INFORMAL SCIENCE LEARNING:
INFLUENCES OF EXLANATORY ELABORATION AND LEARNER CONTROL ON KNOWLEDGE AQCUISTION

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Submitted to the Graduate Faculty of

Arts and Sciences in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy

University of Pittsburgh

2004

UNIVERSITY OF PITTSBURGH

FACULTY OF ARTS AND SCIENCES

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It was defended on

September 7th, 2004

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FOREWARD

I’d like to express my deep appreciation to my committee – Chris Schunn Ph.D., Jonathan Schooler, Ph.D., Sam Donovan, Ph.D., Julie Fiez, Ph.D., and especially my advisor, Kevin Crowley, Ph.D., for the indispensable advice and support that they provided for me. I’d also like to thank Randi Engle, Ph.D., Michel Ferrari, Ph.D., and Stephanie Siler for their invaluable feedback, as well as my fellow lab mates Lelyn Saner, Kwangsu Cho and others, for the helpful conversations. Lastly, I’d like to thank my wife for her support and encouragement that helped to make all of this possible.

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The Cognitive Load and Active Processing learning theories offer seemingly conflicting implications to educators regarding the most effective way to present instructional materials. The apparent contradiction between these bodies of research was investigated in terms of a Region of Proximal Learning (RPL) framework. The results from Experiment 1 provide evidence that the RPL can successfully unify these separate areas of research and provide more useful guidance to educators. Experiment 2 examined how the affordance of Learner Control (LC), an inherent aspect of the Web, may interact with the Region of Proximal Learning. Results from this experiment provide evidence that individuals can utilize LC to adaptively select material of appropriate difficulty for their ability level. However, this did not lead to increased learning.

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1. INTRODUCTION

Informal learning is a research area which, in contrast to formal in-school learning, is focused on the learning that occurs outside of the classroom (Resnick, 1987). Such learning can take place in a variety of different environments such as in museums (e.g. Crowley & Jacobs, 2002; Leinhardt, Crowley, & Knutson, 2002), public spaces, or through broadcast media such as television and radio (e.g. Crane, Nicholson, Chen, & Bitgood, 1994; Dhingra, 2003).

One relatively new form of informal learning, which is the focus of this research, is that of the Web. While the Web is still a relatively new form of media, it has undergone an explosive growth in use. In fact, teenagers and young adults are now on average spending more time each week on the Web (17 hours) than watching television (Harris Interactive, 2003). This startling shift in behavior has been brought about, in part, by the widespread availability of the Web, which is now readily accessible to over 168 million Americans (Nielsen//NetRatings, 2003). In addition to commerce and entertainment, one important use of the web is that of education; however, there has been very little empirical research on the instructional effectiveness of the web (Graesser, Leon, & Otero, 2002). Hence, this is an area in which additional research is sorely needed. This need is reflected in the recommendations put forth in a recent government report on the use of the Web to enhance learning (Web-based Education Commission, 2000), which advocate for a national mobilization in this area on the order of earlier efforts for finding a cure for polio or landing a man on the moon – in addition to calling for the construction of a new educational research framework of how people learn on the Web.

The claims commonly made for the instructional efficacy of the Web, like those made for most new educational technologies, often exceed that which can be justifiably supported given the existing empirical evidence (Dillon, 1996). While it is true that technological innovations such as the Web do open up promising new educational possibilities that should be fully explored, one also needs to be mindful that the empirical support for such beliefs is still, at best, rather tenuous (Chen & Rada, 1996; Dillon & Gabbard, 1998). The Web, like all instructional technologies, is a *tool*, and as such there are going to be some areas (and perhaps some individuals) for which is it better suited than others. Of course, one must also consider the alternative that there are in fact, no significant advantages to the Web. However, we will examine another possibility – that the relative lack of findings for instructional advantages of the Web exists because early research may not have been sufficiently discriminating in identifying and studying the technology's rather unique *affordances*.

The investigation described herein concentrates upon the specific affordances of the web that have direct relevance to learning and instruction. One key affordance of the web is found in its inherent nonlinearity -- the web offers individuals much greater control over the learning process by allowing them to choose the type, amount, and sequence of the content they view. In contrast to reading a *standard text*[1] -- for example a science textbook or popular science magazine – the Web (i.e. *hypertext)* affords greater control over the manner in which the instructional activity may unfold (see section on Learner Control). Before delving into the issue of how the affordance of learner control may influence the learning process, it is important to first situate learning from the web within a broader theoretical context – that of Text and Discourse processes.

In their review of research on discourse comprehension, Graesser, Millis, and Zwaan (1997) made two important distinctions. First, they made the distinction between written text and conversations. Given the structure and format of the Web, this paper will be focused on the area

[1] "Text" and "Hypertext" will be used in the more general sense, including both sentential and diagrammatic information (Larkin and Simon, 1987; Otero, Leon, & Graesser, 2002).

of written text. A second important distinction made was between discourse comprehension and production (see Crowley & Siegler, 1999 and Siegler, 1995 for direct comparisons). A number of existing studies have documented the instructional advantages of discourse production (e.g. Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Chi, de Leeuw, Chiu, & LaVancher, 1994). This paper will instead be primarily focused on the area of discourse comprehension.

Explanation Elaboration

The term *explanation elaboration* here refers to the degree to which an explanation delves into the specific, complex details of a phenomenon. One exciting pedagogical possibility of the Web is that it allows educational designers to readily create explanations of varying degrees of elaboration, thereby helping to reduce the problems associated with forcing individuals into one-size-fits-all instruction. For example, one could simply describe how the flow of air over a wing becomes turbulent when it is at too great an angle of inclination. Alternatively, one could provide a more elaborated explanation about how the turbulence of fluid occurs when "secondary random motions are superimposed or added to the principle flow." Thus, in comparison to a simple, unelaborated explanation, an elaborated explanation provides additional information and delves deeper into the domain content, thereby increasing the difficulty of the task of reading and comprehending the material. However, an elaborated explanation also increases the number of inferences required for comprehension, potentially inducing more *active processing* that in turn would lead to greater learning. On the other hand, it will also increase the learners' *cognitive load* that instead may overwhelm the learner, resulting in lower learning. As will be discussed in greater detail below, this leads to significant problems in terms of making outcome predictions as well as in terms of instructional design implementations.

As suggested above, the issue of explanation elaboration is important for a number of reasons. First, the use of textual materials plays an enormous role in science education, and learning from science texts is especially difficult for a number of reasons. Such materials are typically designed to teach new knowledge and therefore the content is, by design, unfamiliar to learners (Chambliss, 2002). The text often includes “mathematical language, with symbols and formulas that are difficult to ground in everyday experience” (Graesser, et al., 2002, p. 1). Furthermore, educational designers often fail to provide enough information for students to fully comprehend and construct appropriate mental models of the content being taught (Beck, McKeown, & Gromoll, 1989; Graesser, et al., 2002). In addition, there can be serious negative consequences if students are presented with inappropriate explanations. For instance, if the material is too easy, the instructional activity may be inefficient and induce unnecessary boredom. More importantly, if the explanatory material is too difficult, the instructional activity will lead to comprehension breakdowns and cause frustration on the part of the learner, and may even negatively affect students’ metacognitive abilities and epistemic attitudes since they may come to believe that they should not expect science texts to make sense, thereby creating a vicious downward spiral (e.g. Graesser, et al., 2002; Otero, 2002).

1.1.1. Explanation Elaboration: Theory

Since much of web-based science explanations are textual, it is essential to understand the psychological processes involved when people read and process text. It is helpful to note at the outset that while paper text and electronic text (i.e. text appearing on a computer screen) differ in perceptual characteristics (e.g. polarity-- the contrast between character color and background color) the empirical findings indicate that there is no significant difference in terms of comprehension (Dillon, 1992; Egan, Remde, Gomez, Landauer, Eberhardt, and Lockbaum, 1989; Obourne & Holton, 1988). Dillon (1992, p. 1304) was able to state that given such improvements one could now hold that the "comprehension of material is not negatively affected by presentation medium." This allows individuals reading simple text (i.e. without hyperlinks -- as opposed to hypertext) on a computer to be treated as fundamentally equivalent to reading from text in the traditional paper format.

Comprehension, like cognition in general, can be characterized as taking place at multiple levels. For instance, imagine an individual who reads or listens to an explanation on why popcorn pops that includes the following: *when heated, the water in the popcorn kernel changes into steam*. The surface level deals with the parsing and processing of specific words. At the next higher level, this sentence can be viewed in terms of propositions that represent the meaning of the text, which is commonly referred to as the textbase (Kintsch, 1988, 1994). For instance, the sentence above can be represented propositionally as:

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If Heated [Water, State: Liquid, Location: Kernel]
   Then [Water, State: Vapor, Location: Kernel]
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At the next higher level is what is referred to as the situation model (or mental model). This level of representation is focused on the situation (or object) described by the text. So in the example above, it refers to a situation in which the liquid water inside popcorn kernel(s) is transformed to steam due to the application of an outside heat source. Of greater importance though is that at the situation model level, the "information provided by the text is elaborated from prior knowledge and is integrated with it" (Kintsch, 1994, p. 294). Thus, continuing with our example, hypothetical readers would attempt to integrate the new information into their current understanding. Notably, background knowledge that *water expands when heated and is* *turned into steam* can be brought to bear on the current information and allow the generation of an inference that the heating of the water will result in increased pressure inside the kernel, thereby causing it to "pop".

Given this paper's interest in the topic of meaningful learning -- learners being able to productively use the information they've encountered, not merely being able to recall it -- the most appropriate level for our analyses is that of the situation model (mental model) level. As Kintsch (1994) notes "normally reproduction of a text and real understanding are correlated, so that text memory becomes a prerequisite for learning, although this is not necessarily so" (p. 294). Furthermore, Kintsch (1994) explains that the "distinction between *memory* for a text and *learning* from a text … appears to be a matter of how complete and elaborate a situation model is constructed during comprehension" [emphasis added] (p. 295). In other words, while text-based representations can be considered a simple form of learning, it is the derided "rote memorization" version that is associated with inert knowledge. As such, it is impoverished and superficial when compared to deeper learning that occurs at the level of situation model representations. Given our goal of enhancing meaningful learning, the question then becomes how to help learners create rich and elaborated situation models.

Although there is a wide variety of research on ways of enhancing meaningful learning from reading expository texts, they can generally be categorized as belonging to one of two approaches. The first approach seeks to make reading and comprehension easier. Research from this approach is well captured by the *cognitive load* perspective, which as mentioned earlier, suggests that learning is enhanced when cognitive demands on the learner are minimized. The second approach is to make reading and comprehension somewhat more difficult. Research from this approach is well captured by the *active processing* perspective, which suggests that the learner should be induced to more actively process the given information. These two key viewpoints warrant closer inspections and will therefore be discussed in greater detail.

1.1.1.1. Explanation Elaboration: Theory -- Cognitive Load (CL) Perspective

Increased explanatory elaboration, which here means the presentation of additional challenging materials, is expected to lead to higher levels of cognitive load on the learner. According to this perspective, the increased cognitive load limits the amount of available cognitive resources, which results in a reduction of learning (e.g. Chandler & Sweller, 1991; Sweller & Chandler, 1994; Sweller, van Merrienboer, & Pass, 1998). One implication of this perspective is that educators should employ a strategy of reducing the difficulty of instructional materials in order to enhance learning.

This perspective is best demonstrated by a series of experiments by Mayer, Bove, Bryman, Mars, and Tapango, (1996) which compared learning from science texts that were at different levels of elaboration. In one experiment, undergraduates were pre-screened for their domain knowledge of the science topic under study. Only those undergraduates low in prior domain knowledge were included in the later intervention phase of the experiment. One of the texts read included only the basic information of the science topic being studied, while a second text read included significantly more information. Afterwards, on a problem-solving transfer task, the participants who had read the simpler text gained significantly more knowledge than those who had read the more extensively elaborated text, presumably due to a reduced cognitive load with the simpler text.

1.1.1.2. Explanation Elaboration: Theory -- Active Processing (AP) Perspective

Increased explanatory elaboration (which was defined earlier as referring to the reading of additional, challenging materials) is expected to encourage learners to engage in more *active processing* (i.e. generating more inferences, etc.). According to this perspective, the increased inference making will lead to enhanced learning.

This perspective is best demonstrated by research on text and discourse processes. An early study that highlighted the importance of the role of text organization on meaningful learning was conducted by Mannes and Kintsch (1987). In preparation for reading a difficult science text, individuals were assigned to one of two groups – half to a *consistent* condition that read an outline in which background information was presented in an order similar to the main text, while the other half were assigned to an *inconsistent* condition that read an outline in which the same background information was presented, but in an order unrelated to the main text. On a cued recall test, the participants who had received the consistent outlines scored significantly higher than those who had received the inconsistent outlines. In contrast, on a problem-solving test, participants who had received the inconsistent outline condition scored significantly higher than those who had received the consistent outlines.

These seemingly contradictory findings can be accounted for in terms of individuals constructing textbase and situation model representations of the text (Kintsch, 1988). When participants were given the consistent outline, they created a textbase and situation model of the material. When they subsequently read the main text, it was structurally similar and the newer material was easily placed into preexisting “slots”. In contrast, when the participants who were given the inconsistent outline subsequently read the main text, it was quite dissimilar and the task of maintaining a coherent comprehension required significant revisions of the readers’ situation model. Thus, presentation of the inconsistent outline induced the reader to become more active in processing the material and therefore create a richer, more elaborate situation model, which resulted in more meaningful learning as demonstrated by the superior performance on the problem solving tasks. The advantage of having individuals engage in active processing has been demonstrated in a number of studies (e.g. Chan, Burtis, Scaramalia, & Bereiter, 1992; Chi, et al., 1989, 1994; Slamecka & Graf, 1978). Of course, it is possible that an individual might intentionally or unintentionally fail to engage in such situation model elaboration, and in such cases one would not expect to see enhanced learning.

The productive use of such newly learned information critically depends upon the learner being able to retrieve the appropriate information when faced with a transfer problem-solving task, and without a richly elaborated situation model, learners will be forced to rely more heavily on their textbase representations, which will allow them to answer memory questions, but will be of only minimal help for the inferential reasoning required for problem-solving tasks.

Of course, it should be noted that this gain in learning due to triggering of situation model elaborations also places an increased load on the cognitive resources of the learner, and for less able students this additional cognitive load may be problematic. In particular, the increased difficulty means that learners may be unable to generate the necessary inferences to build or maintain a coherent representation of the text. In such cases comprehension may break down partially or even completely, leading to significantly reduced learning.

1.1.2. Explanation Elaboration: Evidence

The study by Mannes and Kintsch (1987), discussed above, helps to illustrate the importance of text difficulty and learning. Individuals who were given preparatory outlines that were inconsistent with the science texts they later read (making the process more challenging) resulted in significantly greater learning on transfer tasks.

