between pre-tests 1 and 2 (Figure 3). These results suggest that the visual integration of the Oz display not only makes initial identification of simple display elements more difficult than a conventional Cessna display, but may make identification initially more difficult for novices who have had some experience with another flight display.

Post-test Results.

As each novice had been exposed to each of the two displays, each performed two post-tests; once after all flight maneuvers had been performed for the first display (post-test 1), and again after all flight maneuvers had been performed for the second display (post-test 2). The post-test questionnaire focused explicitly on flight performance and the use of system power in flight, and measured the accuracy of participants’ open-ended responses for three question types: flight maneuvers, the effect of power on system performance, and predicting the future effect of power on system state.

For flight maneuvers, participants’ responses were compared to a hierarchical task analysis of the flight maneuvers as defined by two subject matter experts (See Appendix 8 –Task Analyses of Flight Maneuvers), and coded as either correct or incorrect based on comparison to expert responses. For describing and predicting the effect of power,
participants’ responses were compared to expert responses and coded for correct or incorrect answers.

**Flight maneuvers.** Evaluation of novice responses to flight maneuvers showed two notable findings. First, novices who trained on the Oz display (M=9.75, SD=3.11) were significantly more accurate on post-test 1 than novices trained on a Conventional display (M=6.81, SD=3.78) \( F(1,30) = 5.762, p<.02 \) (Figure 4). This replicates novice performance observed in previous studies, supporting the conclusion that Oz supports greater knowledge acquisition after 6 hours of flight time (Smith and Boehm-Davis, 2005, Smith, 2007). Second, for post-test 2, the Conventional-Conventional display condition scored marginally lower than all other display conditions \( t(28) = 1.93, p=.06 \) (Figure 4). No other significant effects were found. This suggests that use of the Oz display improves novice understanding of basic flight maneuvers beyond what is learned using only a conventional Cessna display.

**Describing the effects of power.** Two significant findings emerged from analysis of novice descriptions of power’s effect on flight. First, post-test 1 scores indicated that novices who were initially trained on the Oz display described the effects of power significantly more accurately than novices initially trained on a Conventional display \( F(1, 30) = 5.76, p<.02 \). This replicated prior results (Smith and Boehm-Davis, 2005) and suggested that the use of functional display properties in training improve novice understanding of the functional relationship. Second, Post-Test 2 scores indicated that novices trained only on a conventional display had significantly fewer correct answers
and novices who initially trained on the Oz display, and then transferred to a conventional display (M=2.75, SD=.71), (p<.04). Similar to the pre-test results noted earlier, the Oz-Conventional display condition was the only group to show a decrease in accuracy between post-tests 1 and 2 (Figure 5), though the change between sessions was not statistically significant. These results suggest that while training with the Oz display prior to flying a conventional display does show some negative transfer of training, the improvements in knowledge of power’s effect are still significantly greater than training with a conventional display alone.

Predicting the Effects of Power. Two significant findings emerged from analysis of novices’ prediction. First, novices trained on the Oz display showed greater accuracy for predicting the effect of power than novices trained on a Conventional display at Post-Test 1 \( t(30) = 8.51, p=.01 \). This finding replicates the effects of Smith and Boehm-Davis (2005), indicating that novices trained on the Oz display are better able to predict the effect of power on future system state.

Second, post-hoc analysis of Post-Test 2 indicated that the average correct answers for novices trained only on Oz (M= 8.5, SD=.76) were significantly higher than the average correct answers in the Oz-Conventional transfer condition (M=4.75, SD=2.55) (p<.01), and the Conventional-Conventional transfer condition (M=5.38, SD=.71), (p<.05) (Figure 6). All display conditions showed significant increases in accuracy, except for Oz-Conventional. Similar to both the pre-tests and describing the
effects of power, only the Oz-Conventional display condition showed a decrease in accuracy between time 1 and 2, though this difference was not statistically significant (Figure 6). This suggests that the benefits observed for prediction may be tied to the display used. When using the Oz display, novices showed improved accuracy on prediction tasks. However, when the same novices who showed improved prediction with Oz shifted to a conventional display, their accuracy was nearly identical to novices who trained only on a conventional display (Figure 6). Conversely, novices who showed lower performance with the conventional display improved once transferred to the Oz display. Unlike the other post-test measures, improvements for prediction appear to be tied to the display used, and do not effectively transfer from functional (Oz) display to conventional display use.

Performance results

Performance results are designed to explicitly measure piloting skill on real-world flight maneuvers. Performance was evaluated by comparing flight performance against the optimal flight path for a given maneuver. The deviations from the flight path and optimal flight settings will be referred to as flight technical error (FTE). FTE was calculated for four aspects of each flight maneuver – power settings, airspeed, altitude, and heading – by measuring the root mean squared error from optimal settings/path for each flight maneuver. The potential of functional displays to serve as a training device was evaluated by comparing the FTE in novice performance across three display transfer conditions: Oz-Oz compared to Conventional-Conventional, Oz-Conventional compared
to Conventional-Conventional, and Oz-Oz compared to Oz-Conventional. For each of these 3 comparisons, performance was compared on the final trial of each maneuver using a one-way ANOVA. Tables 4, 5, and 6 indicate which conditions had more accurate performance; F values and p values are included when the differences are significant (p<.05).

Comparison of Oz-Oz to Conventional-Conventional. The goal of comparing flight performance with Oz to conventional display performance is to replicate and extend earlier work (Smith and Boehm-Davis, 2005) that showed more accurate performance with the Oz display. Several insights emerged from the flight performance data. First, novices trained on the Oz display showed significantly less FTE across all maneuvers and flight measures. Of the 32 available measures (8 maneuvers x 4 measures), novices trained on the Oz display showed reliably less FTE (p<.05) on 17 (53%), and less FTE on 29 of the 32 maneuvers overall (91%) (Table 4). In contrast, novices trained only on the conventional display showed less FTE than novices trained on the Oz display alone for only 3 measures (9%), and were not significantly different on any of the three measures. A sign test indicated that novices trained only on the Oz display were more frequently accurate than novices trained on a conventional display alone (p<.01). These findings suggest that flight performance with the Oz display is significantly more accurate across all maneuvers than performance with a conventional flight display. This both extends and replicates Smith and Boehm-Davis’ (2005) results,
showing that the performance benefits previously observed with Oz display use were not diminished as a function of additional experience.

Second, novices trained on Oz were always more accurate in controlling both power and airspeed than novices trained on the Conventional display. Novices trained on Oz showed significantly less FTE from optimal power settings compared to novices on a conventional display for 3 of 8 maneuvers (37%), and were more accurate on all maneuvers. In comparison, novices using the Conventional display never showed less FTE for power than novices trained on Oz (Table 4). Similarly, five of the eight maneuvers (63%) performed showed a significant (p<.05) benefit in airspeed control for novices trained on Oz (two other maneuvers reported p<.06; if these two are included, 88% of all maneuvers showed a performance benefit for the Oz display) (Table 4). Viewed together, this finding suggests that functional display use significantly improves control of the variables displayed in the functional relationship.

Finally, novices trained on the Oz display showed significantly less FTE for the control of both altitude and heading. Novices trained on the Oz display showed significantly less altitude FTE for 5 of 8 maneuvers (63%), with novices trained on a conventional display showing more accurate flight performance on only one maneuver. A similar pattern was observed with FTE for heading, as novices trained on the Oz display showed significantly less FTE than novices trained on a conventional display in 4 of 8 maneuvers (50%) (Table 4). In comparison, novices trained on a conventional display were more accurate on heading on 2 of 8 maneuvers, though neither difference
was statistically significant. The finding of improved control for altitude and heading may be tied to using a graphically integrated display (emergent features), greater accuracy through improved maintenance of power, or a combination of both factors.

*Comparison of Oz-Oz to Oz-Conventional.* The goal of comparing novices trained only on the Oz display against novices trained on Oz and then transferred to a conventional flight display is to evaluate whether novices trained on Oz retain their accuracy in performance when flying a conventional display. Several trends emerged when comparing the conditions. First, novices using only the Oz display were significantly more accurate than novices who transferred from Oz to a conventional display on 9 of 32 maneuvers (28%). Though not statistically significant, novices trained on the Oz display alone also showed less FTE on 16 of the 32 total measures (50%). A sign test indicated that novices who transferred from Oz to Conventional were not significantly more or less frequent than novices trained only on the Oz display. Given that novices who trained only the Oz display showed less FTE on 91% of the maneuvers compared to novices trained on a conventional display, the lower rate of improved performance when comparing the Oz display to novices who transferred to a conventional display (50%) suggests that novices who transferred to a conventional display after using the Oz display do retain some of the skill acquired during Oz display use.

Second, novices who trained on the Oz display were generally more accurate in controlling both power and airspeed than novices trained on the Conventional display.
When compared to novices who transferred from Oz to a conventional display, novices trained only on Oz showed significantly less FTE from optimal power settings on two of the eight maneuvers (25%), and were more accurate on six of eight maneuvers (75%) (Table 5). Airspeed showed a similar pattern, with four of the eight maneuvers (50%) showing a significant (p<.05) benefit in airspeed control for novices trained only on Oz (Table 5). Together, the findings indicate that novices who transferred to a conventional display did not maintain the same skill level for management of power and airspeed as novices who continued training with the Oz display.