The issue of structuring text to enhance meaningful learning was further explored in a set of studies that varied the local and global coherence of science texts (McNamara, Kintsch, Songer, & Kintsch, 1996). Traditionally, one would seek to maximize learning by making a text as easy to read and comprehend (i.e. maximally coherent) as possible. However, just as an *inconsistent* outline/text combination from the previous study (Mannes & Kintsch, 1987) led to more learning, McNamara et al. theorized that a more challenging text (i.e. minimally coherent) would lead to better learning for students who possessed the required background knowledge because it would induce them to more actively process the information and create more elaborate situation models -- utilizing their background knowledge to fill in coherence gaps -- thus bringing about a deeper integration of new and old knowledge. This integration, in contrast to an episodic memory of the specific text (text base), should also lead to enhanced retrieval of information due to the newly established connections of text concepts with the related concepts in the learner's long-term memory. Thus, one would be most likely to see the impact of the more challenging text structure on assessments that more directly tap into the learner's situation model, such as problem-solving transfer tasks.

The difficulty of the science text used in the McNamara et al. study (1996) included two conditions -- (1) a maximally coherent text, and (2) a minimally coherent text. Coherence was maximized by several techniques such as replacing pronouns with specific referents, and providing explicit connections between sentences and between paragraphs and the main topic of the text. Conversely, coherence was minimized by replacing specific referents with pronouns and deleting connections between individual sentences and between paragraphs and the main topic of the text. Participants who were *lower* in background knowledge performed significantly better when given the *maximally* coherent text. In contrast, the participants who were *higher* in background knowledge performed significantly better when given the *minimally* coherent texts. Thus we see that simpler texts may be better for some individuals while more challenging texts (i.e. “elaborated explanations” in the proposed study) are preferable for other individuals (this issue will be explored in greater detail in section 4).

The effect on learning from increased explanation elaboration is unclear. In some cases the more challenging material may lead to more active processing and enhanced learning. However, the increased difficulty may overwhelm the learner’s cognitive resources and instead bring about reduced comprehension and learning. As noted by Graesser et al. (2002), “the key challenge is to arrange the learning environment so that the right text is available to the right student at the right time” (p. 3). One way of accomplishing this would be by providing learners with varying degrees of explanations and allowing them to *choose the right text* for themselves in the given situation. Of course this raises a number of other questions regarding how one determines the appropriate explanation, which will be addressed in detail in the following section.

Learner Control

The Web is in essence, a massive hypermedia system. Hypermedia systems consist of interconnected nodes of information (e.g. web pages containing text and graphics) that are connected via hyperlinks (also referred to as links). The nodes, in the case of the Web, are web pages (also referred to as pages) that are typically composed of text, graphics, or some combination of text and graphics. The links typically consist of brief text or a graphic icon that is "clickable" so that when the user selects a link, a new page is rapidly made available to the user.

This allows hypermedia users to be "freed from the linear, highly directed flow of printed text" (Marchionini, 1988, p. 8). Thus, in contrast to standard text, information on the Web can typically be accessed nonsequentially and in a variety of differing orders.

1.1.3. Learner Control: Theory

There is no agreed upon formal definition of "linearity", but the term will be used herein as referring to learners taking a more direct path through the information space. Non-linearity will then be used to refer to learners taking a less direct path through the information space -- one that may include "detours" to explore relevant, but secondary material.

While the vast majority of the Web and Hypermedia literature makes a clear distinction between text ("linear") and the Web ("non-linear") it should be noted that such a distinction is an oversimplification. Previous studies have shown that people's reading behavior of text is not simply a start-to-finish linear process (Balcytience, 1999; Dillon, Richardson, & McKnight, 1989; Horney, 1993). That said, what we can claim is that the non-linear structure of Hypermedia should make it *more likely* that people will engage in non-linear movement through the information space.

The Web's non-linearity affordance raises the issue of *learner control*, which refers to the degree to which the learner has input on the manner in which an instructional activity unfolds. It is a continuous measure of varying degrees; minimal user control (e.g. merely clicking on a "next" button to advance to the subsequent predetermined material); moderate user control (e.g. unfettered choice on the pacing and *sequencing* of an educational activity); and significant user control (e.g. unfettered choice on the pacing and sequencing of an educational activity as well as control over the *type* and *amount* of instructional content viewed).

The varying levels of learner control raise significant difficulties with conducting empirical research on this subject. In particular, the lack of experimental control for conditions of high learner control makes it difficult to determine the causal relationships involved. For instance, imagine the situation where a student is given significant learner control, and decides to view the instructional content in an atypical sequence and not go over some parts of the lesson. If the student's learning is less than when given the same lesson with less learner control, is the decrease in learning due to increased learner control or merely due to not viewing as much of the instructional lesson? Potential techniques for helping to minimize such problems with confounding will be discussed later in the methods section.

As implied above, the web's non-linearity and greater degree of learner control result in learning processes that are inherently more intentional and goal-directed (see section on learner goals). One direct implication of this is that *personal interest* in the instructional topic and other intrinsic motivational factors (e.g. Dweck, 1986; Iyengar & Lepper, 2000; Lepper, 1988; Tobias, 1994) will play a significant role in Web-based education since learners are just "one-click-away" from terminating the lesson (also see learning goals and interest sections). As Wolfe, Myers, & Cummins, (2001) commented, the alternative to a particular web-based instruction may be no instruction whatsoever.

As noted by Hidi (1990), *interest* is central for determining the types of information we *select* and persist in processing, in preference to other types of available information. For instance, Volmeyer and Rheinberg (2000) found that the degree of learner interest had a significant positive correlation with the amount of training "rounds" that students chose to undergo when learning about a complex dynamic simulation. So one would predict that in situations in which individuals have control over the viewing of instructional material, that there would be a positive correlation between the amount of material viewed and an individual's degree of interest in the topic under study.

However it is still an open question whether or not increased learner control translates into increased learning, even when individuals have higher degrees of interest in the topic under study. The results from prior research on learner control will be briefly summarized below.

1.1.4. Learner Control: Evidence

Increased Learning. Studies of the effects of learner control generally find no differences in learning. However, a small number of studies have found learning gains under specific circumstances in which small amounts of control were provided but were limited to just choosing the number of practice and review problems (e.g. Gray, 1987; Kinzie, Sullivan, & Berdel, 1988; Lee & Lee, 1991; Shute, Gawlick, & Gluck, 1998).

Decreased Learning. Some studies have found the opposite results, namely that when individuals were given learner control, their achievement *decreased* (e.g. Belland, Taylor, Canelos, & Baker, 1985; Tennyson, Park, & Christensen, 1985; Tennyson, Welsh, Christensen, & Hajovy, 1985). One likely cause for this reduction is inadequate metacognitive strategies or learning goals which seek to minimize effort instead of maximizing learning (see sections on metacognition and learning goals).

No Differences in Learning. Two recent peer-reviewed journal publications -- a hypertext meta-analysis (Chen & Rada, 1996) and an in-depth review of quantitative hypermedia research (Dillon & Gabbard, 1998) are empirical reviews of hypermedia and learning and will thus serve as a good starting point. The meta-analysis (Chen & Rada, 1996) attempted to compare 23 experimental studies in terms of *effectiveness* (i.e. achievement scores and the degree to which users moved to and encountered what was considered to be relevant information) and *efficiency* (i.e. amount of time required to complete task). Of most relevance here are findings regarding effectiveness -- the meta-analysis included 13 studies in which effectiveness measures were obtained (total combined sample size = 466). They found a moderately small effect size (r=.12) favoring the use of hypermedia over non-hypermedia. The second major hypermedia publication was the in-depth review of quantitative hypermedia research by Dillon and Gabbard (1998). Echoing the difficulties voiced by Chen and Rada (1996), Dillon and Gabbard admitted that their attempt to synthesize such a disparate set of literature was an extremely difficult task. In addition, they were only able to find 30 published studies that met their minimal standards of acceptability -- namely, that studies be: quantitative, empirical, and experimentally valid (i.e. not confounded). In brief, the review found that hypermedia was overall comparable to other instructional methods. Dillon and Gabbard note that the "majority of experimental findings to date indicate no significant comprehension differences using hypermedia or paper" (p. 326).

A series of studies by Hegarty, Narayanan, and Freitas (2002) that compared learning about complex machines (e.g. toilet tanks, car brakes, bicycle pumps) from standard text versus hypermedia is representative of this body of research (also see Becker & Dwyer, 1994; Gray, 1987; McGrath, 1992; Shin, Schallert, & Savenye, 1994). There were *no significant differences* in terms of learning between the different conditions. The authors note that the “studies clearly indicate that it is the content and structure of instructional material, and not the media and modalities in which they are presented that is important for comprehension of complex devices.” (p. 372).

In a related study on reading and learning choice, Schraw, Flowerday, and Reisetter (1998) examined affective and cognitive gains from reading texts in which participants were either given or denied the choice of the selection of reading material. While the subjects in the choice condition (i.e. learner control) had more favorable attitudes toward the experience, there were no differences in cognitive outcomes. The authors summarize the research by concluding, "strong claims about the relationship between choice and cognitive engagement are inflated, at least with regard to adult readers. Many of these claims, in our opinion, appear to be anecdotal in nature and based on a strong folk-psychological belief that choice invariably enhances all manner of performance." (p. 711).

1.1.5. Learner Control: Summary and Predictions

One important affordance of the Web is its non-linearity, which can provide individuals with much greater control over the learning process. While many have speculated that the increased learning control of the Web would translate into increased learning, the empirical evidence reviewed fails to support this speculation. However, while direct comparisons between standard text (i.e. paper) and hypertext (i.e. Web) failed to find significant differences, one might speculate that there could be a significant effect of learner control when implemented in conjunction with explanations of varying degrees of elaboration.

Unifying Framework

As noted earlier, two conflicting approaches to enhancing learning suggest either to make the explanation *less* challenging (reducing cognitive load) or, to make the explanation *more* challenging (inducing more inference making and active processing).

One theory that may help account for this apparent contradiction is Metcalfe's (2002) theory of a *Region of Proximal Learning* (RPL), which she defined as a "region of materials or concepts just beyond the grasp of the learner that is most amenable to learning" (p. 350). Metcalfe explicitly acknowledged this theory's intellectual debt to the work of Vygotsky (1986) who proposed that there is a Zone of Proximal Development, which is a region just beyond the individual's ability to master on his or her own but can be accomplished with external support. While Vygotsky's Zone of Proximal Development (ZPD) emphasized the social aspects of learning and development, many researchers in education have interpreted the ZPD in a more general manner (e.g. Hung, 2001; Luckin, 2001; Murray & Arroyo, 2002, 2004)[2]. However, in order to avoid confusion about the use of the term, as highlighted by Chaiklin (2003), this paper will frame this issue in terms of Metcalfe's more appropriate Region of Proximal Learning (RPL) framework.

Before examining the Region of Proximal Learning, it will be helpful to first discuss the theory it is frequently contrasted with – the Discrepancy Difference Model (e.g. Dunlosky & Hetzog, 1998; Nelson & Narens, 1994; Thiede & Dunlosky, 1999). This model proposes that an individual first determines the "degree of discrepancy" between one's current knowledge state and one's desired knowledge state for a set of items. Next, the individual selects the most discrepant (i.e. least understood) items for study. The model predicts that when people are given a choice regarding selecting materials to study (e.g. pair associations of Spanish-English vocabulary lists), they will choose to focus on the most difficult items (i.e. most discrepant). An exhaustive review by Son and Metcalfe (2000) did find that the majority of studies (almost exclusively simple recall designs) did report results that provided support for this model. However, contrary to predictions of the Discrepancy Difference Model, several more recent studies have found that many times people choose to focus on learning easy and intermediate items instead of the predicted difficult items (Mazzoni & Cornoldi, 1993; Mazzoni, Cornoldi,

[2] For instance as noted by Brown, Ellery, and Campione (1998) "A *zone of proximal development* is a learning region that learners can navigate with aid from a supporting context, including but *not limited to people*. It defines the distance between current levels of comprehension and levels that can be accomplished in collaboration with other people or *powerful artifacts*." (p. 349-350, emphasis added).

Tomar, & Vecchi, 1997; Metcalfe, 2002; Metcalfe & Kornell, 2003; Son & Metcalfe, 2000; Thiedle & Dunlosky, 1999). It was in reaction to the inadequacies of the Discrepancy Difference Model that Metcalfe (2002) proposed her Region of Proximal Learning (RPL) theory.

The region of proximal learning framework holds that concepts that are either already learned or are too difficult to master given the learner's current level of understanding, are outside the individual's region of proximal learning. The most instructionally effective materials will be those that are just slightly beyond the learner's current understanding (Metcalfe & Kornell, 2003). Based on the region of proximal learning, one would expect there to be a range of intermediate difficulty that should lead to optimal learning (see figure 1 below). More specifically, if the explanation were too easy for an individual, then the first strategy of making the explanation *more* challenging should be used to improve learning. If, on the other hand, the explanation were too difficult, the second strategy of making the explanation *less* challenging should be used in order to enhance learning.

As noted by Wiley and Schooler (2001), "it has long been held that there is an optimal match between reader and text that may result in the best learning outcomes" (p. 250). This immediately raises the question of the factors that would lead to such an optimal match.

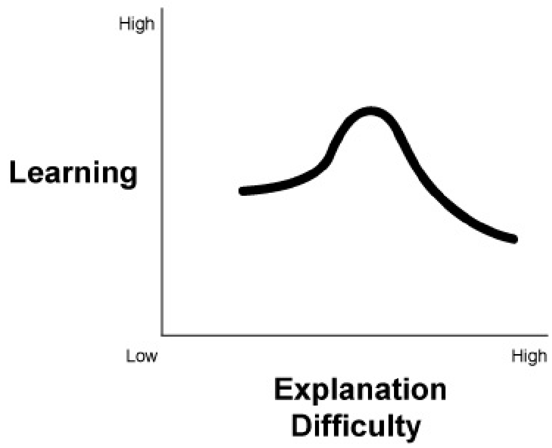


Figure 1 Hypothesized learning as a function of explanation difficulty.

The range of optimal learning will vary from person to person, based on multiple factors. We can predict that for *Strong* students (i.e. those with higher amounts of Prior Domain Knowledge) there will be significantly greater learning of basic information (i.e. that which is not directly covered in the elaborations) in the more challenging elaborated explanations (EE) sections. In contrast, for *Weak* students (i.e. those with lower amounts of Prior Domain Knowledge) there will be significantly greater learning of basic information in the less challenging unelaborated explanation (UE) sections. There are a number of factors that will influence an individual's region of optimal learning, such as the person's amount of domain knowledge of the subject in question, as well as their metacognitive and reading skills.

1.1.6. Unifying Framework: Prior Knowledge

Previous research has shown that prior knowledge significantly affects comprehension and learning (Alexander, Kulikowich, & Schulze, 1994; Bransford & Johnson, 1972; Chiesi, Spilish, & Voss, 1979; Mayer & Gallini, 1990; Mayer, Steinhoff, Bower, & Mars, 1995; McNamara 2001; McNamara & Kintsch, 1996; McNamara, et al., 1996). In order for individuals to create rich situation models of the explanation content, they need to generate inferences interconnecting different aspects of the explanation as well as linking the new information to what they already know (i.e. prior domain knowledge). Given that the purpose of expository texts is by definition to teach new information, the domain content is, by design, unfamiliar to learners (Chambliss, 2002). Thus the initial stage of learning about a new subject domain will be especially difficult. However, once over this initial hurdle, the impact of prior domain knowledge becomes beneficial, creating a virtuous cycle (i.e. positive feedback) in which the increased knowledge leads to an increased ability to learn, leading to greater domain knowledge, and so forth.

A process model of learning from text was put forward and tested by Britton, Stimson, Stennett, and Gulgoz (1998). An individual's domain knowledge significantly influenced how much they would learn from reading an explanation. Similarly, when examining learning from science texts in the classroom, Cottrell and McNamara (2002) found that prior knowledge was the best predictor for exam performance. In both cases though, there were significant interactions between an individual's prior knowledge and their metacognitive ability. This will be explored further in the following section.

1.1.7. Unifying Framework: Metacognition and Reading Ability

The process model of learning from text created by Britton et al. (1998) found that metacognitive ability significantly interacted with an individual's domain knowledge in influencing learning from text. Similarly, O'Reilly and McNamara (2002) found that metacognitive ability could help students to compensate for a lack of domain knowledge.

When applied to the task of reading and learning from an explanation, metacognition refers to the process of comprehension monitoring (i.e. looking for inconsistencies or gaps in understanding) and the process of engaging in strategies for creating appropriate situation models. Such strategies include processes such as generating elaborations and connecting the new information with one's prior knowledge (e.g. Chi et al., 1989, 1994). Of course, not all metacognitive strategies are equally effective. For instance, in a study by Cote, Goldman, and Saul (1998), elementary school children were given explanations of varying difficulty and asked to think aloud while reading them. One of the most common strategies employed was simply to *ignore* and *skip over* any problems they encountered. This may be even more common when students read science texts. Phillips and Norris (1999) found that when individuals read expository science text, they approached the task with a "deference epistemic stance" in which the readers simply gave up trying to reconcile their prior knowledge with the new information presented in the explanation.

While there is a great deal of evidence for the use of a range of optimal learning, there are still several important unresolved questions. First, do individuals have the ability to accurately determine and select instructional material that is actually within this range? Secondly, even if individuals have this ability, are they then willing to actually *choose* this material?

Research by Atkinson (1972) showed that compared to learning from a randomized list of vocabulary words, individuals learned significantly more vocabulary words when given personal control over the difficulty level of the material. Thus we see some evidence for the benefit of learner control when used in conjunction with instruction of varying difficulty. However, the learners' metacognitive judgment and learning strategy selection were far from optimal – the subjects learned more than twice as much when the computer tutor selected the problems from the set of items of moderate difficulty.

While individuals may have the ability to choose and select information within their region of proximal learning, this does not guarantee that they will do so -- this will depend at least in part on their learning goals.

1.1.8. Unifying Framework: Learning Goals

There are two primary learning goals employed -- maximizing learning or minimizing effort. Students seeking to maximize their learning gains are often required to exert greater effort and engage in what Bereiter and Scardamalia (1989) refer to as *intentional learning*. This occurs when students "actively try to grasp the central messages of the text and try to relate them to his or her own knowledge" (p. 368).

Alternatively, some students do not seek to maximize their learning, but instead merely seek to minimize the amount of mental exertion expended, which will be referred to here as the *effort minimization* approach. This approach was surprisingly common in informal web learning studies (e.g. Vergo, Karat, Karat, Pinhanez, Arora, Cofino, et al., 2001) in which it was found that potential learners had preferences that often did not include maximization of learning. More specifically, individuals were not particularly interested in engaging in the more active interactions (e.g. engaging in chat, recording notes, etc.) but instead preferred the more T.V.-like passive interactions such as watching streaming video (i.e. a finding summed up by the paper's title "Less Clicking, More Watching*")*. In situations in which there are high degrees of learner control, the importance of learner goals will be even more pronounced.

One factor that influences the choice of learner goals is the subjective interest individuals have in the topic under study. Although interest has long been held to be of major importance to instruction (e.g. Dewey, 1913), it is only fairly recently that more rigorous empirical approaches have started being used in an attempt to operationalize and determine interest's unique contribution to learning (Hidi & Baird, 1986).

1.1.9. Unifying Framework: Interest

One important distinction for helping to better understand the concept of interest was made by Hidi (1990; Krapp, Hidi, & Renninger, 1992) between what she called *individual* interest and *situational* interest. Individual interest is a characteristic of a person, is relatively stable, and is deeply connected to the individual's knowledge and values. In contrast, situational interest is a characteristic of an environment, is relatively unstable, and is elicited by aspects of a learning environment. While clearly there are interactions between these two aspects, one can view the psychological state of someone being "interested" (e.g. increased concentration and feelings of enjoyment) as being primarily triggered by either aspects of the individual (i.e. they have an interest in the topic) or the situation (i.e. a presentation technique that is novel or highly salient).

When examining learning from text, instead of using the term "individual interest", the term *topic interest* is normally used and refers to a relatively stable evaluative orientation toward a certain domain or topic (Ainley, Hidi, & Berndoff, 2002; Schiefele, 1999). In the experiments presented here, the focus was on how individuals' interest in the domain of science and the topic of the aerodynamics of flight, might influence subsequent learning.

In addition to the issue of selecting instructional content, some have speculated that interest may influence the type of processing and strategies employed by learners such that students with greater topic interest would be more likely to employ "deeper" learning strategies leading to enhanced learning (e.g. Alexander, Kulikowich, & Jetton, 1994; Krapp, et al., 1992). However, at the present time, this relationship has not yet been established and awaits further empirical research.

Previous research, such as the meta-analyses by Schiefele and his colleagues (Schiefele, 1999; Schiefele, Krapp, and Winteler (1992), has indicated that the average correlation between interest (personal and situational) and student achievement (e.g. knowledge acquisition, grades, etc.) is approximately 0.30 and accounts for about 10% of the variance in learning across different subject domains, and age groups. Schiefele (1999) noted that the relationship between interest and learning from text appears to be independent of "text length, nature of text (narrative vs. expository), method of learning text (e.g. recognition vs. recall), age (or grade level), reading ability, prior knowledge, and text difficulty" (p. 265). Similarly, a study by Alexander, et al., (1994) examined this issue in greater detail. They had undergraduate students read two expository science texts. After accounting for the students' topic knowledge, interest accounted for an additional 5 percent of the variance for predicting comprehension outcomes.

One would therefore predict that knowledge gains in studies examining learning from text should have comparable results -- with interest having a correlation of about 0.30 with learning (and accounting for 5-10% of the variance).

1.1.10. Unifying Framework: Summary and Predictions

The cognitive load theory research discussed earlier suggested that the simplification of instructional material would enhance learning. In contrast, research from the active processing perspective makes the opposite prediction, so that making instructional material more challenging would enhance learning. This apparent contradiction might be explained by the fact that increasing (or decreasing) the difficulty of an explanation may move it either into or out of an individual's region of proximal learning (see Figure 2 below).

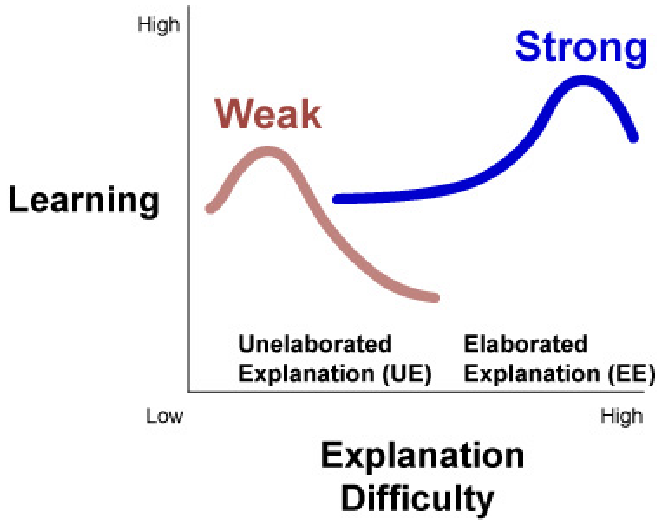


Figure 2 Predicted learning -- explanation difficulty and prior domain knowledge.

Hence, it is predicted that if one had a simple, unelaborated explanation (UE), increasing its difficulty such as done with a more challenging elaborated explanation (EE), one might see a relative decrease in learning for weaker students and a relative increase in learning for stronger students.

At the same time, when the existing literature and theoretical frameworks above are considered additively, it is suggested that the affordance of learner control might have the potential to significantly enhance learning if it were to be instantiated in conjunction with another design feature – varying degrees of *explanation elaboration*. In comparison to a simple, unelaborated explanation (UE), an elaborated explanation (EE) provides additional information and delves deeper into the domain content, increasing the difficulty of the task of reading and comprehending the material. The elaborated explanation also increases the number of inferences required for maintaining comprehension, encouraging more *active processing* that may lead to greater learning. However, it will also increase the learners' *cognitive load* which may overwhelm the learner, leading to lower learning. This issue is currently unresolved and in need of further research.

The greater control for the learner afforded by the Web provides educational designers with the potential for readily creating explanations of varying degrees of elaboration -- the level of which the learners can select for themselves, instead of being forced into a one-size-fits-all instructional lesson. As discussed above, the effectiveness of such instruction will depend on several factors, including characteristics of the learners themselves (e.g. metacognitive ability, prior knowledge, learning goals, etc.).

Overview of Studies

The first experiment was concerned with assessing the feasibility and applicability of using the Region of Proximal Learning as a unifying framework to account for the seemingly contradictory research from the Cognitive Load and Active Processing perspectives. After pre-test assessments of prior knowledge and abilities, all of the participants read an introductory text section on the science of flight, which was presented as a single web page. All participants in both the Elaborated Explanation (EE) and Unelaborated Explanation (UE) conditions then rated the difficulty of this text, and were asked to read a second text section covering basic information on four main factors influencing flight (i.e. wing angle, shape, surface area, and airspeed). However, the text for the participants in the Elaborated Explanation (EE) condition contained four *additional* challenging elaborations (one for each of the four aerodynamic factors)[3]. For the participants low in prior domain knowledge (i.e. "Weak") the increased difficulty of processing this additional information was predicted to impair learning of the basic information (i.e. the

[3] Unlike research that increased the difficulty of a text by degrading its readability (e.g. McNamara et al., 1996), these studies increase the difficulty by providing additional material that is conceptually more difficult. For instance, the second elaboration (see Figure 4) introduces the issue of intermolecular forces underlying the concept of viscosity.

information contained in both versions of the text) due to excessive cognitive load. In contrast, for the participants high in prior domain knowledge (i.e. "Strong") the increased difficulty was predicted to lead to more active processing, but not excessive cognitive load, and enhance learning of the basic information. Learning was assessed via a set of recall, near inference, and far inference (i.e. transfer) questions. The primary hypothesis for this experiment can be more formally described as follows:

> *Hypothesis 1 (Experiment 1)*: In comparison to the reading of a simple unelaborated explanation (UE -- basic information), an elaborated explanation (EE – basic information plus additional challenging information) will differentially affect the learning gains of the basic information presented. More specifically, it is predicted here that stronger individuals (i.e. those higher in prior domain knowledge) will learn significantly *more* basic information when given more difficult elaborated explanations (i.e. EE > UE). In contrast, weaker individuals (i.e. those lower in prior domain knowledge) will learn significantly *less* basic information when given the challenging elaborated explanations (i.e. UE > EE).

The second experiment was concerned with how the affordance of learner control, an inherent aspect of the Web, would interact with the proposed unifying framework of the Region of Proximal Learning. This experiment was similar to the first, with the main difference being that in the Elaborated Explanation (EE) condition, participants had control over the reading of elaborations. If participants wanted to see an elaboration, he or she would click on an embedded hyperlink and read the text in a pop-up window. It is noted that the addition of learner control to the EE condition of this study greatly reduced experimental control, making predictions more difficult. Individual factors such as learning goals and personal interest in the topic under study were expected to play a greater role in such situations. The primary hypothesis for this experiment can be more formally described as follows:

Hypothesis 2 (Experiment 2): Building upon the first experiment, it was predicted that the additional learner control afforded by the Web would allow individuals to adaptively select explanations most appropriate for their ability level, minimizing the differential effect of ability level. More specifically, this was predicted to allow individual of varying ability, particularly weaker individuals, to better optimize their learning.

2. EXPERIMENT 1

Experiment 1 was designed to address the apparent contradictions between the Cognitive Load and Active Processing perspectives. It may be that having individuals read a text with additional, challenging elaborated explanations will lead to a relative increase or decrease in learning, depending upon their level of prior domain knowledge. An additional goal of this experiment was to examine the relationship between individuals' interest in a topic and their overall learning gains, which previous research had shown to be significantly correlated.

Method

2.1.1. Participants

The participants were 48 (males = 23, females = 25) undergraduate students from the University of Pittsburgh, from the department of Psychology subject pool, and recruited (for pay) from the wider University community.[4]

2.1.2. Design

The experiment was a three-factor mixed-model repeated-measures analysis of variance (ANOVA) design: 2 (condition: UE, EE) X 2 (prior domain knowledge: Weak, Strong) X 2 (time: Pretest, Posttest). The first factor was a between-subjects factor in which participants were randomly assigned to either the Unelaborated Explanation (UE) condition, or the Elaborated Explanations (EE) condition. In the unelaborated explanation condition, the participants were provided with basic information needed for the creation of a situation/mental model. In the

[4] A total of 103 participants were run altogether (i.e. including both experiment 1 and 2), but 7 were excluded due to their failure to complete one or more pre-test assessment. Recruitment was continued until 96 participants (48 for each study) were acquired.

elaborated explanation condition, the participants were again provided with basic information needed for the creation of a situation/mental model, but was also given additional challenging material on the topic of the aerodynamics of flight. The second factor, prior domain knowledge, was determined by participants' domain knowledge as assessed by pre-test scores. Due to the focus on low versus high prior knowledge comparisons, a tripartite split was performed on the 24 participants randomized into each condition. The participants in each condition were ranked according to their prior domain knowledge. The 8 lowest scoring participants were categorized as "Weak" whereas the 8 highest scoring participants were categorized as "Strong."[5] The third factor, time, was a pretest-posttest repeated measure, (see Table 1 below).

Table 1 Experiment 1: Between-Subjects Design

		Prior Domain Knowledge	
		Weak (W)	Strong (S)
Explanation	Unelaborated Explanation (UE) *(Basic Info)*		
	Elaborated Explanation (EE) *(Basic + Challenging Info)*		

The text was presented within a single web page document. Participants had no control over whether to read the elaborations, unlike in experiment 2 where the viewing of such elaborations was optional.

[5] The excluded intermediate tripartite cases are included in table 1 in Appendix C.

The dependent measure was the amount of domain knowledge learned (i.e. basic info only[6]), which was assessed via the domain knowledge instrument administered before and after the instructional intervention (see Appendix A).

2.1.3. Materials

Explanations.[7] Aerodynamics (i.e. the science of flight) was the topic for these studies. This is a fairly popular informal science topic, in part, because people find the topic both relatively familiar and interesting. The topic is also surprisingly complex, readily allowing the creation of explanations at a large range of levels. The specific text (i.e. the specific textual and pictorial information) that was utilized was constructed from multiple sources: award winning informal learning websites such as “HowStuffWorks.com” (Brain & Adkins, 2003) and the informal science education website by NASA (Benson, 2003), as well as a number of aerodynamics and flight texts (Anderson, 1997; Anderson & Eberhardt, 2001).

Content Structure. The organization of the text can best be represented as consisting of two main sections -- an introductory text section followed by the main text section which included four explanation elaborations (see figure 3 below)[8].