Third, novices who transferred to a conventional display showed greater accuracy for altitude control and comparable heading accuracy compared to novices who trained only on the Oz display (Table 5). Novices who transferred to a conventional display showed less FTE for altitude on 7 of 8 flight maneuvers (88%), though only one of flight maneuvers was statistically significant. Novices who transferred to a conventional display also performed comparably on heading; novices trained only on Oz had significantly less FTE for heading on only two out of eight maneuvers (25%), and both groups showed less FTE on four maneuvers each.

Taken together, the comparison results indicate that skills gained via functional display use may be retained when a novice transfers to a new display. Furthermore, it appears that novice ability to control the aircraft may actually be improved after use of a functional display.
Comparison of Oz-Conventional and Conventional-Conventional. The most important question of this study is whether prior training on the Oz display improves flight performance with a conventional display. By comparing novices who transferred from Oz to a conventional display against novices who only used the conventional display, the effectiveness of the Oz display as a training tool for flight performance can be assessed. Several insights emerged from comparing the display conditions. First, novices who transferred to the conventional display were more accurate overall than novices that only trained on the Conventional display. Of the 32 flight measures, novices who trained on the conventional display showed significantly less FTE on 16 of the 32 measures (50%), and less FTE on 24 of the 32 maneuvers overall (75%). Novices who trained on a conventional display had significantly less FTE on only one measure (3%), and less FTE on a total of eight measures (25%)(Table 6). A sign test indicated that novices trained first on the Oz display were more frequently accurate than novices trained on a conventional display alone (p<.01).

Second, novices who transferred to a conventional display showed better control of power and airspeed than novices who only trained on a conventional display. Novices who transferred to a conventional display showed significantly less FTE for power on two maneuvers (25%), as well as less flight technical error on six of the eight maneuvers overall (75%). Airspeed showed a stronger trend, with novices that transferred to a conventional display showing significantly less FTE for airspeed on four of the eight maneuvers (50%), and less FTE on six of the eight maneuvers overall (75%) (Table 6).
Third, novices transferring to a conventional display condition showed significantly more accurate performance for controlling altitude and heading. Novices who transferred from Oz to a conventional display showed significantly less FTE for altitude on six of the eight flight maneuvers (75%). For heading, novices transferring from the Oz display to conventional showed significantly less FTE for four of eight maneuvers, while novices trained only on conventional showed significantly less FTE than the Oz display on only one maneuver (Table 6). Taken together, the findings indicate that novices trained first on a functional display show significant improvements for all aspects of flight over novices who have trained only on a conventional display.

**Concept mapping**

Concept mapping measures the knowledge structure of participants; unlike open-ended questions, concept mapping allows us to directly view the relationships between various concepts (Novak, 1990). This visualization of how concepts are related also allows comparison of expert and novice models to assess novice knowledge in relation to a knowledge standard (Figure 7). The goal of using concept mapping in this study is to assess novice piloting knowledge by comparing the knowledge structures of novices against a knowledge standard - in this case, a concept map of expert flight knowledge (Harper, Hoeft, Evans, & Jentsch, 2007). This comparison allows the quantification of novice knowledge, which can then be compared across various display conditions (Coffey, Carnot, Feltovich, Feltovich, Hoffman, Cañas, and Novak, 2003). Furthermore, concept mapping can be used to isolate and examine specific areas of knowledge.
structures – for example, knowledge related only to the functional relationship can be isolated and compared to evaluate knowledge differences. Therefore, concept mapping will be used to evaluate (1) changes in total system knowledge between display conditions and (2) changes in knowledge related to the functional relationship of power and airspeed.

To evaluate novices’ knowledge, participant responses were coded using the link comparison technique (Evans, Kochan, & Jentsch, 2003). This is a relational technique, which compares a master concept map (created by three flight instructors), to the novice’s concept map. This method has been used previously to evaluate similarities between experts and novices (Evans, Kochan, & Jentsch, 2003; Smith-Jentsch et al, 2001). The link comparison method uses a dichotomous scoring system. If a novice connects two concepts that were also connected by the expert(s), then the novice is assigned a score of 1 (agreement with the expert). Alternately, if (1) the novice connects two concepts that were not connected on the master concept map, or (2) the novice does not connect two concepts that were connected on the master scoring map, the novice is assigned a score of 0. Using this coding system, a score of 1 or 0 is obtained for each possible connection.

The agreement between expert and novice can then be calculated as a percentage overlap score between the expert concept map and the individual novice concept map. The scores for each individual maneuver can also be summed by participant and the average agreement compared across training conditions. Novices completed concept
maps for three maneuvers – ascending, banking (both of which require the input of power and are directly communicated by the Oz display), and descending (during this maneuver, the Oz display does not provide input). Performance results were analyzed for each maneuver using repeated measures ANOVA. Results are reported for two aspects of novice knowledge - total agreement and a subset of agreement for power use.

Several general insights should be emphasized from the concept mapping results. First, Oz display use improved knowledge of power use for maneuvers that required power input more than any other display regiment. In both cases, continuous use of a conventional display led to the lowest understanding of the power relationship. This is especially impressive given the low number of available connections for the power subset. Second, novices who only used the Oz display produced the greatest understanding of total system than any other condition, while novices trained only on the Conventional display showed the lowest amount of system knowledge. Finally, it should be noted that no knowledge differences were observed for the descending maneuver, which does not directly leverage the functional relationship of power and airspeed when performing the maneuver.

Expert agreement for power items.

Ascending. No significant effect of display was observed, although the lack of an effect is likely due to the large variance observed between participants. A significant effect for trials was observed $F(2, 36) = 4.84, p=.04$, with higher expert agreement
observed over time suggesting that all groups did increase in knowledge over the course of the trials.

*Turning.* A significant main effect for display was observed $F(1, 18) = 6.19$, $p=.02$, indicating that average expert agreement was significantly higher for novices in the Oz only condition ($M=25.3\%, SD=7.3\%$) than novices trained in the conventional only condition ($M=14.6\%, SD=6\%$). Post-hoc analysis of the final trial showed that participants in the Oz only condition scored marginally higher than those in all other display conditions $t(17.76) = 1.88$, $p=.07$ (Figure 7). There were no significant differences between trials.

*Descending.* No significant differences for display or trial were observed for expert agreement for power while descending.

*Expert agreement for system items.*

*Ascending.* A significant main effect of display was observed $F(1, 18) = 8.97$, $p=.01$. Post hoc analysis indicated that average expert agreement on the total system was marginally higher overall for novices trained in the Oz-Oz display condition ($M=16\%, SD=7\%$) than novices trained in the conventional only condition ($M=8\%, SD=6\%$) $t(14)=.0328$, $p=.07$. Post-hoc analysis on the final trial, however, indicated no significant differences between display conditions. This was likely due to high variability in individual agreement scores, as the averaged group scores reflected a pattern similar to the system agreement results observed for the turning maneuvers. There was no significant main effect for trials.
Turning. A significant main effect for display was observed $F(1, 18) = 26.3$, $p=.00$. Post-hoc analysis indicated that average expert agreement was significantly higher for novices trained in the Oz-Oz display condition ($M=13.5\%, SD=5.7\%)$ than novices trained in the Conventional-Conventional display condition ($M=4.7\%, SD=4\%$) $t(15) = .094, p=.01$. The Conventional-Conventional display condition scored significantly lower than all other display conditions $t(22.22)=-3.30,p=.00$ (Figure 8).

Descending. No significant differences were observed between display conditions.
CONCLUSION

This paper argues that the presentation of functional information on a flight display should not only support greater knowledge acquisition compared to using a display with non-functional graphics, but may support the transfer of newly acquired knowledge to a flight display with non-functional display properties. To evaluate this claim, novice knowledge and performance were compared across three training regimens: training only on a display with some functional properties (Oz), training using a display that presents physical information (a conventional Cessna display), or training on a functional display (Oz) prior to using a conventional Cessna flight display. Two research questions were proposed. Would a functional (Oz) display show greater knowledge and performance benefits than novices trained on a conventional display alone? Would novices trained on a functional (Oz) display prior to being trained on a physical (conventional) display show significantly greater knowledge and performance than novices trained only on a physical (conventional Cessna) display?

Data suggests that novices trained on a display with functional properties show significantly more accurate knowledge and performance for power management than novices trained only on a conventional display. Analysis of performance and knowledge data showed significantly higher scores for novices trained exclusively on the Oz display.
than novices trained only on a conventional display. Novices trained only on the Oz display generally showed the highest overall scores on both knowledge tests and concept maps for power management, often scoring significantly higher than all other training conditions. This effect was also observed for overall system understanding, as novices trained only on Oz were better able to describe total system interactions for a specified flight maneuver and showed higher concept map agreement scores for overall system.

In contrast, novices trained only on a conventional display often showed the lowest performance of all training conditions, with significantly lower overall performance on both knowledge tests and concept maps than novices trained only on the Oz display. Performance results reflected the pattern observed in the knowledge tests and concept maps, as novices trained only on the Oz display showed significantly more accurate performance across most flight maneuvers (Table 4). Taken as a whole, the results suggest that novices trained exclusively on the Oz display had (1) a significantly greater knowledge of the functional relationship than novices trained only on a conventional display, (2) a greater understanding of the flight system overall than novices trained only on a conventional display, and (3) significantly more accurate performance on flight tasks in general.