[6] The assessments were designed to allow “room” for participants to use the additional information provided in the elaborated explanations, but coding here will focus on the basic information that was provided to all the participants.
[7] “Explanation” will refer to higher level, mental model/situation model representation of the domain topic, “Text” will refer to the specific verbal and diagrammatic information viewed by the participants.
[8] Length of text sections: Introductory Text Section: 1,283 words, Main Text Section: 862 words, Elaboration 1: 185 words, Elaboration 2: 190 words, Elaboration 3: 253 words, and Elaboration 4: 471 words.

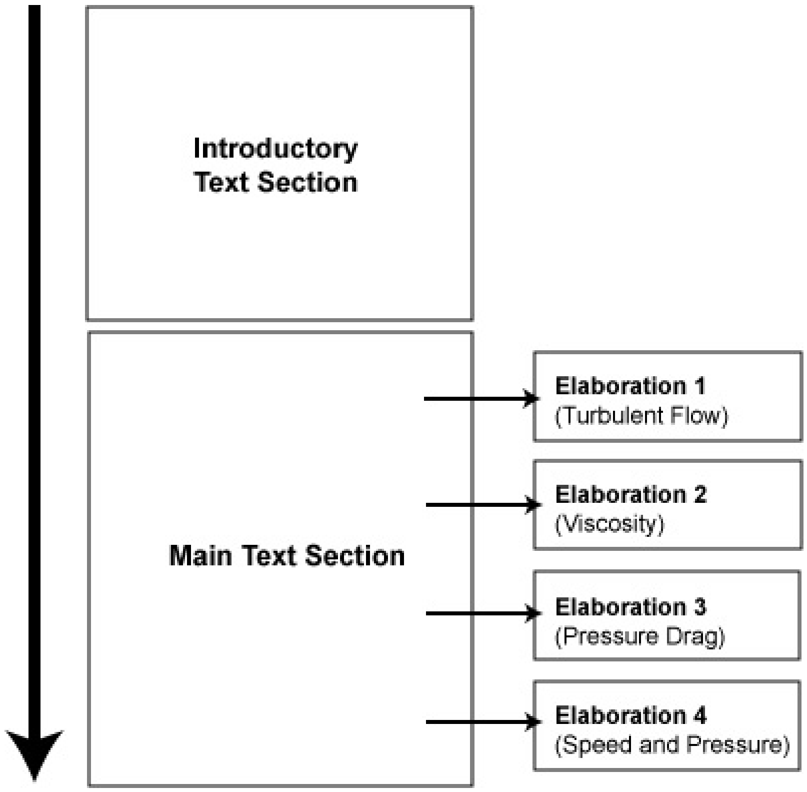


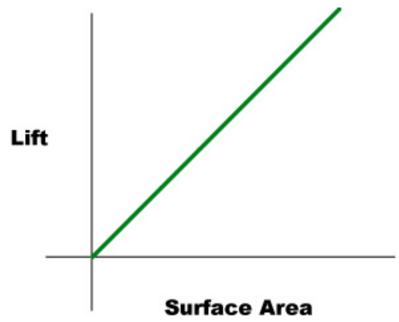
Figure 3 Diagram of the overall text structure and arrangement of the elaborated explanations.

An example of part of the main text section, along with the second elaboration (Viscosity) is provided below in Figure 4.

Wing Structure

Another important set of related factors is the wing's surface area and shape.

Surface Area
Increasing the surface area of a wing allows more air to be deflected, proportionately increasing the lift. So if you double the surface area, you double the lift (as shown below).



One type of drag is called *friction drag* and is the result of the friction between the fluid and the surface of the object.

This friction is determined in part by the fluid's *viscosity*, which is a measure of how resistant it is to flow.

<-- Previous Next -->

---Additional Information---
This friction is determined in part by the fluid's *viscosity,* which is a measure of how resistant it is to flow.

The absolute viscosity of a fluid is a measure of its resistance to shear stresses, which act tangentially to the object's surface. Viscosity can be thought of as an "internal friction" of a fluid, which is determined by its composition (i.e. the intermolecular forces between the molecules). Greater viscosity (i.e. more resistant to flow), results in greater frictional drag.

Consider a fluid flowing over a surface as illustrated in the picture below. Due to viscosity, the film of fluid next to the surface will be sticking to it and will, therefore, have zero velocity. Fluid further away from the surface will slip over the fluid beneath it as it moves to the right. Since each successive layer of fluid will slip over the layer below it, the velocity of the fluid will increase with the distance from the surface over which the fluid is flowing.

This creates a thin layer of fluid near the surface in which the velocity changes from zero at the surface to the free stream value away from the surface. This layer is called the *boundary layer* because it occurs on the boundary of the fluid.

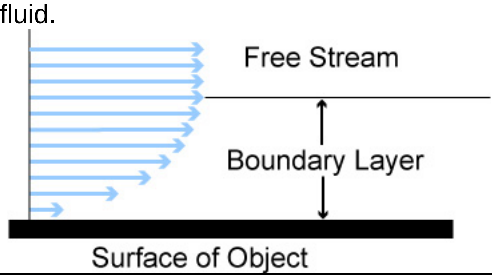


Figure 4 Excerpt from science text (hyperlink denoted by underlined text).

The accuracy of the materials were reviewed and verified by a local domain expert -- University of Pittsburgh professor Dr. Michael Kolar, the current Dean of the School of Engineering and a former NASA engineer.

2.1.4. Procedure

The experiment was completed during a single session that was comprised of three phases: pretest, intervention, and posttest (see Table 2 below for the Schedule of Data Collection and see Appendix A to review the assessment instruments and instructional text).

Participants in the pretest phase were administered multiple instruments for the purpose of determining their baseline level of study-relevant academic abilities, interests, exposure, and knowledge (for statistical comparisons and correlations of these factors, see Results below and the Tables of Appendix C).

2.1.5. Measures

Nelson-Denny Reading Test. This instrument (Nelson & Denny, 1973) is a timed test comprised of 7 reading comprehension passages that provides measures of comprehension and reading rate. It was administered during the pretest phase of the study as a measure of participants' reading abilities. Reported reliability ranges from .88 to .95 (Brown, Fishco, & Hanna, 1993), and it is reported to have predictive validity of academic success (Feldt, 1988).

Metacognitive Awareness of Reading Strategies Inventory (MARSI). This is a 30-item self-report scale that measures readers' awareness of the self-control mechanisms that they utilize while monitoring and regulating their efforts to comprehend a text (Mokhtari & Reichard, 2002).

This scale was also administered during the pretest phase of the investigation; it was used to provide a rough baseline measure of participants' use of metacognitive reading strategies.

Need For Cognition Scale. This scale consists of 18 items that evaluate participants' tendencies to engage in cognitive tasks that require mental effort (Cacioppo & Petty, 1982; Cacioppo, Petty, and Kao, 1984). Participants rated each item using a 5-point Likert-type scale, based on the extent to which they believed each item characterized them. This scale was administered during the pretest phase of the study in order to establish baseline levels across participants regarding their predisposition to engage in mentally taxing tasks. Reported reliability ratings have been found to be high, with Cronbach's alpha calculated to be .90 (Cacioppo et al., 1984).

During the pretest phase, participants in this investigation were also administered four instruments created specifically for this experiment. First, the *Web Experience Questionnaire* was designed and utilized in order to measure how familiar participants were with using the Web. This was followed by the *Science & Topic Interest Rating Scale*, which is a brief set of questions that was created in order to determine participants' interest in Science in general, and Aerodynamics in particular. Following this was an *Academic Background Questionnaire*, which focused on prior science courses that participants had taken and was designed for the purpose of estimating their previous exposure to science learning.

Lastly, a *Domain Knowledge Assessment* was designed for the purpose of measuring participants' knowledge in the area that the study texts focused upon, i.e., the aerodynamics of flight. This is the only scale that was administered in both the pretest and posttest periods of the study, and its usage permitted the participants' knowledge gain scores to be assessed following the study intervention. This assessment consisted of 22 questions designed to gauge participants' understanding of the domain of aerodynamics covered in the unelaborated explanations (i.e. the questions targeted the basic information presented in all conditions) (see Appendix A). One question was entirely open-ended and included solely for use with future mental model analyses in conjunction with verbal protocol analyses. The remaining 21 questions were coded for the presence of correct, relevant idea units.

The coding involved three different categories of answers – those involving (1) Recall, (2) Near Inference, or (3) Far Inference. For instance, one question was: “What is the pressure of air *above* a wing compared to that of the surrounding air? If it is different, explain why.” One correct answer to the question would be: “It’s lower, but it depends on the angle of the wing.” In this example, the idea that the “pressure is lower” is correct and because it’s an idea that was explicitly stated in the text read by the participants, it would be coded as a correct Recall Idea Unit. The second part of the answer that the “pressure depends upon the angle of the wing” is also correct and because it’s an idea that was not explicitly stated in the text, but instead required the participant to combine two ideas from different sentences, it would be coded as a correct Near Inference Idea Unit. There were several problem-solving questions in which participants were required to transfer and apply the material to a new situation. For instance, one question involved making a design decision on modifying an airplane to increase its lift by either doubling the power of the engine or doubling the area of the wings. This question requires that the participant make Far Inferences -- integrating multiple sections of the text to determine the correct answer (i.e. that one should double the engine size -- Lift and Surface Area are linearly related while Speed and Lift are exponentially related). A Correct answer to such a problem would be coded as a correct Far Inference Idea Unit. The maximum possible score one could obtain is 89 (57 for Recall, 10 for Near Inference, and 22 for Far Inference).

Answers to the domain knowledge questions were randomize and coded “blind” by the experimenter. That is to say, the coder had no knowledge of an answer’s temporal sequence (pretest or posttest), condition (UE or EE), or prior domain knowledge (Weak or Strong). A subset of the data (15%) was randomly selected and coded by two research assistants who were blind to both the status of the data and experimental hypothesis. Analysis of the coding performed by the experimenter and the subset of data coded by the research assistants (calculated across both experiments), established a Kappa of 0.85, indicating sufficient interrater reliability.

Table 2 Schedule of Data Collection

PHASE	TASKS
Pretest (~60 min.)	Reading Comprehension Test Metacognition Rating (MARSI) Need for Cognition (NFC) Rating Web Experience Questionnaire Science & Topic Interest Rating Academic Background Questionnaire *Domain Knowledge Assessment* Talk-aloud Practice [Break for participant]
Intervention (~30 min.)	Reading of Introductory Text Section Difficulty Rating (baseline) Reading of Main Text Section (UE or EE) Difficulty Rating [Break for participant]
Posttest (~30 min.)	*Domain Knowledge Assessment* Learning Goals & Strategies Rating

In preparation for the instructional intervention, participants were given a text on the architecture of bridges (Talk – aloud Practice) which served as a means for them to practice and become familiarized with engaging in the talk-aloud procedure. This practice text also served as a "baseline" for comparison in the subsequent difficulty rating. After this practice, participants were required to take a break of several minutes.

The intervention phase consisted of the participant reading the appropriate two sections of the text.[9] Each section was immediately followed by a brief Likert-scale difficulty measurement which served as a manipulation check that the elaborated explanations were in fact perceived to be more difficult. After completing the second difficulty rating, participants were again required to take a break of several minutes.

Lastly, the posttest phase consisted of the identical domain knowledge assessment given in the pretest phase. This was followed by a structured self-report exercise, designed by the author for the study, that inquired about the goals and strategies employed by the participant while reading the text (see Appendix C).

Results

2.1.6. Baseline Equivalence between Conditions

Baseline levels of both domain-related knowledge and ability of participants were statistically compared across both conditions (and both experiments). An alpha level of .05 was used for all statistical tests. No significant differences between conditions or experiments were found on any pre-test measure (i.e. Prior Domain Knowledge, Reading comprehension (Nelson-Denny), Metacognitive Strategy (MARSI), Need for Cognition, Web Experience, Topic Interest, or Academic Background) (see Tables 3-8 in Appendix C).

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[9] The reading of the practice text, Introductory Text Section, and Main Text Section were videotaped for future analyses.

2.1.7. Text Difficulty Manipulation

The texts were composed with two main sections. The first section, Introductory Text, introduced basic aerodynamic principles to the participants. The content of this section was identical between conditions and it was therefore predicted that there would be no significant differences in perceived difficulty between participants.

A pair of difficulty estimation questions were completed immediately after reading the Introductory Text, and involved a Likert scale rating comparing the difficulty of the recently read text to that of the earlier practice text (i.e. (1) Much Easier, (4) Same, (7) Much Harder). A one-way ANOVA was performed and as predicted, there were no significant differences in perceived difficulty of the Introductory Text between conditions, Unelaborated Explanations (UE) (M = 3.88, SD = 1.15), Elaborated Explanations (EE) (M = 4.13, SD = 1.03), $F(1, 30) = 0.42$, $p = .52$. The second difficulty estimation question was a Likert scale rating of how much "mental effort" was involved in reading the text (i.e. (1) Extremely low, (2) Very low, (3) Low, (4) Neither low nor high, (5) High, (6) Very high, (7) Extremely high). A one-way ANOVA was performed and as predicted, there were no significant differences in mental effort involved in reading the Introductory Text between conditions, UE (M = 4.38, SD = 0.72), EE (M = 4.75, SD = 1.34), $F(1, 30) = 0.97$, $p = .33$.

The second section, Main Text, covered four main aerodynamic factors: (1) Wing Angle of Inclination, (2) Wing Surface Area, (3) Wing Shape, and (4) Airspeed. In the EE condition, each of the four subsections contained additional challenging information over-and-above what was presented in the UE condition. The content of this section was very different between conditions and it was therefore predicted that the EE condition would be judged to be significantly more difficult than the UE condition.

As before, the pair of difficulty estimation questions was completed immediately after reading the Main Text, and involved a Likert scale rating comparing the difficulty of the recently read text to that of the earlier practice text (i.e. (1) Much Easier, (4) Same, (7) Much Harder).

A one-way ANOVA was performed and as predicted, there was a significant difference in perceived difficulty of the Main Text between conditions. The UE condition (M = 4.63, SD = 1.36) was perceived as significantly less difficult than the EE condition (M = 5.69, SD = 1.01), F(1, 30), = 6.27, p = .02 (See first row Table 3 below).

Independent samples t-tests were performed, and as predicted, revealed that *Weak* participants found the EE (M = 5.75, SD = 1.28) condition was (marginally) significantly more difficult than the UE (M = 4.63, SD = 1.60) condition, t(14) = 1.43, p = .07 (one-tailed). Similarly, *Strong* participants found the EE (M = 5.63, SD = 0.74) condition was also significantly more difficult than the UE (M = 4.63, SD = 1.19) condition, t(14) = 2.02, p = .03 (one-tailed). (See first row of Table 4 below).

The second difficulty estimation question was also completed immediately after reading the Main Text, and involved a Likert scale rating of how much "mental effort" was involved in reading the text (i.e. (1) Extremely low, (2) Very low, (3) Low, (4) Neither low nor high, (5) High, (6) Very high, (7) Extremely high). A one-way ANOVA was performed, and as predicted, there was a significant difference in perceived difficulty (i.e. "mental effort") of the Main Text between conditions. The Unelaborated Explanation (UE) condition (M = 4.94, SD = 1.00) was perceived as less difficult than the Elaborated Explanation (EE) condition (M = 5.88, SD = 0.96), F(1, 30) = 7.35, p = .01 (See second row of Table 3 below).