Novices trained on a functional (Oz) display prior to being trained on a physical (conventional) display also showed significantly greater knowledge and performance results than novices trained only on a physical (conventional) display. Several results suggest that training on the Oz display provided positive transfer of training to flying the
conventional display. First, novices trained in the Oz-Conventional display condition were significantly better at describing the relationship between power and the rest of the system, and were marginally better at describing the use of power in the context of specific flight maneuvers. Novices trained on the Oz display generally showed higher scores for the functional relationship on most concept maps, though the variability between scores/lack of power for detecting differences with concept maps makes this relationship more difficult to illustrate statistically than the knowledge tests.

Performance results indicate a similar pattern, with novices trained first on the Oz display showing significantly improved performance for power management and airspeed for several flight tasks. Though many of the tasks were not statistically different, novices trained only on a Conventional Cessna display never performed significantly better than novices who transferred from the Oz display to a conventional display on any of the maneuvers (Table 7). Novices who trained with the Oz display prior to transferring to the conventional display showed significantly better power management on two maneuvers, and significantly more accurate control of airspeed on four of the eight possible maneuvers (all other maneuvers did not show significant differences between the two display conditions – See Table 7).

The result of improved power management, however, should also manifest itself in the control of the aircraft’s position. In comparing the performance of the Oz-Conventional condition and Conventional-Conventional condition against the Oz-Oz condition for control of heading and altitude, a striking difference emerges. For altitude,
novices trained on the Conventional display alone performed less accurately than novices trained only on the Oz display on 7 of 8 possible flight tasks (Table 6). In comparison, novices trained on the Oz display before transitioning to the conventional display showed no differences from the Oz display on controlling the aircraft for altitude, and even showed significantly better performance than the Oz display for descending. A similar pattern was also observed for heading, with novices transferring to a conventional display only differing twice from the Oz display for control of heading. These results suggest that positive transfer of training did occur for novices trained on a functional display prior to beginning training on a conventional flight display.

The combination of knowledge and performance results observed in this study support both hypotheses, indicating that the performance and knowledge improvements acquired during use of a functional (Oz) flight display will transfer to a conventional flight display. This suggests that use of the Oz display as a training device may support more efficient knowledge acquisition and improved flight performance over the course of a training program. The use of functional relationships as an effective method in flight has been argued for previously (Hutchins, 1995, Lintern et al., 1999, Dinadis & Vicente, 1999); this study extends this conclusion to show that benefits gained by using functional metaphors not only benefit the user, but also promote the transfer of flight knowledge to displays that may not possess the same functional or graphical properties.

Additional evidence suggests that the improvements in knowledge may extend to diagnosis of system faults. At the end of all sessions, participants performed an
additional trial of straight and level flight with an induced engine failure. Participants were asked if they noticed any difference in flight performance, and if so, to identify the cause of the difference. All novices who had trained only with the Oz display correctly diagnosed that the engine lacked sufficient power. Similarly, 7 of 8 novices who transferred from the Oz to the conventional display correctly diagnosed a lack of power. In comparison, only 1 of the 9 novices trained on just a conventional display was able to correctly identify a lack of power as the cause. This suggests that presenting a more transparent interface may not only lead to improved knowledge, but support more accurate diagnosis of issues relating to the functional relationship displayed. However, further research will be needed to further investigate this finding.

These results make a strong argument for the implementation of functional properties in aviation as a training device. However, some caveats should be noted to the application of functional design principles. First, the additional information on an aviation display increases the complexity and potential for information overload. For example, novices were always better at identifying display elements on a functional display, even after extended flight with the Oz display. This suggests that the additional complexity that the display presented did inhibit identification of display elements. Second, a functional display could potentially diminish aspects of flight performance if display features were not presented in a similarly compelling fashion. For example, the Oz display presents a highly integrated, central view of power, airspeed, and the horizon line, while the measurements for altitude and heading are presented in the periphery (both
appear at the sides of the X and Y axis, respectively). Performance improvements have been consistently observed for power, airspeed, and pitch, while heading has not shown improvements across a number of studies (Smith, Boehm-Davis, & Chong, 2004, Smith and Boehm-Davis, 2005, Smith, Boehm-Davis, and Fadden, 2005). This suggests that the separation of heading outside of the emphasized functional area may inhibit regular maintenance of heading compared to training with a conventional display. These results underscore the potential dangers of emphasizing one display feature to the detriment of other display elements. Given that flight requires a pilot to perform a series of multiple interleaved tasks, the challenge for designers is to create a design that communicates functional properties while similarly supporting multiple tasks. This will require a parsimonious organization of functional relationships in the context of the multiple demands placed on the operator, rather than the simple addition of greater amounts of functional information. The strength of functional design will be in the structured application of functional properties consistent with an analysis based approach of functional opportunities within the constraints of the environment.

Further, the benefits of functional display must be tempered against what there currently is still unknown. More longitudinal research must be conducted to determine the long-term effect of functional display use in aviation. Having shown repeated trends of improvements in novice pilots, it seems appropriate to begin evaluating whether functional display use can reduce the overall number of trials required to attain competency, similar to Taylor et al. (2005). Further research, then, should evaluate
whether the improvements tied to Oz display use actually reduce the number of trial required to attain competency on a conventional display over the course of private pilot training.

Finally, this line of research should be extended to more externally valid aspects of flight. This research has shown additional benefits for the tasks of flight control, but does not provide additional insight into functional display’s effect on multi-task performance that is necessary for flight. While this line of research has shown the efficacy of flight displays for simple aviation tasks, the use of visual metaphor for training purposes could be expanded to more complex maneuvers for more externally valid purposes. By applying the display design principles detailed in this and other studies, future flight training programs could become more effective and efficient overall.
Table 1. Maneuvers performed by participants.

<table>
<thead>
<tr>
<th>Power Requirement</th>
<th>Maneuver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular Power Management</td>
<td>Maintain Airspeed in Straight and Level Flight</td>
</tr>
<tr>
<td></td>
<td>Ascend 1000ft at 500 fpm</td>
</tr>
<tr>
<td></td>
<td>Slow Flight: Straight and level at 60 knots.</td>
</tr>
<tr>
<td></td>
<td>Slow Flight while Ascending: Participants climb at 500 fpm while maintaining 60 knots.</td>
</tr>
<tr>
<td></td>
<td>Banking (Standard Rate Turn): 360 degree standard rate turn.</td>
</tr>
<tr>
<td></td>
<td>Ascend 1000 Ft., Bank Left/Right 360 Degrees</td>
</tr>
<tr>
<td>Minimal Power Management</td>
<td>Descend 1000 Ft at 500 FPM.</td>
</tr>
<tr>
<td></td>
<td>Increase Speed from 85-110</td>
</tr>
</tbody>
</table>
Table 2. Feedback given to novices during performance maneuvers.

<table>
<thead>
<tr>
<th>Situation</th>
<th>Experimenter Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overpowered</td>
<td>“You are overpowered. Reduce power with your throttle.”</td>
</tr>
<tr>
<td>Underpowered</td>
<td>“You are underpowered. Increase power with your throttle.”</td>
</tr>
<tr>
<td>Above Altitude</td>
<td>“You are above the required altitude. Lower your altitude.”</td>
</tr>
<tr>
<td>Below Altitude</td>
<td>“You are below the required altitude. Increase your altitude.”</td>
</tr>
<tr>
<td>Overspeed</td>
<td>“Your speed is too fast. Reduce your speed.”</td>
</tr>
<tr>
<td>Underspeed</td>
<td>“Your speed is too slow. Increase your speed.”</td>
</tr>
<tr>
<td>Past Heading</td>
<td>“You are past the required heading. Return to a heading of ___.”</td>
</tr>
<tr>
<td>Not at Heading</td>
<td>“You are not yet to the required heading. Return to a heading of ___.”</td>
</tr>
<tr>
<td>Banked more than 15 Degrees</td>
<td>“Your bank angle is too great. Reduce your bank angle.”</td>
</tr>
<tr>
<td>Banked less than 15 Degrees</td>
<td>“Your bank angle is too little. Increase your bank angle.”</td>
</tr>
</tbody>
</table>
Table 3. Example testing process for each participant.

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Classroom Training 1</td>
</tr>
<tr>
<td>2.</td>
<td>Pre-Test 1</td>
</tr>
<tr>
<td>3.</td>
<td>Concept Map 1</td>
</tr>
<tr>
<td>4.</td>
<td>Flight Trials 1-3 (Experimenter Feedback on Trials 1 &amp; 3)</td>
</tr>
<tr>
<td>5.</td>
<td>Concept Map 2</td>
</tr>
<tr>
<td>6.</td>
<td>Flight Trials 4-6 (No Experimenter Feedback)</td>
</tr>
<tr>
<td>7.</td>
<td>Post-Test 1</td>
</tr>
<tr>
<td>8.</td>
<td>Concept Map 3</td>
</tr>
<tr>
<td>9.</td>
<td>Classroom Training 2 (Same or Different Display per Condition)</td>
</tr>
<tr>
<td>10.</td>
<td>Pre-Test 2</td>
</tr>
<tr>
<td>11.</td>
<td>Concept Map 4</td>
</tr>
<tr>
<td>12.</td>
<td>Flight Trials 1-3 (Experimenter Feedback on Trials 1 &amp; 3)</td>
</tr>
<tr>
<td>13.</td>
<td>Concept Map 5</td>
</tr>
<tr>
<td>14.</td>
<td>Flight Trials 4-6 (No Experimenter Feedback)</td>
</tr>
<tr>
<td>15.</td>
<td>Post-Test 2</td>
</tr>
<tr>
<td>16.</td>
<td>Concept Map 6</td>
</tr>
<tr>
<td>17.</td>
<td>Study Completed</td>
</tr>
</tbody>
</table>

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Table 4. Comparison of Oz-Oz (O-O) to Conventional-Conventional (C-C).
Significant results at $p<.05$ are indicated by * and name of the display condition with significantly less error. Measurements that indicated a performance benefit for C-C are highlighted in blue.

<table>
<thead>
<tr>
<th>Maneuvers</th>
<th>Power</th>
<th>Airspeed</th>
<th>Altitude</th>
<th>Heading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight and Level</td>
<td>O-O, $p=.01^*$</td>
<td>O-O, $p=.01^*$</td>
<td>O-O, $p=.07$</td>
<td>O-O</td>
</tr>
<tr>
<td>Slow Flight</td>
<td>O-O</td>
<td>O-O, $p=.06$</td>
<td>O-O, $p=.01^*$</td>
<td>O-O, $p=.01^*$</td>
</tr>
<tr>
<td>Ascending</td>
<td>O-O</td>
<td>O-O, $p=.01^*$</td>
<td>O-O, $p=.01^*$</td>
<td>C-C</td>
</tr>
<tr>
<td>Slow Flight Ascending</td>
<td>O-O</td>
<td>O-O, $p=.06$</td>
<td>O-O, $p=.01^*$</td>
<td>O-O, $p=.01^*$</td>
</tr>
<tr>
<td>Banking</td>
<td>O-O</td>
<td>O-O</td>
<td>C-C</td>
<td>O-O</td>
</tr>
<tr>
<td>Banking and Ascending</td>
<td>O-O, $p=.04^*$</td>
<td>O-O, $p=.02^*$</td>
<td>O-O</td>
<td>C-C</td>
</tr>
<tr>
<td>Increase Airspeed</td>
<td>O-O, $p=.01^*$</td>
<td>O-O, $p=.05^*$</td>
<td>O-O, $p=.01^*$</td>
<td>O-O, $p=.01^*$</td>
</tr>
<tr>
<td>Descend</td>
<td>O-O, $p=.01^*$</td>
<td>O-O, $p=.02^*$</td>
<td>O-O, $p=.03^*$</td>
<td>O-O, $p=.01^*$</td>
</tr>
</tbody>
</table>
Table 5. Comparison of Oz-Oz (O-O) to Oz-Conventional (O-C).

Significant results at p<.05 are indicated by * and name of the display condition with less error. Measurements that indicated a performance benefit for O-C are highlighted in blue.

<table>
<thead>
<tr>
<th>Maneuvers</th>
<th>FTE</th>
<th>Power</th>
<th>Airspeed</th>
<th>Altitude</th>
<th>Heading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight and Level</td>
<td></td>
<td>O-O</td>
<td>O-O</td>
<td>O-C</td>
<td>O-C</td>
</tr>
<tr>
<td>Slow Flight Ascending</td>
<td></td>
<td>O-O</td>
<td>O-O, p=.02*</td>
<td>O-C</td>
<td>O-O, p=.01*</td>
</tr>
<tr>
<td>Banking and Ascending</td>
<td></td>
<td>O-O, p=.01*</td>
<td>O-O, p=.04*</td>
<td>O-C</td>
<td>O-C</td>
</tr>
<tr>
<td>Increase Airspeed</td>
<td></td>
<td>O-C</td>
<td>O-C</td>
<td>O-O</td>
<td>O-O</td>
</tr>
<tr>
<td>Descend</td>
<td></td>
<td>O-O, p=.01*</td>
<td>O-O, p=.04*</td>
<td>O-C, p=.04*</td>
<td>O-C</td>
</tr>
</tbody>
</table>
Table 6. Comparison of Oz-Conventional (O-C) and Conventional-Conventional (C-C).

Significant results at p<.05 are indicated by * and name of the display condition with less error. Measurements that indicated a performance benefit for C-C are highlighted in blue.

<table>
<thead>
<tr>
<th>Maneuvers</th>
<th>Power</th>
<th>Airspeed</th>
<th>Altitude</th>
<th>Heading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight and Level</td>
<td>O-C, p=.01*</td>
<td>O-C, p=.01*</td>
<td>O-C, p=.02*</td>
<td>O-C, p=.04*</td>
</tr>
<tr>
<td>Slow Flight Ascending</td>
<td>C-C</td>
<td>O-C, p=.01*</td>
<td>O-C, p=.01*</td>
<td></td>
</tr>
<tr>
<td>Slow Flight</td>
<td>O-C</td>
<td>C-C</td>
<td>O-C, p=.01*</td>
<td></td>
</tr>
<tr>
<td>Banking</td>
<td>O-C</td>
<td>O-C, p=.03*</td>
<td>O-C</td>
<td>C-C, p=.01*</td>
</tr>
<tr>
<td>Banking and Ascending</td>
<td>C-C</td>
<td>O-C</td>
<td>C-C</td>
<td></td>
</tr>
<tr>
<td>Increase Airspeed</td>
<td>O-C, p=.01*</td>
<td>O-C, p=.01*</td>
<td>O-C, p=.01*</td>
<td>O-C, p=.04*</td>
</tr>
<tr>
<td>Descend</td>
<td>O-C</td>
<td>O-C</td>
<td>O-C, p=.01*</td>
<td>O-C, p=.01*</td>
</tr>
</tbody>
</table>
Figure 1. The Oz Display overlaid on a Cessna 172 display.
Figure 2. Pre-test - average correct response to power related questions by display condition
Figure 3. Pre-test – Average correct response to display questions by display condition.
Figure 4. Post-Test – Average correct responses for power use within tasks by display condition
Figure 5. Post-Test – Average correct responses for power’s relation to system in performing specific tasks by display condition
Figure 6. – Post-Test - Average correct responses for the prediction of power’s effect on system performance by display condition
Figure 7. – Expert template concept map, used for novice concept map comparison. Propositions related to the functional relationship are highlighted in red.
Figure 8 – Novice agreement with expert concept map of power use for turning
Figure 9. Novice agreement with expert concept map of system use for turning
APPENDIX 1: PILOT STUDY PURPOSE AND METHOD

Purpose

The purpose of the pilot study was twofold: first, the pilot study was used to establish the effectiveness of concept mapping for measuring knowledge changes in relation to the proposed flight tasks. Second, the study evaluated whether knowledge differences between the two display training conditions were large enough to reliably compare using the concept mapping methodology.

Method

To assess the specific ways in which a functional display affects novice flight performance, Study 1 replicated the experimental design used in Smith and Boehm-Davis (2005) with a suite of more sensitive tasks. Participants were trained on either a conventional Cessna display (physical information only) or the Oz display (Physical and Functional information) overlaid on the Cessna display. Between several sessions, novices completed concept maps to assess changes in their knowledge structure.

Participants

Participants consisted of twenty undergraduate students (from George Mason University. Twenty students (10 males and 10 females) participated, ranging from 18-40 years old. None of the participants reported any prior flight training or piloting experience. Participants were recruited from the George Mason University psychology subject pool, and were compensated for
their participation with course credit and $30. All participants reported normal or corrected-to-normal vision, and no participants reported being colorblind.

**Apparatus**

An Elite iGATE Personal Computer Aided Training Device (PCATD) driven by a PC running Microsoft Flight Simulator 2002 was used to simulate the flight environment. The simulator was configured to run as a Cessna 172D flying over the Dade County Airfield (KDCD). The OZ display was run by the same PC, and cover the central six dials of a conventional Cessna instrument panel (see Figure 1). Flight performance data produced by Microsoft Flight Simulator 2002 was broadcast on a local network to a second personal computer for data collection. A third personal computer was used for all pre-tests, post-tests, and concept maps. The TPL-KATS software used for the completion and analysis of concept maps was provided by University of Central Florida’s Team Performance Laboratory. Prior to training, participants were given a demographic questionnaire and a packet of slides to follow along with during flight training.

**Experimental Design**

A 2 (Conventional/OZ display) X 6 (Trials) X 8 (Maneuvers) repeated-measures mixed design was used, with display between subjects, and trials and maneuvers as within subject variables (See Appendix 5 – Experimental Design for Study 1). A Trial was defined as a set of 8 maneuvers, with one session consisting of 2 trials. Trials were administered across 3 sessions. In the first trial for each of the first 2 sessions, participants received feedback from the experimenter during performance of the maneuvers. For the final flight session, all trials were performed without feedback.
Concept maps were collected three times. The first concept map was presented directly after classroom training, but prior to the first session (prior to flight). The second concept map was performed during the third session (the mid-point of the experiment), while the third concept map was completed at the end of the final session (after all flight has been completed).

**Procedures**

After signing a consent form, participants were presented with a short questionnaire requesting demographic information. Once the questionnaire was completed, participants was seated in front of a computer monitor and presented with a printed packet of flight information excerpted from Microsoft Flight Simulator 2002’s Training Module. Participants then listened to a lecture detailing the basic principles of flight and an introduction to the instrument panel. Principles and maneuvers that were not readily understood by the participants were demonstrated by the flight instructor on the simulator. Following the training session, participants were presented with a short written pre-test (consisting of a mix of open-ended and completion questions), and were instructed on how to use the concept mapping software. For clarity, an example concept map was performed with the instructor. The time required to complete the each session was approximately two hours.