Again, independent samples t-tests were performed and revealed that *Weak* participants found the EE (M = 6.13, SD = 0.84) condition was significantly more difficult than the UE (M =

4.88, *SD* = 0.99) condition, $t(14) = 2.73$, $p = .01$ (one-tailed) while *Strong* participants found the EE ($M = 5.63$, $SD = 1.06$) condition was not significantly more difficult than the UE ($M = 5.00$, $SD = 1.07$) condition, $t(14) = 1.17$, $p = .13$ (one-tailed). (See second row of Table 4 below).

Table 3 Main Text Difficulty by Condition

	Condition: UE	Condition: EE
Main Text Difficulty Est. "Relative Difficulty"	4.63 (1.36)	5.69 (1.01)
Main Text Difficulty Est. "Mental Effort"	4.94 (1.00)	5.88 (0.96)

Note: Tables display mean scores with standard deviations in parentheses.

Table 4 Main Text Difficulty by Condition and Prior Domain Knowledge

	Condition: UE		Condition: EE	
	Weak	Strong	Weak	Strong
Main Text Difficulty Est. "Relative Difficulty"	4.63 (1.60)	4.63 (1.19)	5.75 (1.28)	5.63 (0.74)
Main Text Difficulty Est. "Mental Effort"	4.88 (0.99)	5.00 (1.07)	6.13 (0.84)	5.63 (1.06)

2.1.8. Knowledge Gains

The overall knowledge gains (i.e. recall, near inference, and far inference) for participants were examined via a two-way (Condition, Domain Knowledge) repeated measures (Time) ANOVA. As predicted, there were significant gains in knowledge over time for all participants, $F(1,28) = 145.53$ $p < .001$. The interactions of Time X Condition (UE, EE) and Time X Domain Knowledge (Weak, Strong) were not significant, $F(1, 28) = 0.13$, $p = .72$; $F(1, 28) = 0.31$, $p = .58$. The main effect of Condition was not significant, $F(1, 28) = 0.15$, $p = .70$. The main effect of Domain Knowledge was significant, $F(1, 28) = 160.25$, $p < 0.001$. The interaction of Condition and Domain Knowledge was not significant, $F(1,28) = 2.35$, $p = .14$.

Most importantly, as predicted, there was a significant interaction between Time (pretest, posttest), Condition (UE, EE) and Domain Knowledge (Weak, Strong), $F(1, 28) = 6.39$, $p = .02$. In other words, it was predicted that there would be a significant interaction between Condition and Domain Knowledge such that Strong participants would learn significantly *more* basic information in the Elaborated Explanation (EE) condition (i.e. EE > UE) while Weak participants would learn significantly *less* basic information in this condition. Thus, support is shown for a key prediction of this experiment.

Additional analyses (i.e. independent samples *t*-tests) were performed comparing Strong and Weak participants across conditions. When data from the Strong participants were analyzed, it was revealed that they gained significantly *more* knowledge in the Elaborated Explanation (EE) condition ($M = 15.25$, $SD = 7.06$) than the Unelaborated Explanation (UE) condition ($M = 9.56$, $SD = 4.80$), $t(14) = 1.89$, $p = .04$ (one-tailed). When data from the Weak participants were analyzed, Weak participants were found to have gained (marginally) significantly *less* knowledge in the Elaborated Explanation (EE) condition ($M = 9.19$, $SD = 4.12$) than the Unelaborated Explanation (UE) condition ($M = 13.44$, $SD = 5.82$), $t(14) = 1.69$, $p = .06$ (one-tailed). Again, support is shown for important predictions of this experiment (see Table 5 and Figure 5 below).

Table 5 Domain Knowledge -- Pretest to Posttest changes, by Condition and Prior Domain Knowledge

	Condition: UE		**Condition: EE**	
	Weak	**Strong**	**Weak**	**Strong**
Pretest Score: Domain Knowledge	10.81 (3.60)	31.25 (4.00)	9.75 (4.31)	30.31 (3.33)
Posttest Score: Domain Knowledge	24.25 (8.13)	40.81 (6.26)	18.93 (4.49)	45.56 (7.40)
Pretest-Posttest Gain Scores	13.44 (5.82)	9.56 (4.80)	9.19 (4.12)	15.25 (7.06)

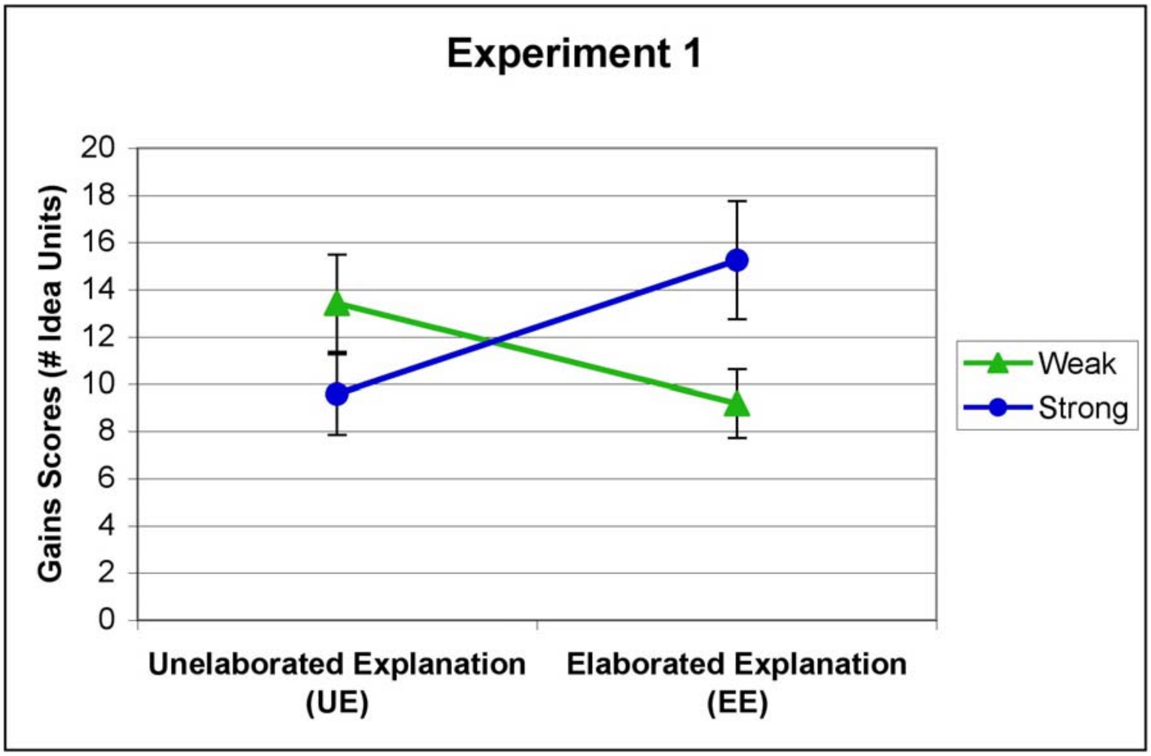

Figure 5 Gain scores by condition and level of prior domain knowledge.

2.1.8.1. Knowledge Gains - Recall

The knowledge gains involving recall for participants were examined via a two-way (Condition, Domain Knowledge) repeated measures (Time) ANOVA. As predicted, there were significant gains in knowledge over time for all participants, $F(1,28) = 160.17$ $p < .001$. The interactions of Time X Condition (UE, EE) and Time X Domain Knowledge (Weak, Strong) were not significant, $F(1, 28) = 0.35$, $p = .56$; $F(1, 28) = 0.69$, $p = .41$. The main effect of Condition was not significant, $F(1, 28) = 0.09$, $p = .77$. The main effect of Domain Knowledge was significant, $F(1, 28) = 95.68$, $p < 0.001$. The interaction of Condition and Domain Knowledge was significant, $F(1,28) = 6.02$, $p = .02$.

Most importantly, as predicted, there was a significant interaction between Time (pretest, posttest), Condition (UE, EE) and Domain Knowledge (Weak, Strong), $F(1, 28) = 4.21$, $p = .05$. In other words, it was predicted that there would be a significant interaction between Condition and Domain Knowledge such that Strong participants would learn significantly *more* basic information in the Elaborated Explanation (EE) condition (i.e. EE > UE) while Weak participants would learn significantly *less* basic information in this condition. Thus, support is shown for a key prediction of this experiment.

Additional analyses (i.e. independent samples *t*-tests) were performed comparing Strong and Weak participants across conditions. When data from the Strong participants were analyzed, it was revealed that they had not gained significantly more knowledge in the Elaborated Explanation (EE) condition ($M = 11.50$, $SD = 4.77$) than the Unelaborated Explanation (UE) condition ($M = 9.25$, $SD = 2.89$), $t(14) = 1.14$, $p = .14$ (one-tailed). When data from the Weak participants were analyzed, Weak participants were found to have gained significantly *less* knowledge in the Elaborated Explanation (EE) condition ($M = 7.06$, $SD = 3.79$) than the Unelaborated Explanation (UE) condition ($M = 11.13$, $SD = 5.50$), $t(14) = 1.72$, $p = .05$ (one-tailed). This finding is consistent with study predictions (see Table 6 and Figure 6 below).

Table 6 Domain Knowledge: Recall -- Pretest to Posttest changes, by Condition and Prior Domain Knowledge

	Condition: UE		**Condition: EE**	
	Weak	**Strong**	**Weak**	**Strong**
Pretest Score: Domain Knowledge	7.62 (2.59)	18.31 (4.17)	6.00 (3.25)	20.06 (2.60)
Posttest Score: Domain Knowledge	18.75 (6.64)	27.56 (4.10)	13.06 (3.57)	31.56 (6.01)
Pretest-Posttest Gain Scores	11.13 (5.50)	9.25 (2.89)	7.06 (3.79)	11.50 (4.77)

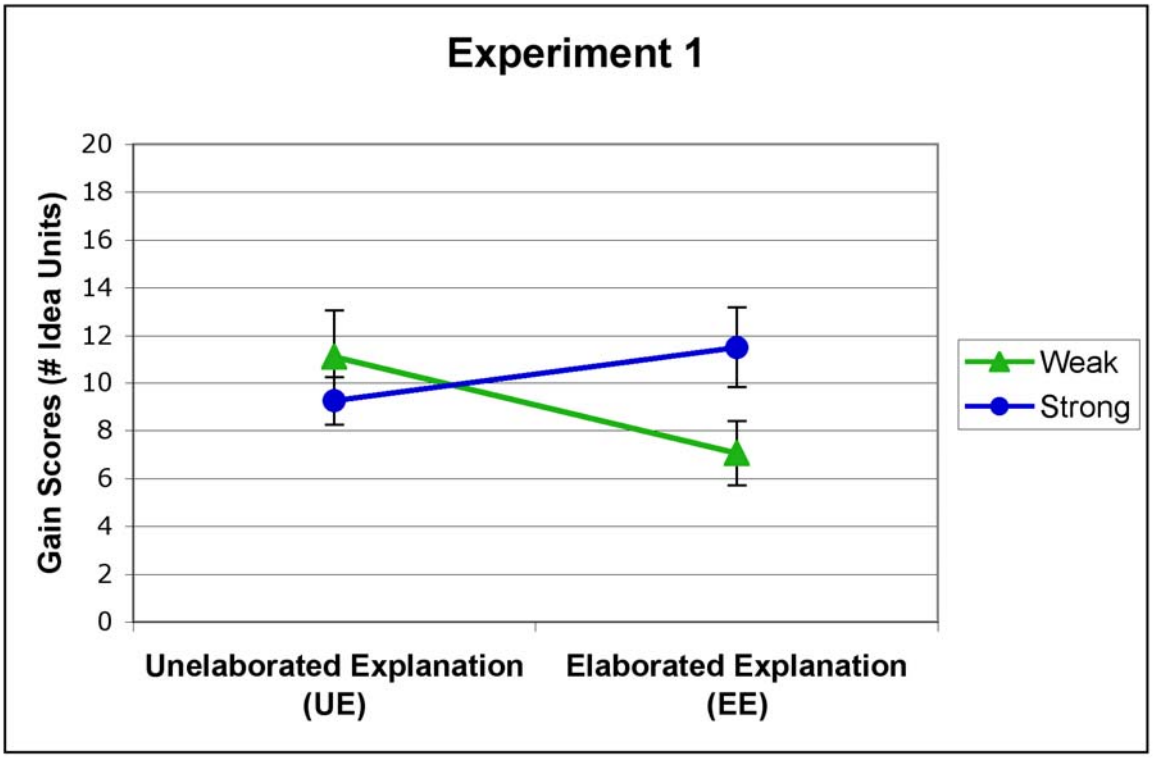

Figure 6 Knowledge Gains - Recall scores by condition and level of prior domain knowledge.

2.1.8.2. Knowledge Gains – Near Inference

The knowledge gains involving near inference for participants were examined via a two-way (Condition, Domain Knowledge) repeated measures (Time) ANOVA. There were significant gains in knowledge over time for all participants, $F(1,28) = 6.66$ $p = .02$. The interactions of Time X Condition (UE, EE) and Time X Domain Knowledge (Weak, Strong) were not significant, $F(1, 28) = 1.89$, $p = .19$; $F(1, 28) = 0.24$, $p = .63$. The main effect of Condition was not significant, $F(1, 28) = .90$, $p = .35$. The main effect of Domain Knowledge was significant, $F(1, 28) = 15.19$ $p = 0.001$. The interaction of Condition and Domain Knowledge was not significant, $F(1,28) = 2.03$, $p = .17$. The interaction between Time (pretest, posttest), Condition (UE, EE) and Domain Knowledge (Weak, Strong) was not significant, $F(1, 28) = .24$, $p = .63$.

Additional analyses (i.e. independent samples *t*-tests) were performed comparing Strong and Weak participants across conditions. When data from the Strong participants were analyzed, it was revealed that they had not gained significantly more knowledge in the Elaborated Explanation (EE) condition (M = 1.00, SD = 2.07) than the Unelaborated Explanation (UE) condition (M = .06, SD = 1.32), $t(14) = 1.08$, p = .30. When data from the Weak participants were analyzed, Weak participants were found to have not gained significantly less knowledge in the Elaborated Explanation (EE) condition (M = 1.00, SD = 1.16) than the Unelaborated Explanation (UE) condition (M = .56, SD = .94), $t(14) = .83$, p = .42 (see Table 7 and Figure 7 below).