To begin the second training session, the participant was seated at the simulator and familiarized with its controls. When operating the conventional display, participants were presented with a reference power table for the simulated Cessna. Participants were then instructed to perform a series of maneuvers. Participants received specific instructions on the objective of each maneuver, and were told to fly as accurately as possible. As the maneuver was initiated, the experimenter manually marked the data using a data harvester program developed
on site. Each maneuver ended when the participant leveled off within 10 feet of the target altitude and 3 degrees of the target heading. After each maneuver was completed, the aircraft was adjusted by the experimenter to the position required for the next maneuver.

A complete “trial” consisted of a total of 8 maneuvers. After the first trial, participants were excused for a short break, followed by another trial of 8 maneuvers. Maneuvers were counterbalanced across participants and trials. For each trial involving experimenter feedback, the experimenter monitored the performance of the novice and offered in-session guidance based on the principles taught in the instruction session. To ensure consistency and avoid bias, guidance was limited to a series of phrases directly related to the material initially taught to the novices (See Table 4).

After the first trial of the second session (the midway point of the experiment, and the end of any instructor assistance), participants filled out a second concept map. After two sessions were completed, the following session was performed by the participant without assistance from the instructor. Once the participant had completed all flight sessions, the final concept map was completed. Following the concept maps, a series of open-ended questions were provided, with each question specifically requesting an explanation of the procedures the participant followed to complete a given maneuver (See Appendix 11-12 for examples of the post-tests for each display). Once the post-test was completed, the participant was debriefed and excused from the experiment.
APPENDIX 2: PILOT STUDY PRE & POST-TESTS

Purpose

Pre-Test results were used to probe novice knowledge directly following classroom training. Post-Test results were used to evaluate novice knowledge following all flight sessions. Pre and Post-Test results were both used to compare differences in knowledge test performance between the two display types. As a secondary goal, the pre and post-test results were used to validate the results observed in Smith and Boehm-Davis (2005).

Pre-Test Results.

Pre-tests were coded for correct or incorrect answers, and totaled across participants. Differences in average number of correct answers were then compared across display conditions using a t-test. No significant differences were observed between display conditions.

Post-Test Results

Open-Ended Responses for Tasks

Participants’ open-ended responses for flight maneuvers were compared to a hierarchical task analysis of the flight tasks as defined by two subject matter experts (See Appendix 8 – Hierarchical Task Analyses of Flight Maneuvers). Participant responses were then coded as either correct or incorrect based on comparison to expert responses.
*Overall correct answers for maneuvers.* Novices trained on the Oz display (M=45.3, SD=12.6) responded correctly on all maneuvers significantly more often than novices trained on a conventional display (M=19.9, SD=11.97) \( t(18) = 2.80, p=.01 \). On average, novices trained on the Oz display responded correctly on 62% of all possible questions, while novices trained on a conventional Cessna display answered an average of 41% correct (Figure 10).

*Correct references to power when ascending.* Novices trained on the Oz display (M=11.1, SD=6.1) responded correctly to questions regarding power significantly more than novices trained on a conventional Cessna display (M=5.3, SD=2.71) \( t(12.4) = 2.74, p=.02 \). Novices trained on the Oz display answered 42.7% of all possible answers regarding power correctly, while novices trained on the Oz display answered 20.4% correctly (Figure 11).

*Open-Ended Response – Describing the Effects of Power*

Participants were given several questions to directly assess novices understanding of power’s effect on airspeed, power’s effect when descending, and banking and power. Participants’ responses were totaled, and the average totals across maneuvers were compared across display conditions.

*Power’s effect on airspeed.* When directly probed for the effect of power on airspeed, no significant differences were observed between question types. A trend of greater correct answers for novices trained on the Oz display was observed, similar to the answers observed on task and power prediction questions. It is believed that the lack of significance was due to a lack of power
from a restricted number of questions (2) and possible answers (2).

*Open-Ended Responses – Predicting the Effects of Power.*

Finally, participants were given a series of questions that provided the users with a power setting and an air speed. Participants were then asked what the future state of the aircraft would be if the current power setting was maintained. Participants’ responses were coded for correct or incorrect answers and the average number of total correct were compared across display conditions.

*Predicting effect of power on system state.* Novices trained on the Oz display were significantly more accurate at responding to questions correctly (M=6.2, SD=2.2) than novices trained on a conventional Cessna display (M=1.3, SD=1.3) \( t(18) = 6.02, p=.00 \). On average, novices trained on the Oz display predicted the effect of power of system state correctly with 68.9% accuracy, while novices trained on a conventional display correctly predicted the effect of power 14.4% of the time (Figure 12).

*Discussion*

Several conclusions can be drawn from the pre and post-test results. The lack of differences on the pre-test results suggests two possible observations. First, the lack of an effect suggests that the classroom training did not provide any significant benefit for either display. Second, the lack of a difference between the two groups indicates that it is unlikely that there were any systematic knowledge differences between the groups of novices sampled for the study. Neither group appeared to possess significantly more prior knowledge or acquired the information significantly better than the other.
The post-test results, however, show significant differences across the three concept maps. This leads to several conclusions. First, the results argue that underlying system knowledge is significantly improved by training with the Oz display, even after only 6 hours of training. Second, the results indicate that significant differences in knowledge performance can be observed using concept mapping methodology. This pattern of the results replicates the learning effect observed in Smith and Boehm-Davis (2005), though the current study’s effect size for testing performance was not as strong as the results for Smith and Boehm-Davis (2005).
Figure 10. Average percentage correct – responses for tasks by display
Figure 11. Average percent correct – correct responses for power by display
Novice Accuracy for Predicting the Effect of Power on Future System State

Figure 12. Average percent correct – responses for predicting the effect of current power settings on future system state.
APPENDIX 3: PILOT STUDY CONCEPT MAPPING RESULTS

The concept map results for the pilot study had two primary goals – first, to evaluate the viability of concept mapping as a methodology to detect changes in the quantity of underlying knowledge over trials. Second, the results were used to discover whether post-test differences between display conditions reported in Smith and Boehm-Davis (2005) would be reflected in the concept mapping results.

Concept Map Coding Scheme

Participant’s responses were coded using the link comparison technique (Evans, Kochan, & Jentsch, 2003). This is a relational scoring technique that compares a master concept map (in this case, created by three flight instructors) to the novice’s concept map. This method has been used previously to evaluate similarities between experts and novices (Evans, Kochan, & Jentsch, 2003; Smith-Jentsch et al, 2001). The link comparison method uses a dichotomous scoring system. If a novice connects two concepts that were also connected by the expert(s) then the novice is assigned a score of 1 (agreement with the expert). Alternately, if (1) the novice connects two concepts that were not connected on the master concept map, or (2) the novice does not connect two concepts that were connected on the master scoring map, the novice is assigned a score of 0. Using this coding system, a score of 1 or 0 is obtained for each possible connection.

The agreement between expert and novice can then be calculated as a percentage overlap score between the expert concept map and the individual novice concept map. The scores for each individual maneuver can also be summed by participant and the average completion compared across training conditions. Novices completed concept maps for three maneuvers – ascending, banking (both of which require the input of power and are directly communicated by
the Oz display), and descending (during this maneuver, the Oz display does not provide input). Performance results were analyzed for each of the using a repeated measures ANOVA. Results for each maneuver are reported below.

Concept map results for ascending.

Agreement for Power. A significant main effect of display was observed $F(1, 18) = 9.82, p=.01$, indicating that the average expert agreement was significantly higher for novices trained on the Oz display (M=27.3%, SD=15.6%) than novices trained on a conventional Cessna display (M=12%, SD=10.3%) (Figure 13). The results indicate that there was no significant main effect for trials.

Agreement for System. A significant main effect of display was observed $F(1, 18) = 8.97, p=.01$, indicating that the average expert agreement on the total system was significantly higher for novices trained on the Oz display (M=16%, SD=7%) than novices trained on a conventional Cessna display (M=8%, SD=6%) (Figure 14). The results indicate that there was no significant main effect for trials. A significant display by trial interaction $F(2, 36) = 4.84, p=.04$ was observed, with a within-subjects contrast between displays showed a significant difference in expert agreement for display type between trials one and two.

A series of one-way ANOVA’s showed no significant difference between display conditions in trial one, while significant differences in expert agreement were observed in trial two $F(1, 18) = 8.15, p=.01$ and three $F(1, 18) = 11.07, p=.00$. In trial two, novices trained on the Oz display showed significantly higher agreement with experts (M=17.5%, SD=9%) than novices trained on the conventional display (M=6.8%, SD=6.6%). This pattern was repeated in trial three, with novices trained on the Oz display showing greater expert agreement (M=16.3%, SD=6.4%) than novices trained on a conventional Cessna display (M=7.2%, SD=5.5%).
Concept map results for turning

*Agreement for power.* A significant main effect for display was observed $F(1, 18) = 6.19, p=.02$, indicating that average expert agreement was significantly higher for novices trained on the Oz display ($M=25.3\%, SD=7.3\%$) than novices trained on a conventional Cessna display ($M=14.6\%, SD=6\%$) (Figure 15). There were no significant differences between trials.

*Agreement for system.* A significant main effect for display was observed $F(1, 18) = 26.3, p=.00$, indicating that average expert agreement was significantly higher for novices trained on the Oz display ($M=13.5\%, SD=5.7\%$) than novices trained on a conventional Cessna display ($M=4.7\%, SD=4\%$) (Figure 16). The results indicate that there were no significant differences between trials. A significant main effect of trials was observed $F(2,36) = 8.04, p=.00$). Post-hoc trial comparisons were performed using the Bonferroni method. The results indicated that there were significant differences between trial one ($M=5\%, SD=5\%$) and both trials two ($M=12\%, SD=10\%$) and three ($M=9\%, SD=5\%$).

Concept map results for descending

*Agreement for power.* No significant differences for display or trial were observed for expert agreement for power while descending.

*Agreement for system.* A significant main effect for display was observed $F(1, 18) = 10.51, p=.01$, indicating that average expert agreement was significantly higher for novices trained on the Oz display ($M=13.8\%, SD=7.4\%$) than novices trained on a conventional Cessna display ($M=6.8\%, SD=6.4\%$) (Figure 17). There was no significant main effect for trials.
Discussion

Several inferences can be made from the knowledge differences observed using concept mapping. First, the results argue that system knowledge and knowledge of the functional relationship is significantly improved by training with the Oz display. Second, the results indicate that differences in knowledge gained via functional display use can be measured using concept mapping methodology. The results suggest that concept mapping is an appropriate technique for assessing novice understanding of the aircraft, its inter-related system components, and the understanding of the functional relationship between power, thrust, and airspeed. More importantly, the improvements seen in novices training with the Oz display suggest that there are significant knowledge benefits that may transfer from initial training with the Oz display. This informed the second study that evaluates changes in knowledge and performance when transferring between displays.
Figure 13. Novice agreement with experts on power for ascending.
Figure 14. Novice agreement with experts on overall system for ascending across trials.
Figure 15. Novice agreement with experts on power for turning across trials.
Figure 16. Novice agreement with experts on system for turning across trials.
Figure 17. Novice agreement with experts on overall system for descending across trials.
APPENDIX 4: PILOT STUDY PERFORMANCE RESULTS

Flight performance coding

To evaluate flight performance across display conditions, each novice’s performance was compared to an optimal flight profile. FTE was calculated as the root mean square error (RMSE) of total deviations from optimal performance for power (RPM), airspeed, altitude, and heading. Each maneuver is reported below with all significant differences in FTE reported.

Straight and Level Flight

Power. No significant differences were observed between display types. Novices trained on the Oz display set their power closer to an optimum power setting, but the difference was not statistically significant.

Airspeed. No significant main effects were observed for display or trials. Post-hoc analysis of trials using a series of one way ANOVA’s indicated that novices trained on the Oz display showed significantly less FTE for airspeed than novices trained on a conventional flight display on trials four $F(1,19)= 8.44, p=.01$ and five, $F(1,19)= 4.08, p=.05$, However, no differences were observed for the sixth and final trial (Figure 18).

Altitude. A significant main effect for display condition was observed $F(1,18)= 6.26$, $p=.02$, with novices trained on the Oz display showing significantly less FTE ($M = 524.07, SD= 54.28$) than novices trained on a conventional Cessna display ($M=677.16, SD=51.73$). Post hoc analysis using a series of one way ANOVAs’ indicated that novices trained on the Oz display showed significantly less FTE for altitude on trial 5 $F(1,19)= 7.59, p=.01$ and a marginal effect
on the sixth and final trial $F(1,19)=3.37$, $p=.08$ (Figure 19). There was no significant effect of trials.

**Heading.** No significant differences in heading were observed between display types. 

**Ascending**

**Power.** A significant main effect for display condition was observed $F(1,18)=31.76$, $p=.00$, with novices trained on the Oz display using significantly more power ($M=1530.38$, $SD=86.43$) than novices trained on a conventional Cessna display ($M=1253.06$, $SD=55.97$) (Figure 20). There was no significant effect of trials.

**Airspeed.** No significant differences were observed between display conditions.

**Altitude.** No significant differences were observed for altitude.

**Heading.** A significant main effect for display condition was observed $F(1,18)=8.34$, $p=.01$, with novices trained on the Oz display significantly displaying significantly less FTE from the target heading ($M=184.69$, $SD=41.32$) than novices trained on a conventional Cessna display ($M=234.10$, $SD=41.39$) (Figure 21). There was no significant effect of trials.

**Descending**

No significant differences were observed between display conditions or across trials for all performance measures.

**Slow Flight**

**Power.** No significant differences were observed between display conditions. A significant main effect for trials was observed $F(5,18)=5.12$, $p=.00$, indicating that power usage significantly decreased across trials (Figure 22). No significant display by trial interaction was observed.
Airspeed. No significant differences were observed between display conditions. A significant main effect for trials was observed $F(1,18)=3.54$, $p=.01$. Pairwise comparisons indicated that novices were able to maintain their target airspeed significantly more accurately between trial one and trials five and six. Similarly, novices were significantly more accurate on trials four, five, and six when compared to trial 2. There was no significant display by trial interaction.

Altitude. A significant main effect for display was observed $F(1,18)=9.45$, $p=.01$, indicating that novices trained with the Oz display showed significantly less FTE in maintaining altitude ($M=942.41$, $SD=165.21$) than novices trained on a conventional Cessna display ($M=1218.51$, $SD=218.17$) (Figure 23). A significant main effect for trials was also observed $F(5,18)=5.16$, $p=.00$, indicating a significant decrease in FTE for altitude across trials (Figure 23). Pairwise comparisons of trials showed the first trial to have significantly greater FTE than trials three through six. Similarly, trial two showed significantly greater FTE than trials four and five. No significant display by trial interaction was observed.

Heading. No significant differences were observed between display conditions or across trials for heading.

Banking

No significant differences were observed between display conditions or across trials for heading, airspeed, or power.

Altitude. A significant main effect for display was observed $F(1,18)=15.71$, $p=.00$, indicating that novices trained with the Oz display showed significantly less FTE in maintaining altitude ($M=692.82$, $SD=42.10$) than novices trained on a conventional Cessna display ($M=1025.13$, $SD=193.11$) (Figure 24). No significant differences were observed between trials.
Increasing airspeed while maintaining altitude

No significant differences were observed between display conditions or across trials for power, airspeed, heading, or altitude.

Slow flight ascending

No significant differences between display conditions were observed for power, heading, altitude, or airspeed.

Banking while ascending

No significant differences between display conditions were observed for power, heading, altitude, or airspeed.

Discussion

The performance results of the pilot study were somewhat surprising, given previous studies demonstrating clear performance differences between Oz and Conventional displays (Smith et al., 2004, 2005, Smith and Boehm-Davis, 2005, Smith, 2007). Generally, findings have shown performance improvements on aircraft control and power management for tasks that require regular maintenance, including straight and level flight, increasing altitude, turning, and combinations of the three maneuvers. Maneuvers that did not require regular power management, such as increasing airspeed or descending, generally did not show effects of training with either display (Smith et al, 2005, 2005, Smith and Boehm-Davis, 2005).

While the pilot study’s performance data replicated the lack of an effect for maneuvers that did not require regular maintenance of power, the performance results for maneuvers that required power management did not replicate previously observed effects. Novices trained on the Oz display only showed improved performance on ascending and slow flight, while tasks that have showed performance differences in the past (such as straight and level flight and banking)
did not show differences for power management and some cases of FTE. All maneuvers that
required the inclusion of multiple inputs showed no performance differences on either power
management or FTE.

This is especially disconcerting given the significant improvements observed in the
knowledge tests and concept maps. Novices trained on the Oz display responded correctly to
descriptions of maneuvers and understood more of the system as a whole; however, this
improvement in knowledge was not also reflected in the performance results. When compared to
Smith and Boehm-Davis (2005) data, it becomes clear that the 2005 Oz novices performed
significantly better than the group sampled for the pilot study.

Figure 18. Straight and level flight – FTE for airspeed
Figure 19. Straight and level flight – FTE for altitude
Figure 20. Ascending – FTE for power
Figure 21. Ascending – FTE for heading

Figure 22. Slow flight – FTE for power use
Flight Technical Error for Altitude in Slow Flight

Figure 23. FTE for altitude in slow flight
Figure 24. Banking - FTE for altitude
Table 7. Experimental design

<table>
<thead>
<tr>
<th>Session Training</th>
<th>Trial</th>
<th>Maneuvers</th>
<th>Experimenter Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flight Session 1</td>
<td>Trial 1</td>
<td>8</td>
<td>Yes</td>
</tr>
<tr>
<td>Flight Session 2</td>
<td>Trial 2</td>
<td>8</td>
<td>No</td>
</tr>
<tr>
<td>Flight Session 3</td>
<td>Trial 3</td>
<td>8</td>
<td>Yes</td>
</tr>
<tr>
<td>Flight Session 3</td>
<td>Trial 4</td>
<td>8</td>
<td>No</td>
</tr>
<tr>
<td>Flight Session 3</td>
<td>Trial 5</td>
<td>8</td>
<td>No</td>
</tr>
<tr>
<td>Flight Session 3</td>
<td>Trial 6</td>
<td>8</td>
<td>No</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Concept Map 1</th>
<th>Concept Map 2</th>
<th>Concept Map 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>
Listing of the verbal feedback provided during flight maneuvers. Feedback from the experimenter was provided in Session 1/Trial 1, and Session 2/Trial 1.