Table 7 Domain Knowledge: Near Inference -- Pretest to Posttest changes, by Condition and Prior Domain Knowledge

	Condition: UE		**Condition: EE**	
	Weak	**Strong**	**Weak**	**Strong**
Pretest Score: Domain Knowledge	0.50 (0.60)	2.50 (1.58)	0.44 (0.62)	1.25 (0.65)
Posttest Score: Domain Knowledge	1.06 (1.12)	2.56 (1.27)	1.44 (1.78)	2.25 (1.77)
Pretest-Posttest Gain Scores	0.56 (0.94)	0.06 (1.32)	1.00 (1.16)	1.00 (2.07)

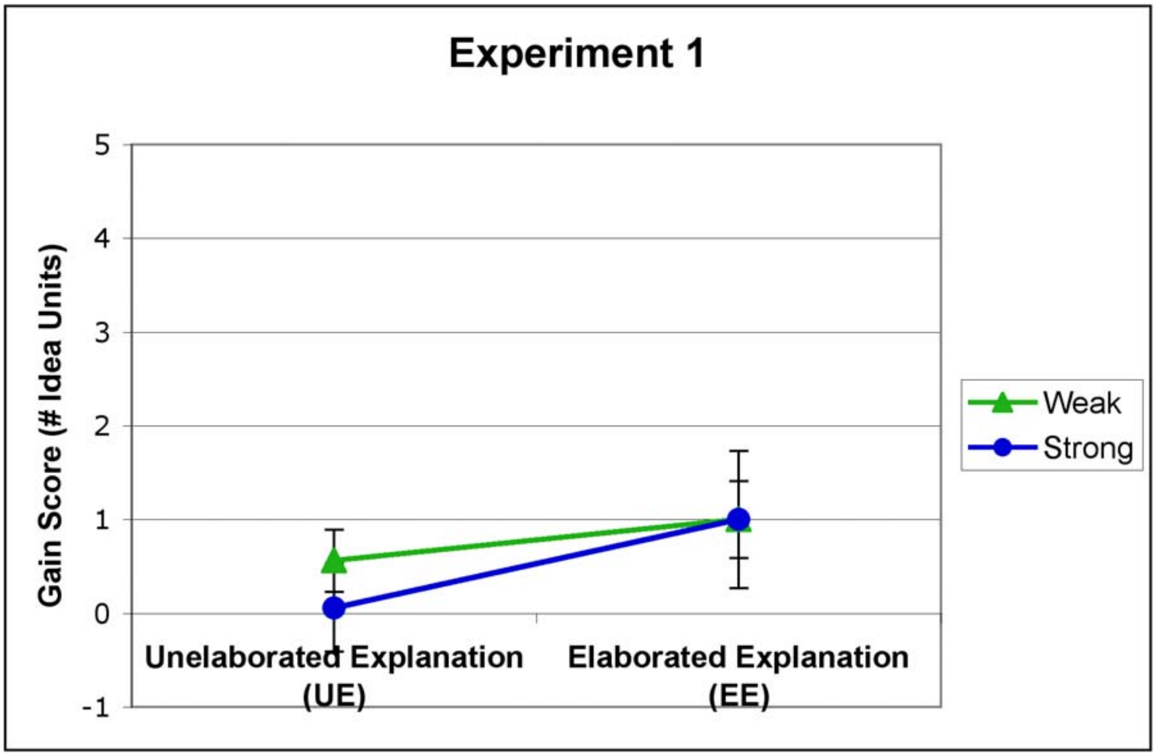

Figure 7 Knowledge Gain - Near Inference scores by condition and level of prior domain knowledge.

2.1.8.3. Knowledge Gains – Far Inference

The knowledge gains involving far inference for participants were examined via a two-way (Condition, Domain Knowledge) repeated measures (Time) ANOVA. As predicted, there were significant gains in knowledge over time for all participants, $F(1,28) = 12.90$ $p = .001$. The interactions of Time X Condition (UE, EE) and Time X Domain Knowledge (Weak, Strong) were not significant, $F(1, 28) = 1.31$, $p = .26$; $F(1, 28) = .01$, $p = .94$. The main effect of Condition was not significant, $F(1, 28) = .01$, $p = .94$. The main effect of Domain Knowledge was significant, $F(1, 28) = 78.62$, $p < .001$. The interaction of Condition and Domain Knowledge was not significant, $F(1,28) = .11$, $p = .75$.

Most importantly, as predicted, there was a (marginally) significant interaction between Time (pretest, posttest), Condition (UE, EE) and Domain Knowledge (Weak, Strong), $F(1, 28) = 3.65$,

p = .07. In other words, it was predicted that there would be a significant interaction between Condition and Domain Knowledge such that Strong participants would learn significantly *more* basic far inference information in the Elaborated Explanation (EE) condition (i.e. EE > UE) while Weak participants would learn significantly *less* basic information in this condition. Thus, support is shown for an important prediction of this experiment.

Additional analyses (i.e. independent samples t-tests) were performed comparing Strong and Weak participants across conditions. When data from the Strong participants were analyzed, it was revealed that they gained significantly *more* knowledge in the Elaborated Explanation (EE) condition (M = 2.75, SD = 2.73) than the Unelaborated Explanation (UE) condition (M = .25, SD = 1.34), $t(14)$ = 2.33, p = .02 (one-tailed). This finding is consistent with study predictions. When data from the Weak participants were analyzed, Weak participants were not found to have gained significantly less knowledge in the Elaborated Explanation (EE) condition (M = 1.13, SD = 3.14) than the Unelaborated Explanation (UE) condition (M = 1.75, SD = 1.54), $t(14)$ = .51, p = .62, (see Table 8 and Figure 8 below).

Table 8 Domain Knowledge: Far Inference -- Pretest to Posttest changes, by Condition and Prior Domain Knowledge

	Condition: UE		**Condition: EE**	
	Weak	**Strong**	**Weak**	**Strong**
Pretest Score: Domain Knowledge	2.69 (1.58)	10.44 (2.37)	3.31 (1.67)	9.00 (2.58)
Posttest Score: Domain Knowledge	4.44 (2.26)	10.69 (2.88)	4.44 (2.76)	11.75 (3.05)
Pretest-Posttest Gain Scores	1.75 (1.53)	0.25 (1.34)	1.13 (3.14)	2.75 (2.73)

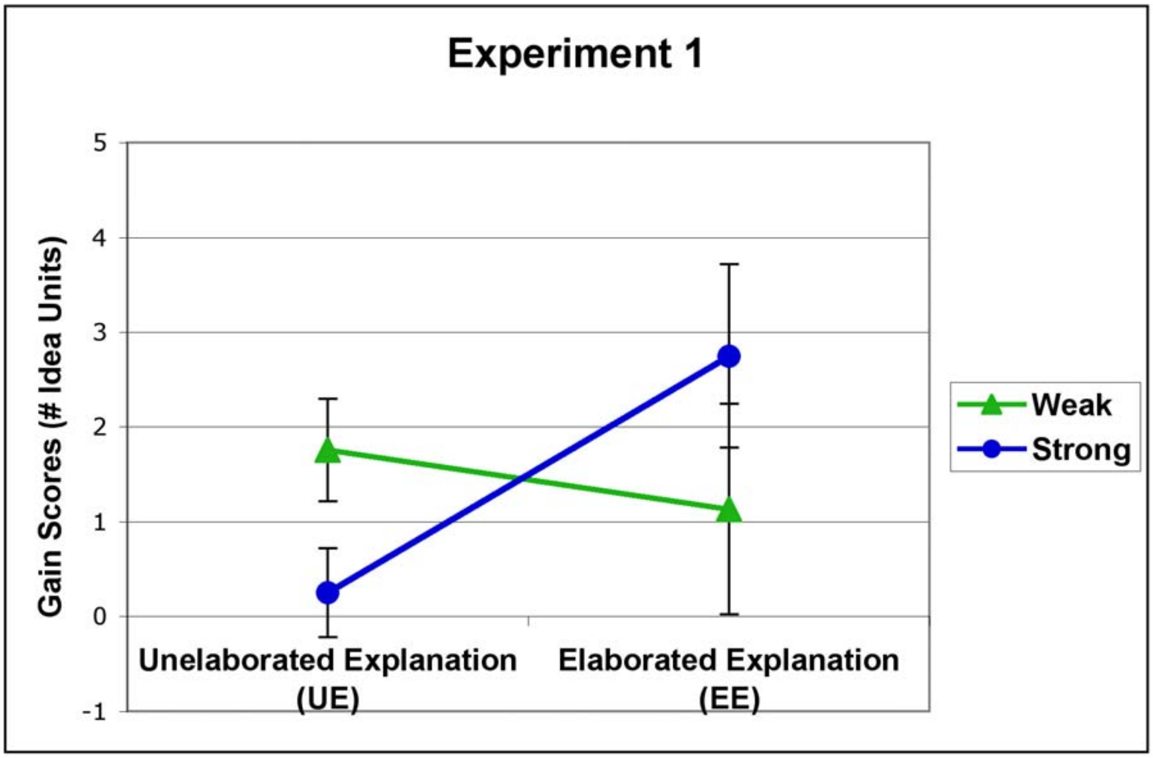

Figure 8 Knowledge Gain - Far Inference scores by condition and level of prior domain knowledge.

2.1.9. Intentional Learning

One factor held to be of importance for instruction is “intentional learning”, which is the degree to which individuals seek to maximize their learning by actively engaging with the material under study and trying to incorporate it with their current knowledge. The average of four questions in the Learning Goals and Strategies Measurement taken at the end of the experiment were chosen to represent the degree of “intentional learning” of participants. The participants were asked to rate on a Likert scale (i.e. (1) Not at all, (4) Somewhat, (7) Definitely) what their goals when reading the texts. The questions regarding their goals were the degree to which they were: (1) Connecting the material to things that they already knew about, (2) Building a “mental picture” of the material, (3) Maximizing how much they would learn, and (4) Connecting the various facts and ideas together.

An examination of the direct relationship between intentional learning and knowledge gains failed to find significant correlations for either the Unelaborated Explanation (UE) condition ($r(16) = -.06$, $p = .41$) or the Elaborated Explanation (EE) condition ($r(16) = .22$, $p = .20$).

A reexamination of the hypothesis (i.e., looking at the potential interaction between prior domain knowledge and conditions) was performed after the exclusion of 5 participants whose average score on the Learning Goals and Strategies measurement was below the designated midpoint cutoff (i.e. means less than 4.0). The knowledge gains for participants were examined via a two-way (Condition, Domain Knowledge) repeated measures (Time) ANOVA. As predicted, there were significant gains in knowledge over time, $F(1,23) = 155.40$, $p < .001$. The interactions of Time X Condition (UE, EE) and Time X Domain Knowledge (Weak, Strong) were not significant, $F(1,23) = 0.003$, $p = .96$; $F(1,23) = 0.027$, $p = .87$. The main effect of Condition was not significant, $F(1,23) = 0.35$, $p = .56$. The main effect of Domain Knowledge was significant, $F(1, 23) = 139.99$, $p < .001$. The interaction of Condition and Domain Knowledge was significant, $F(1,23) = 4.51$, $p = .05$.

Most importantly, as predicted, there was a significant interaction between Time (pretest, posttest), Condition (UE, EE) and Domain Knowledge (Weak, Strong), $F(1, 23) = 10.62$, $p = .003$. In other words, it was predicted that there would be a significant interaction between Condition and Domain Knowledge such that Strong participants would learn significantly *more* basic information in the Elaborated Explanation (EE) condition (i.e. EE > UE) while Weak participants would learn significantly *less* basic information in this condition. Thus, with the participants who did not make criteria on the intentional learning scales removed, the key prediction for this experiment was supported.

Additional analyses (i.e. independent samples *t*-tests) were performed comparing Strong and Weak participants across conditions. When data from the Strong participants were again analyzed, it was again revealed that they again gained significantly *more* knowledge in the Elaborated Explanation (EE) condition (M = 16.36, SD = 6.83) than the Unelaborated Explanation (UE) condition (M = 9.56 SD = 4.80), $t(13) = 2.25$, $p = .02$ (one-tailed). When data from the Weak participants also were reanalyzed, Weak participants were found to have gained significantly *less* knowledge (versus only marginally less in the earlier analysis without the intentional learning constraint) in the Elaborated Explanation (EE) condition (M = 9.33, SD = 4.86) than the Unelaborated Explanation (UE) condition (M = 15.92, SD = 4.13), $t(10) = 2.53$, $p = .015$ (one-tailed). Again, support is shown for important predictions of this experiment (see Table 9 and Figure 9 below).

Table 9 Domain Knowledge -- Pretest to Posttest Changes, by Condition and Prior Domain Knowledge (with Intentional Learning Constraint)

	Condition: UE		**Condition: EE**	
	Weak	**Strong**	**Weak**	**Strong**
Pretest Score: Domain Knowledge	11.25 (4.13) (n=6)	31.25 (3.99) (n=8)	9.83 (3.72) (n=6)	30.50 (3.55) (n=7)
Posttest Score: Domain Knowledge	27.17 (7.08) (n=6)	40.81 (6.26) (n=8)	19.17 (4.12) (n=6)	46.86 (6.95) (n=7)
Pretest-Posttest Gain Scores	15.92 (4.13) (n=6)	9.56 (4.80) (n=8)	9.33 (4.86) (n=6)	16.36 (6.83) (n=7)

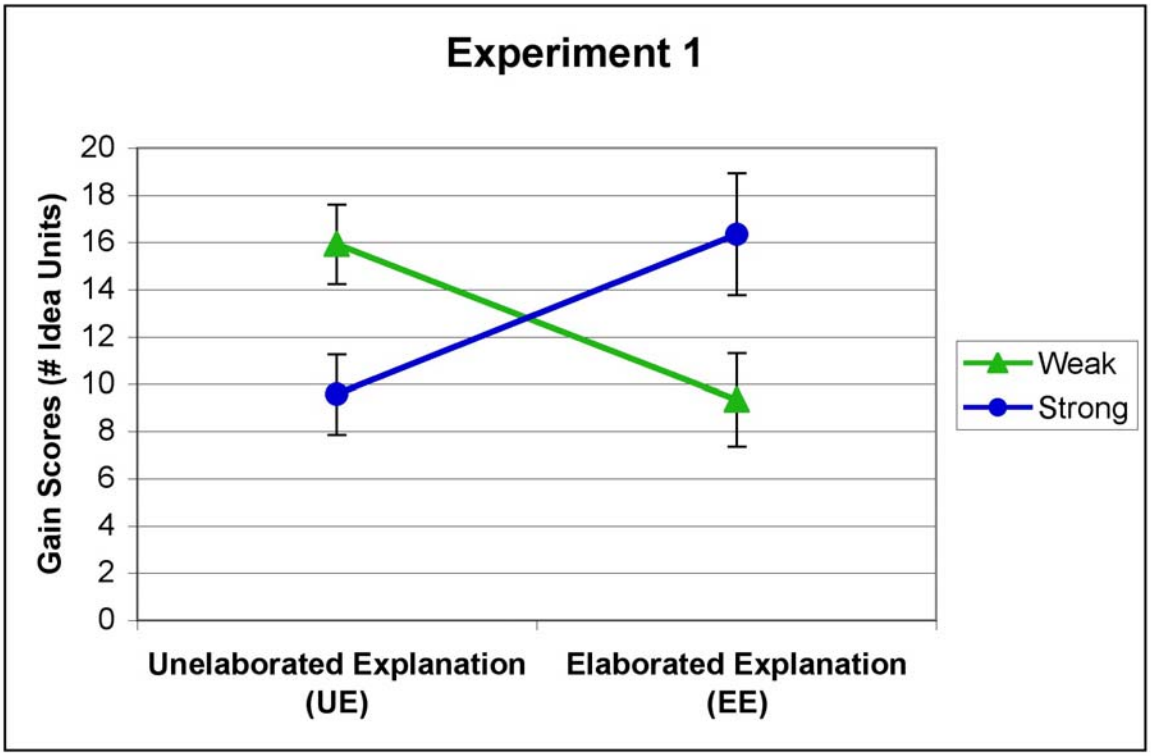

Figure 9 Gain scores by condition and level of prior domain knowledge (with Intentional Learning constraint).