**Table 8. Listing of experimenter feedback**

<table>
<thead>
<tr>
<th>Situation</th>
<th>Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overpowered</td>
<td>“You are overpowered. Reduce power with your throttle.”</td>
</tr>
<tr>
<td>Underpowered</td>
<td>“You are underpowered. Increase power with your throttle.”</td>
</tr>
<tr>
<td>Above Altitude</td>
<td>“You are above the required altitude. Lower your altitude.”</td>
</tr>
<tr>
<td>Below Altitude</td>
<td>“You are below the required altitude. Increase your altitude.”</td>
</tr>
<tr>
<td>Overspeed</td>
<td>“Your speed is too fast. Reduce your speed.”</td>
</tr>
<tr>
<td>Underspeed</td>
<td>“Your speed is too slow. Increase your speed.”</td>
</tr>
<tr>
<td>Past Heading</td>
<td>“You are past the required heading. Return to a heading of ___.”</td>
</tr>
<tr>
<td>Not at Heading</td>
<td>“You are not yet to the required heading. Return to a heading of ___.”</td>
</tr>
<tr>
<td>Banked more than 15 Degrees</td>
<td>“Your bank angle is too great. Reduce your bank angle.”</td>
</tr>
<tr>
<td>Banked less than 15 Degrees</td>
<td>“Your bank angle is too little. Increase your bank angle.”</td>
</tr>
</tbody>
</table>
Listing of maneuvers performed for the pilot study.

Table 9. Listing of maneuvers performed

<table>
<thead>
<tr>
<th>Presentation Order</th>
<th>Maneuver</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Maintain Straight and Level Flight</td>
</tr>
<tr>
<td>2</td>
<td>Ascend 1000ft at 500 fpm</td>
</tr>
<tr>
<td>3</td>
<td>Descend 1000 Ft at 500 FPM.</td>
</tr>
<tr>
<td>4</td>
<td>Slow Flight: Straight and level at 60 knots.</td>
</tr>
<tr>
<td>5</td>
<td>Banking (Standard Rate Turn): 360 degree standard rate turn.</td>
</tr>
<tr>
<td>6</td>
<td>Increase Speed from 85-110</td>
</tr>
<tr>
<td>7</td>
<td>Slow Flight while Ascending: Participants climb at 500 fpm while maintaining 60 knots.</td>
</tr>
<tr>
<td>8</td>
<td>Ascend 1000 Ft., Bank Left/Right 360 Degrees</td>
</tr>
</tbody>
</table>
APPENDIX 8: TASK ANALYSES FOR FLIGHT MANEUVERS

Task Analyses of Flight Maneuvers

A hierarchical task analysis was developed for each maneuver with a subject matter expert. These analyses were developed as a comparison for participants’ open-ended responses on how to perform a particular maneuver. Participants’ responses were compared to the hierarchical task analysis and coded for accuracy. These responses can then be separated into various aspects of maneuvers (power management, attitude control, airspeed) to investigate individual characteristics of each task, or aggregated to provide a measure of overall task accuracy.

Notes
1. Steps 1-4 may be performed in order.
2. If required, Step 4 may also be performed after Step 1. This is based on the pilot’s judgment once referencing the attitude indicator in Sept 1.1.

**Increase Altitude**

Plan 0. Increase Altitude from 2000-3000 ft.

1. Adjust Pitch
   1.1. Visually reference Horizon Line
   1.2. Identify requirement to adjust pitch angle
   1.3. Pull back on yoke to increase pitch

2. Adjust Power
   2.1. Visually reference current airspeed
   2.2. Visually reference power setting
   2.3. Note need to increase power to perform maneuver
   2.4. Adjust throttle to increase power

3. Adjust Trim
   3.1. Visually reference vertical speed indicator
   3.2. Identify requirement to increase trim
   3.3. Increase trim using trim control

4. Adjust Heading
   4.1. Visually reference Heading Indicator
   4.2. Identify requirement to adjust heading angle
   4.3. Adjust yoke to alter heading

**Figure 25. Task analysis for Ascending or Increasing Altitude**
Banking while Maintaining Altitude

Notes
1. Steps 1-4 may be performed in order.
2. If required, Step 4 may also be performed after Step 1. This is based on the pilot’s judgment once referencing the attitude indicator in Sept 1.1.

Figure 26. Task analysis for banking while maintaining altitude

Increase Airspeed while Maintaining Altitude

Notes
1. Steps 1-4 may be performed in order.
2. If required, Step 4 may also be performed after Step 1. This is based on the pilot’s judgment once referencing the attitude indicator in Sept 1.1.

Figure 27. Task analysis for increasing airspeed while maintaining altitude
Banking while Climbing

Notes
1. Steps 1-4 may be performed in order.
2. If required, Step 4 may also be performed after Step 1. This is based on the pilot’s judgment once referencing the attitude indicator in Sept 1.1.

Plan 0. Bank from 90 to 90 while climbing

1. Adjust Pitch
2. Adjust Power
3. Adjust Trim
4. Adjust Heading

1.1. Visually reference Horizon Line
1.2. Identify requirement to increase pitch angle
1.3. Pull back on yoke to increase pitch
2.1. Visually reference current airspeed
2.2. Visually reference power setting
2.3. Note need to increase power to perform maneuver
3.1. Visually reference vertical speed indicator
3.2. Identify requirement to increase trim
3.3. Increase trim using trim control
4.1. Visually reference Heading Indicator
4.2. Identify requirement to adjust heading angle
4.3. Turn yoke to alter heading
4.4. Check heading indicator to verify input’s effect

Figure 28. Task analysis for banking while increasing altitude

Banking while Descending

Notes
1. Steps 1-4 may be performed in order.
2. If required, Step 4 may also be performed after Step 1. This is based on the pilot’s judgment once referencing the attitude indicator in Sept 1.1.

Plan 0. Bank from 90 to 90 while descending

1. Adjust Pitch
2. Adjust Power
3. Adjust Trim
4. Adjust Heading

1.1. Visually reference Horizon Line
1.2. Identify requirement to decrease pitch angle
1.3. Push forward on yoke to decrease pitch
2.1. Visually reference current airspeed
2.2. Visually reference power setting
2.3. Note need to decrease power to perform maneuver
3.1. Visually reference vertical speed indicator
3.2. Identify requirement to adjust trim
3.3. Adjust trim using trim control
4.1. Visually reference Heading Indicator
4.2. Identify requirement to adjust heading angle
4.3. Turn yoke to alter heading
4.4. Check heading indicator to verify input’s effect

Figure 29. Task analysis for banking while descending.
APPENDIX 8: CONVENTIONAL CESSNA 172 DISPLAY PRE-TEST

(Space provided between answers has been minimized to conserve space.)

Project Flight Pre-Test

1. When does an airplane stall?

2. Constant speed is attained when thrust = ____________

3. If the airplane is banked to the right, what direction do the ailerons deflect?

4. If power is increased in level flight, what happens to the airspeed?

5. Identify the flight controls.

![Flight Controls Image]

a. 

b. 

c. 

d. 

e. 

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6. Name the three Axes of flight control.
   a. 
   b. 
   c. 

7. How do you come out of a stall? (Answer briefly.)

8. If attitude is increased and power is not changed, what will happen to the airspeed?

10. What do you use when turning to keep the plane in a coordinated turn?
APPENDIX 9: OZ DISPLAY PRE-TEST

(Space provided between answers has been minimized to conserve space.)

Project Flight Pre-Test

1. When does an airplane stall?

2. Constant speed is attained when thrust = __________

3. If the airplane is banked to the right, what direction do the ailerons deflect?

4. If power is increased in level flight, what happens to the airspeed?

5. Identify the flight controls.

a.

b.

c.
6. Name the three Axes of flight control.

   a.

   b.

   c.

7. How do you come out of a stall? (Answer briefly.)

8. If attitude is increased and power is not changed, what will happen to theairspeed?

9. What do you use when turning to keep the plane in a coordinated turn?
APPENDIX 10: CONVENTIONAL CESSNA 172 DISPLAY POST-TEST

This is the post-test for the conventional Cessna 172 display completed by novices after all flight sessions using the conventional Cessna 172 display. Novices were provided with a power table for questions referring to current power settings.

(Space provided between answers has been minimized to conserve space.)

Questions for the Conventional Cessna 172 Display:

Each of the following questions has a specific situation that you have encountered while performing standard flight maneuvers. Please explain in detail how you accomplished each maneuver. Include:

- How you conceptually perform the maneuver (what factors you considered in your process)
- Physically perform the maneuver (What physical objects you manipulated)
- What you use on the display (What parts of the display do you reference while performing the maneuver)

If you have any questions regarding how to answer the questions, please ask your experimenter. If you do not know the answer, please try to answer to the best of your ability. The experimenter will not be able to provide information specific to the maneuver.
Explain the following maneuvers using the three criteria listed on Page 1:

1. Climb from 2000 to 3000 Feet.

2. Bank from a heading of 90 degrees to 270 degrees.

3. Increase Speed from 85 to 110 knots while maintaining altitude.

4. Bank from a heading of 90 degrees to 90 degrees (360 Degrees) while ascending from 2000 to 3000.

5. Bank from a heading of 90 degrees to 90 degrees (360 Degrees), while descending from 3000 to 2000, while maintaining speed at 85 knots.