2.1.9.1. Knowledge Gains – Recall (Intentional Learning)

After the exclusion of 5 participants whose average score on the Learning Goals and Strategies measurement was below the designated midpoint cutoff (i.e. means less than 4.0), the knowledge gains for participants were examined via a two-way (Condition, Domain Knowledge) repeated measures (Time) ANOVA. As predicted, there were significant gains in knowledge over time, $F(1,23) = 189.23$, $p < .001$. The interactions of Time X Condition (UE, EE) and Time X Domain Knowledge (Weak, Strong) were not significant, $F(1,23) = 1.01$, $p = .33$; $F(1,23) = 0.17$, $p = .68$. The main effect of Condition was not significant, $F(1,23) = 0.42$, $p = .53$. The main effect of Domain Knowledge was significant, $F(1, 23) = 82.59$, $p < .001$. The interaction of Condition and Domain Knowledge was significant, $F(1,23) = 9.25$, $p < .01$.

Most importantly, as predicted, there was a significant interaction between Time (pretest, posttest), Condition (UE, EE) and Domain Knowledge (Weak, Strong), $F(1, 23) = 9.49$, $p = .005$. In other words, it was predicted that there would be a significant interaction between Condition and Domain Knowledge such that Strong participants would learn significantly *more* basic information in the Elaborated Explanation (EE) condition (i.e. EE > UE) while Weak participants would learn significantly *less* basic information in this condition. Thus, with the participants who did not make criteria on the intentional learning scales removed, a key prediction for this experiment was supported.

Additional analyses (i.e. independent samples *t*-tests) were performed comparing Strong and Weak participants across conditions. When data from the Strong participants were again analyzed, it was again revealed that they gained (marginally) significantly *more* knowledge (versus not significantly more without the intentional learning constraint) in the Elaborated Explanation (EE) condition ($M = 12.43$, $SD = 4.31$) than the Unelaborated Explanation (UE) condition ($M = 9.25$ $SD = 2.89$), $t(13) = 1.70$, $p = .06$ (one-tailed). This finding is consistent with study predictions. When data from the Weak participants also were reanalyzed, Weak participants were found to have gained significantly *less* knowledge in the Elaborated Explanation (EE) condition ($M = 7.08$, $SD = 4.39$) than the Unelaborated Explanation (UE) condition ($M = 13.33$, $SD = 4.30$), $t(10) = 2.49$, $p = .02$ (one-tailed). This finding is also consistent with study predictions (see Table 10 and Figure 10 below).

Table 10 Domain Knowledge: Recall -- Pretest to Posttest Changes, by Condition and Prior Domain Knowledge (with Intentional Learning Constraint)

	Condition: UE		Condition: EE	
	Weak	**Strong**	**Weak**	**Strong**
Pretest Score: Domain Knowledge	8.00 (2.79) (n=6)	18.31 (4.17) (n=8)	6.08 (1.93) (n=6)	20.00 (2.80) (n=7)
Posttest Score: Domain Knowledge	21.33 (5.21) (n=6)	27.56 (4.10) (n=8)	13.17 (3.49) (n=6)	32.43 (5.93) (n=7)
Pretest-Posttest Gain Scores	13.33 (4.29) (n=6)	9.25 (2.89) (n=8)	7.08 (4.39) (n=6)	12.43 (4.31) (n=7)

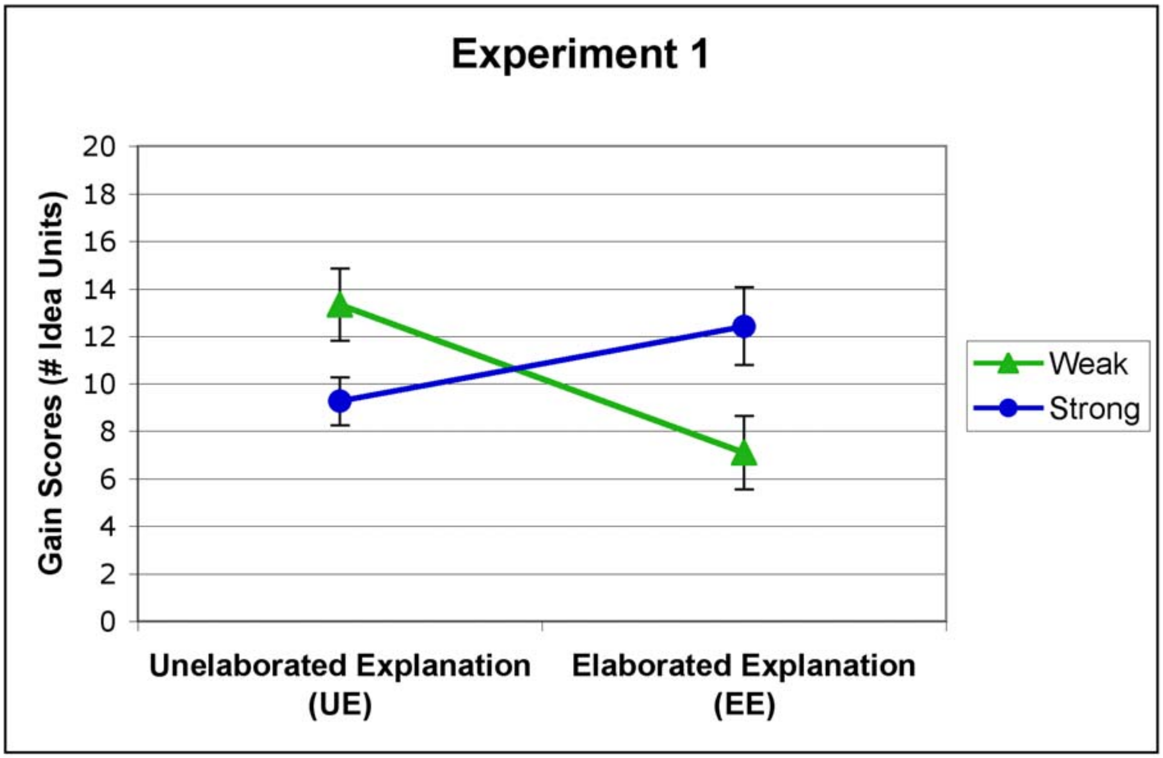

Figure 10 Knowledge Gain (Recall) scores by condition and level of prior domain knowledge (with Intentional Learning constraint).

2.1.9.2. Knowledge Gains – Near Inference (Intentional Learning)

After the exclusion of 5 participants whose average score on the Learning Goals and Strategies measurement was below the designated midpoint cutoff (i.e. means less than 4.0), the knowledge gains for participants were examined via a two-way (Condition, Domain Knowledge) repeated measures (Time) ANOVA. There were significant gains in knowledge over time, $F(1,23) = 5.67$, $p = .03$. The interactions of Time X Condition (UE, EE) and Time X Domain Knowledge (Weak, Strong) were not significant, $F(1,23) = 1.07$, $p = .31$; $F(1,23) = 0.15$, $p = .71$. The main effect of Condition was not significant, $F(1,23) = 1.15$, $p = .30$. The main effect of Domain Knowledge was significant, $F(1, 23) = 8.05$, $p < .01$. The interaction of Condition and Domain Knowledge was not significant, $F(1,23) = 1.15$, $p = .30$. The interaction between Time (pretest, posttest), Condition (UE, EE) and Domain Knowledge (Weak, Strong) was not significant, $F(1, 23) = .57$, $p = .46$.

Additional analyses (i.e. independent samples *t*-tests) were performed comparing Strong and Weak participants across conditions. When data from the Strong participants were again analyzed, it was again revealed that had not gained significantly more knowledge in the Elaborated Explanation (EE) condition ($M = 1.14$, $SD = 2.19$) than the Unelaborated Explanation (UE) condition ($M = .06$ $SD = 1.32$), $t(13) = 1.17$, $p = .26$. When data from the Weak participants also were reanalyzed, Weak participants were found to have not gained significantly less knowledge in the Elaborated Explanation (EE) condition ($M = .92$, $SD = 1.36$) than the Unelaborated Explanation (UE) condition ($M = .75$, $SD = 1.05$), $t(10) = .24$, $p = .82$ (see Table 11 and Figure 11 below).

Table 11 Domain Knowledge: Near Inference -- Pretest to Posttest Changes, by Condition and Prior Domain Knowledge (with Intentional Learning Constraint)

	Condition: UE		**Condition: EE**	
	Weak	**Strong**	**Weak**	**Strong**
Pretest Score: Domain Knowledge	0.67 (0.61) (n=6)	2.50 (1.58) (n=8)	0.58 (0.66) (n=6)	1.14 (0.63) (n=7)
Posttest Score: Domain Knowledge	1.42 (1.07) (n=6)	2.56 (1.27) (n=8)	1.50 (1.38) (n=6)	2.29 (1.91) (n=7)
Pretest-Posttest Gain Scores	0.75 (1.04) (n=6)	.06 (1.32) (n=8)	0.92 (1.36) (n=6)	1.14 (2.19) (n=7)

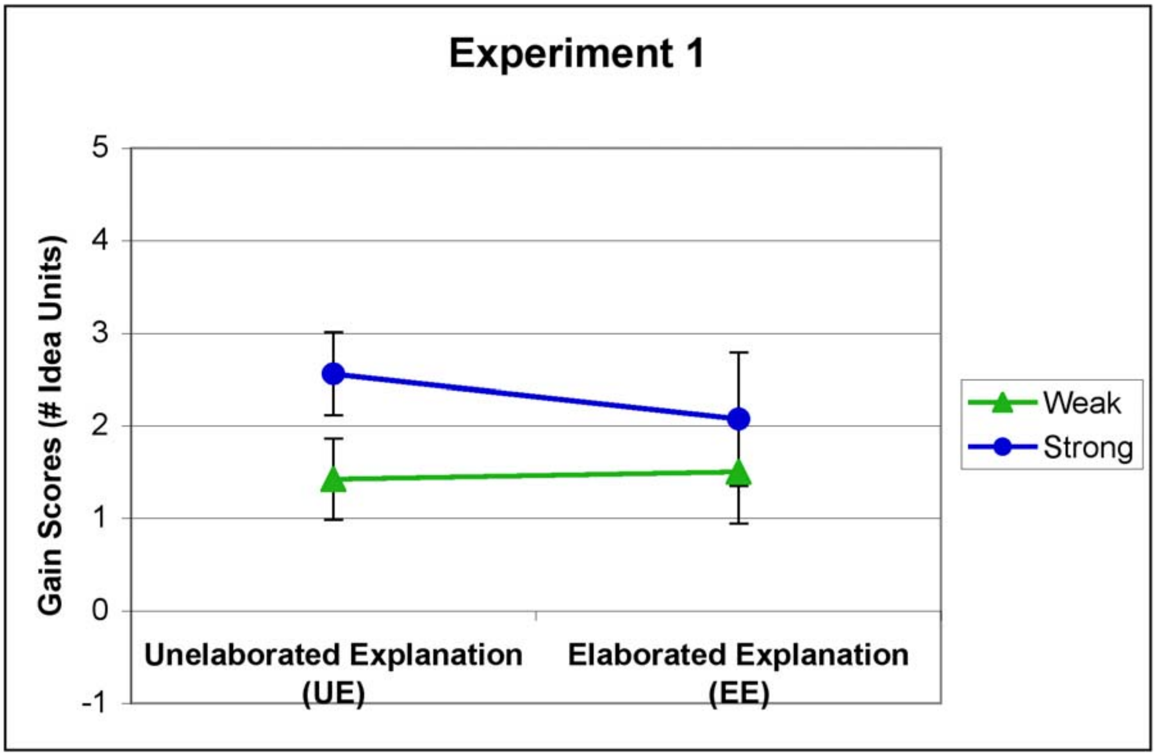

Figure 11 Knowledge Gain (Near Inference) scores by condition and level of prior domain knowledge (with Intentional Learning constraint).

2.1.9.3. Knowledge Gains – Far Inference (Intentional Learning)

After the exclusion of 5 participants whose average score on the Learning Goals and Strategies measurement was below the designated midpoint cutoff (i.e. means less than 4.0), the knowledge gains for participants were examined via a two-way (Condition, Domain Knowledge) repeated measures (Time) ANOVA. As predicted, there were significant gains in knowledge over time, $F(1,23) = 10.25$, $p = .004$. The interactions of Time X Condition (UE, EE) and Time X Domain Knowledge (Weak, Strong) were not significant, $F(1,23) = 1.10$, $p = .30$; $F(1,23) = .01$, $p = .95$. The main effect of Condition was not significant, $F(1,23) = .09$, $p = .77$. The main effect of Domain Knowledge was significant, $F(1, 23) = 63.00$, $p < .001$. The interaction of Condition and Domain Knowledge was not significant, $F(1,23) = .01$, $p = .94$.

Unlike the earlier analysis (i.e. without the intentional learning exclusion) the interaction between Time (pretest, posttest), Condition (UE, EE) and Domain Knowledge (Weak, Strong), did not reach significance, $F(1, 23) = 2.46$, $p = .13$.

Additional analyses (i.e. independent samples *t*-tests) were performed comparing Strong and Weak participants across conditions. When data from the Strong participants were again analyzed, it was again revealed that they again gained significantly *more* knowledge in the Elaborated Explanation (EE) condition ($M = 2.79$ $SD = 2.94$) than the Unelaborated Explanation (UE) condition ($M = .25$ $SD = 1.34$), $t(13) = 2.20$, $p = .02$ (one-tailed)). This finding is consistent with study predictions. When data from the Weak participants also were reanalyzed, Weak participants were not found to have gained significantly less knowledge in the Elaborated Explanation (EE) condition ($M = 1.33$, $SD = 3.56$) than the Unelaborated Explanation (UE) condition ($M = 1.83$, $SD = 1.78$), $t(10) = .31$, $p = .77$ (see Table 12 and Figure 12 below).