Answer the following questions to the best of your ability. Please try to include as much detail as possible.

6. What is power’s relation to speed?

7. If you are descending and increase power, what happens?

8. Banking requires what of power?

The following questions will give you a brief scenario you encountered while flying. Please answer the two questions following each scenario.

9. You are flying at 3000 feet and 105 knots and adjust the power settings so the RPM's are 2386. What does this mean? (Give a detailed explanation.) What most likely will happen?

10. You are flying at 3000 feet and 105 knots and adjust the power settings so the RPM’s are 2200. What does this mean? (Give a detailed explanation.) What most likely will happen?
11. You are flying at 3000 feet and 105 knots and adjust the power settings so the RPM’s are 2520. What does this mean? (Give a detailed explanation.) What most likely will happen?
APPENDIX 11: OZ DISPLAY POST-TEST

This is the post-test for the Oz display. This questionnaire was completed by novices after all flight sessions using the conventional Oz display.

(Space provided between answers has been minimized to conserve space.)

Questions for the Oz Display:

Each of the following questions has a specific situation that you have encountered while performing standard flight maneuvers. Please explain in detail how you accomplished each maneuver. Include:

- How you conceptually perform the maneuver (what factors you considered in your process)

- Physically perform the maneuver (What physical objects you manipulated)

- What you use on the display (What parts of the display do you reference while performing the maneuver)

If you have any questions regarding how to answer the questions, please ask your experimenter. If you do not know the answer, please try to answer to the best of your ability. The experimenter will not be able to provide information specific to the maneuver.
Explain the following maneuvers using the three criteria listed on Page 1:

1. Climb from 2000 to 3000 Feet.

2. Bank from a heading of 90 degrees to 270 degrees.

3. Increase Speed from 85 to 110 knots while maintaining altitude.

4. Bank from a heading of 90 degrees to 90 degrees (360 Degrees) while ascending from 2000 to 3000.

5. Bank from a heading of 90 degrees to 90 degrees (360 Degrees), while descending from 3000 to 2000, while maintaining speed at 85 knots.

Answer the following questions to the best of your ability. Please try to include as much detail as possible.

6. What is power’s relation to speed?

7. If you are descending and increase power, what happens?

8. Banking requires what of power?
The following questions will give you a brief scenario you encountered while flying. Please answer the two questions following each scenario.

9. You are flying at 3000 feet and 105 knots and adjust the power settings so that the green section of the power bar meets the bent wing. What does this mean? (Give a detailed explanation.) What most likely will happen?

10. You are flying at 3000 feet and 105 knots and adjust the power settings so that the green section of the power bar is within the bent wing. What does this mean? (Give a detailed explanation.) What most likely will happen?

11. You are flying at 3000 feet and 105 knots and adjust the power settings so that the green section of the power bar exceeds the bent wing. What does this mean? (Give a detailed explanation.) What most likely will happen?
APPENDIX 12: ADDITIONAL PRE-POST-TEST RESULTS

Post-Test Coding

Describing the Effects of Power

Participants were also given several open-ended questions to directly assess novices understanding of power’s effect on airspeed, power’s effect when descending, and banking and power (See Appendix 10 & 11 – Post-Test Questionnaires). Participants’ responses were totaled and then averaged across maneuvers.

Predicting the Effects of Power

Participants were given a series of questions that provided the users with a power setting and an air speed. Participants were then asked what the future state of the aircraft would be if the current power setting was maintained.

Describing Power’s Effect

Paired samples t-tests were used to evaluate change from time 1 to time 2. The Conventional-Oz transfer condition showed significant increases between time 1 (M=2.0, SD=.93) and time 2 (M=3.0, SD=.76) \( t(7) = -3.06, p=.02 \), and the Oz-Oz condition showed significant increases between time 1 (M=2.25, SD=1.03) and time 2 (M=2.75, SD=.71) \( t(7) = -2.65, p=.03 \) (Figure 5).
APPENDIX 13: ADDITIONAL CONCEPT MAP RESULTS

Figure 30. Novice percent agreement with experts on power usage while ascending
Figure 31. Novice percent agreement with experts on power usage while descending
Expert system agreement for Ascending

A significant display by trial interaction $F (2, 36) = 4.84$, $p=.04$ was observed, with a within-subjects contrast between displays indicating a significant difference in expert agreement for display type between trials one and two. A series of one-way ANOVA’s showed no significant difference between display conditions in trial one, while significant differences in expert agreement were observed in trial two $F (1, 18) = 8.15$, $p=.01$ and three $F (1, 18) = 11.07$, $p=.00$. In trial two, novices trained on the Oz display showed significantly higher agreement with experts ($M=17.5\%, \ SD=9\%$) than novices trained on the conventional display ($M=6.8\%, \ SD=6.6\%$). This pattern was repeated in trial three, with novices trained on the Oz display showing greater expert agreement ($M=16.3\%, \ SD=6.4\%$) than novices trained on a conventional Cessna display ($M=7.2\%, \ SD=5.5\%$) (Figure 32).

![Expert Agreement on System for Ascending](image)

Figure 32. Novice percent agreement with experts on system state while ascending
**Expert system agreement for turning**

A significant main effect of trials was observed $F(2,36) = 8.04$, $p=.00$. Post-hoc trial comparisons using the Bonferroni method indicated that there were significant differences between trial one (M=5%, SD=5%) and both trials two (M=12%, SD=10%) and three (M=9%, SD=5%).
Figure 33. Novice percent agreement with experts on system state for descending
APPENDIX 14: FLIGHT PERFORMANCE RESULTS

Figure 34. FTE for power in straight and level flight
Figure 35. FTE for airspeed in straight and level flight
Figure 36. FTE for altitude in straight and level flight
Figure 37. FTE for heading in straight and level flight
Figure 38. FTE for power in ascending flight
Figure 39. FTE for airspeed in ascending flight
Figure 40. FTE for altitude in ascending flight
Figure 41. FTE for heading in ascending flight
Figure 42. FTE for power in slow flight
Figure 43. FTE for airspeed in slow flight
Figure 44. FTE for altitude in slow flight
Figure 45. FTE for heading in slow flight
Figure 46. FTE for power in slow flight ascending
Figure 47. FTE for airspeed in slow flight ascending
Figure 48. FTE for altitude in slow flight ascending
Figure 49. FTE for heading in slow flight ascending.
Figure 50. FTE for power in banking
Figure 51. FTE for airspeed in banking
Figure 52. FTE for altitude in banking
Figure 53. FTE for heading in banking
Figure 54. FTE for power in banking while ascending.
Figure 55. FTE for airspeed in banking while ascending.
Figure 56. FTE for altitude in banking while ascending.
Figure 57. FTE for heading in banking while ascending.
Figure 58. FTE for power in increasing airspeed.
Figure 59. FTE for airspeed in increasing airspeed.
Figure 60. FTE for altitude in increasing airspeed.
Figure 61. FTE for heading in increasing airspeed.
Figure 62. FTE for power in descending.
Figure 63. FTE for power in descending.
Figure 64. FTE for altitude in descending.
Figure 65. FTE for heading in descending.
APPENDIX 15: STUDY LIMITATIONS

Limitations

Several limitations exist that can provide opportunity for future research. First, the number of participants used appeared to be sufficient for detecting performance differences in maneuvers; however, for detecting subtle differences in knowledge, a larger N would be more appropriate. Previous training studies in aviation have regularly used samples of 76 and higher (Lintern and Taylor, 1997, Taylor, Talleur, Emmanuel, & Rantanen, 2005). It was believed, given the large effect sizes observed in the knowledge tests in Smith and Boehm-Davis, (2005) and Smith (2007) and the significant differences in concept maps observed previously between Oz and conventional displays (Smith, 2007) that a sample size of 8 per cell would be sufficient to detect underlying differences in novices’ concept maps. This was not the case, however, as the large amount of variance between novices’ responses (both within and between conditions) produced standard deviations that were often as large as the mean differences. A larger N of participants should be collected to identify differences due to a training effect from error related to individual differences.

Second, while this study produces significant differences in knowledge and performance between display training conditions, the amount of time spent with each display is still relatively small (12 hours flying, 4 hours classroom training) compared to the basic requirements for a private pilot license (FAA, 2007). Given the short amount of
time participants used a display, it is not apparent whether using a functional (in this case, the Oz) display would make training more efficient over the course of training, or if the Oz display simply provides increased efficiency in early knowledge acquisition. Previous research suggests that a longer, longitudinal study may need to be performed to establish whether using a functional display improves performance over time. Cristofferson, Hunter, and Vicente (1996) compared the daily performance of novices on one of two displays – one using only physical information, while another used both physical and functional information. While novices who used the physical interface showed more variability than the physical and functional interface overall, the average performance between conditions was not significantly different. In fact, an interaction of trial and display revealed that after 60-70 trials (almost 2 months) the physical interface condition matched the physical functional interface condition and actually surpassed it in performance for the remaining 150 trials. These results suggest that a longer-term study will be required to evaluate whether the performance benefits observed here are reflective of a quantitative change in novice ability or a short-term gain that will be negated over time.
REFERENCES
REFERENCES


CARL F. SMITH

CURRICULUM VITAE

Carl F. Smith graduated from Catholic High School in Virginia Beach, Virginia, in 1995. He received his Bachelor of Science in Psychology from Old Dominion University in 2002, and a Master of Arts in Psychology from George Mason University in 2004.