Table 12 Domain Knowledge: Far Inference -- Pretest to Posttest Changes, by Condition and Prior Domain Knowledge (with Intentional Learning Constraint)

	Condition: UE		Condition: EE	
	Weak	**Strong**	**Weak**	**Strong**
Pretest Score: Domain Knowledge	2.58 (1.74) (n=6)	10.44 (2.37) (n=8)	3.17 (1.94) (n=6)	9.36 (2.56) (n=7)
Posttest Score: Domain Knowledge	4.42 (2.65) (n=6)	10.69 (2.88) (n=8)	4.50 (3.07) (n=6)	12.14 (3.06) (n=7)
Pretest-Posttest Gain Scores	1.83 (1.78) (n=6)	0.25 (1.34) (n=8)	1.33 (3.56) (n=6)	2.79 (2.94) (n=7)

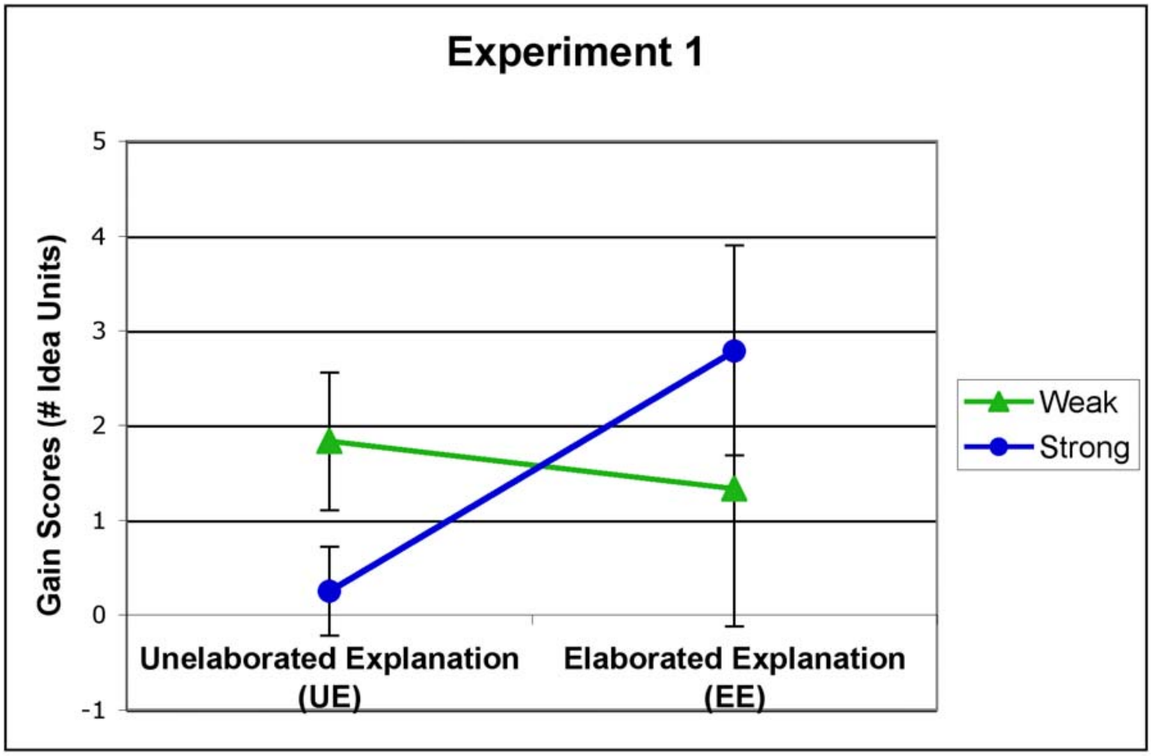

Figure 12 Knowledge Gain (Far Inference) scores by condition and level of prior domain knowledge (with Intentional Learning constraint).

2.1.10. Topic Interest and Learning Gains

Interest in a particular topic of study has the potential to play an important role in learning, particularly in cases in which individuals have a degree of learner control, which will be examined further in experiment 2. Before reading the texts, the degree of participants' interest in science and aerodynamics (i.e. the science of flight) was measured by two Likert scale ratings (1 = Very Boring, 4 = Neutral, 7 = Very Interesting).[10]

There were several general findings involving Topic Interest itself. A paired *t*-test revealed that overall, interest in Science (M = 5.88, SD = 1.07) was significantly higher than interest in Aerodynamics (M = 4.69, SD = 1.23), $t(31) = 4.64$, $p < .001$. An independent samples *t*-test

[10] Two open-ended questions on the amount of free time participants would like to spend learning about science and aerodynamics proved to be extremely variable and therefore are not included here (see Table 5 in Appendix C for these scores).

revealed that Strong participants (*M* = 6.63, *SD* = 0.50) had significantly more interest in Science than Weak participants (*M* = 5.13, *SD* = 0.96), $t(30) = 5.56$, $p < .001$. In contrast, there was no significant difference in interest in Aerodynamics between Strong participants (*M* = 5.00, *SD* = .97) and weak participants (*M* = 4.38, *SD* = 1.41), $t(30) = 1.46$, $p = .15$, (see Tables 13 and 14 below).

Table 13 Interest in topics of Science and Aerodynamics by Condition

	Condition: UE	Condition: EE
Interest in Science	6.00 (0.89)	5.75 (1.24)
Interest in Aerodynamics	4.25 (1.39)	5.13 (0.89)

Table 14 Interest in topics of Science and Aerodynamics by Condition and Prior Domain Knowledge

	Condition: UE		Condition: EE	
	Weak	*Strong*	*Weak*	*Strong*
Interest in Science	5.38 (0.74)	6.63 (0.52)	4.88 (1.13)	6.63 (0.52)
Interest in Aerodynamics	3.63 (1.41)	4.88 (1.13)	5.13 (0.99)	5.13 (0.84)

Participant interest was examined in relation to learning gains. There were no significant correlations between an interest in Science and learning gains, $r(32) = .09$, $p =.64$ (Recall: $r(32) = .24$, $p = .18$, Near Inference: $r(32) = -.07$, $p = .70$, Far Inference: $r(32) = -.20$, $p = .26$). Similarly, with respect to interest in Aerodynamics, there were no significant correlations with learning gains, $r(32) = .01$, $p = .97$ (Recall: $r(32) = .12$, $p = .50$, Near Inference: $r(32) =.08$, $p = .69$, Far Inference: $r(32) = -.26$, $p = .15$). This issue will be revisited in experiment 2 in which participants have a degree of learner control, potentially making topic interest a more potent factor with respect to learning.

Discussion

This experiment was concerned with assessing the feasibility and applicability of using the Region of Proximal Learning (Metcalfe, 2002; Son & Metcalfe, 2000) as a unifying framework to account for the seemingly contradictory research from the Cognitive Load (e.g. Chandler & Sweller, 1991; Sweller & Chandler, 1994; Sweller et al., 1998) and Active Processing perspectives (e.g. Chan et al., 1992; Chi et al., 1989, 1994; Mannes & Kintsch, 1987; McNamara et al., 1996; Slamecka & Graf, 1978).

As predicted, it was found that in comparison to the reading of simple unelaborated explanations, the reading of more challenging elaborated explanations differentially affected the learning gains of those with different levels of prior domain knowledge. More specifically, individuals higher in prior domain knowledge learned significantly *more* basic information (i.e. non-elaborated content) when given more difficult elaborated explanations, while individuals lower in prior domain knowledge learned significantly *less* of the basic information presented.

Of particular interest is the fact that for the most important type of learning – problem-solving transfer tasks involving far inference – the Elaborated Explanation condition resulted in significantly greater learning for Strong participants and did not result in significantly less learning for Weak participants.

This research provides evidence that the Cognitive Load perspective is accurate when describing the learning processes of individuals with minimal prior domain knowledge. Namely, for weaker individuals, simplifying the instructional materials has the potential to enhance learning. However, for individuals with higher levels of prior domain knowledge, the Cognitive Load perspective is *not* appropriate and leads to incorrect predictions. One theoretical implication of the current research is that the Cognitive Load perspective should be updated to reflect this finding and be constrained in application to the learning of individuals with minimal levels of prior domain knowledge. This finding also has important instructional implications. There is widespread belief in the Cognitive Load perspective in many areas of education, particularly in instructional technology. This research can help improve instruction by helping educators to apply the heuristic of "simplification" more selectively based on the characteristics of the learners.

This research also provides evidence that the Active Processing perspective is accurate when describing the learning processes of individuals with moderate to high amounts of prior domain knowledge. Namely, for stronger individuals, making instructional materials more challenging has the potential to enhance learning. However, for individuals with lower levels of prior domain knowledge, the Active Processing perspective is not accurate and leads to incorrect predictions. One theoretical implication of the current research is that the Active Processing perspective needs to be more specific in its predictions and acknowledge that it may not be appropriate for individuals lacking sufficient domain knowledge. This finding also extends prior research (Mannes & Kintsch, 1987; McNamara et al., 1996) which established that lower level structural changes in text coherence – which make reading more difficult – can lead to increased learning for readers with some prior domain knowledge. The current research provides evidence that making reading texts more difficult through the addition of challenging conceptual material can also lead to increased learning for those with sufficient domain knowledge. This finding has important instructional implications. There is widespread belief in the Active Processing perspective in many areas of education. This research will help improve instruction by offering suggestions to educators regarding the utility of employing active processing instructional strategies more selectively based on the characteristics of the learners.

Lastly, this research provides evidence for the appropriateness of using the Region of Proximal Learning (RPL) framework. Previous RPL research has focused on relatively simple learning tasks such as learning vocabulary words from paired lists. The current investigation suggests that this framework can be successfully applied to more complex learning activities. The use of the RPL framework has great potential with the immediate theoretical implication that the apparent contradictions in research from the Cognitive Load and Active Processing perspectives might be resolved via the unifying Region of Proximal Learning framework.

3. EXPERIMENT 2

In experiment 1, it was found that when individuals high in prior domain knowledge (i.e. Strong) read only the basic information contained in the unelaborated explanation (UE) condition, they had *lower* overall learning gains compared to the elaborated explanation (EE) condition (i.e. in which they read the basic information and were required also to read the additional challenging information contained in the elaborated explanations). In contrast, when individuals low in prior domain knowledge (i.e. Weak) read only the basic information contained in the unelaborated explanation (UE) condition, they had *higher* learning gains compared to the elaborated explanation (EE) condition.

It may be that when individuals are provided with the affordance of learner control they will select material most appropriate for their ability level, namely, that within their Region of Proximal Learning. Experiment 2 was designed to examine this issue by providing participants with control over the difficulty of the instructional material encountered. In particular, participants in the elaborated explanation (EE) condition would have the *option* of clicking on embedded hyperlinks to read the elaborated explanations in pop-up windows. It was speculated that this affordance could help Weak individuals reduce the relative decline in learning gains that was expected and demonstrated in experiment 1. Additionally, it was thought that with greater learner control, factors such as individual goals and personal interests might play more important roles in the learning process.

Method

3.1.1. Participants

The participants were 48 (males = 28, females = 20) undergraduate students from the University of Pittsburgh department of Psychology subject pool, as well undergraduates from the wider University community.[11]

3.1.2. Design

The experiment was a three-factor mixed-model repeated-measures analysis of variance (ANOVA) design: 2 (condition: UE, EE) X 2 (prior domain knowledge: Weak, Strong) X 2 (time: Pretest, Posttest). The first factor was a between-subjects factor in which participants experienced either the Unelaborated Explanation (UE) condition, or the Elaborated Explanations (EE) condition. In the unelaborated explanation condition, the participants were provided with basic information needed for the creation of a situation/mental model. In the elaborated explanation condition, the participants were again provided with basic information needed for the creation of a situation/mental model. However, the critical distinction between the two experiments was that unlike in the first experiment where participants in the elaborated explanation (EE) condition were *required* to view all of the elaborated explanations, in the second experiment the participants in the elaborated explanation (EE) condition had the *option* of viewing each elaboration.

The second factor, prior domain knowledge, was based on participants' level of understanding for the chosen subject area (i.e. aerodynamics of flight) as determined by pre-test scores. Due to the focus on low versus high prior knowledge comparisons, a tripartite split was

[11] A total of 103 participants were run altogether (i.e. including both experiment 1 and 2), but 7 were excluded due to their failure to complete one or more pre-test assessment. Recruitment was continued until 96 participants (48 for each study) were acquired.

performed on the 24 participants randomized into each condition. The participants in each condition were ranked according to their prior domain knowledge. The 8 lowest scoring participants were categorized as “Weak” whereas the 8 highest scoring participants were categorized as “Strong.”[12] The third factor, time, was a pretest-posttest repeated measure, (see Table 15 below).

Table 15 Experiment 2: Between-Subjects Design

		Prior Domain Knowledge	
		Weak (W)	Strong (S)
Explanation	Unelaborated Explanation (UE) *(Basic Info)*		
	Elaborated Explanation (EE) *(Basic + Challenging Info)* *Optional Viewing*		

Unlike the first experiment in which all the text was presented within a single web page document, in this case the information was segmented according to topic and placed in separate web pages that were traversed via navigational links at the bottom of each page (i.e. “←Previous” and “Next→” links). The critical difference occurred in the elaborated explanation condition. Unlike the first experiment, in which the participants had no control over reading of the additional challenging material, the participants in the second experiment had the *option* of viewing this material or not. If an individual wanted to read the additional information, they

[12] The excluded intermediate tripartite cases are included in table 1 in Appendix C.

simply clicked on an embedded hyperlink and a pop-up window appeared on the right side of the screen.

The dependent measure was the amount of domain knowledge learned (i.e. basic info only[13]), which was assessed via the domain knowledge instrument administered before and after the instructional intervention (see Appendix A).

3.1.3. Materials

The content of the presented texts (i.e. the Introductory Text Section followed by the Main Text Section with four Elaborated Explanations) was identical to that of the first experiment. The only difference between experiments was that in this case the participants had to click on a hyperlink to open a pop-up window in order to view each elaborated explanation.

3.1.4. Procedure

The experimental procedure was identical to that of experiment 1. Namely, the experiment was completed in a single session, was comprised of three phases: pretest, intervention, and posttest, and contained the same assessments.

Participants in the pretest phase were administered multiple instruments for the purpose of determining their baseline level of study-relevant academic abilities, interests, exposure, and knowledge (for statistical comparisons and correlations of these factors, see Results below and the Tables of Appendix C).

[13] The assessments have been designed to allow "room" for participants to use the additional information provided in the elaborated explanations, but coding here will focus on the basic information provided to all the participants.

3.1.5. Measures

The measures used (i.e. Nelson-Denny reading test, Metacognitive Awareness of Reading Strategies Inventory (MARSI), Need for Cognition scale, Web Experience questionnaire, Science and Topic Interest rating scale, Academic Background questionnaire, and Domain Knowledge assessment) were identical to those of the first experiment.

Results

3.1.6. Baseline Equivalence between Conditions

Baseline levels of both domain-related knowledge and ability of participants were statistically compared across both conditions (and both experiments). An alpha level of .05 was used for all statistical tests. No significant differences between conditions were found on any pre-test measure (i.e. Prior Domain Knowledge, Reading comprehension (Nelson-Denny), Metacognitive Strategy (MARSI), Need for Cognition, Web Experience, Topic Interest, or Academic Background) (see Tables 3-8 in Appendix C).

3.1.7. Text Difficulty Manipulation

As in experiment 1, the texts were composed with two main sections. The first section, Introductory Text, introduced basic aerodynamic principles to the participants. The content of this section was identical between conditions and it was therefore predicted that there would be no significant differences in perceived difficulty.

A pair of difficulty estimation questions were completed immediately after reading the Introductory Text, and involved rating a Likert scale comparing the difficulty of the recently read text to that of the earlier practice text (i.e. (1) Much Easier, (4) Same, (7) Much Harder).

A one-way ANOVA was performed and as predicted, there were no significant differences in perceived difficulty of the Introductory Text between conditions, UE (M = 4.13, SD = 1.41), EE

(*M* = 3.69, *SD* = 1.08), *F*(1, 30) = 0.97, *p* = .33. The second difficulty estimation question was a Likert scale rating of how much "mental effort" was involved in reading the text (i.e. (1) Extremely low, (2) Very low, (3) Low, (4) Neither low nor high, (5) High, (6) Very high, (7) Extremely high). A one-way ANOVA was performed and as predicted, there were no significant differences in perceived difficulty of the Introductory Text between conditions, UE (*M* = 4.63, *SD* = 0.96), EE (*M* = 4.56, *SD* = 1.15), *F*(1, 30) = 0.03, *p* = .87.

The second section, Main Text, covered four main aerodynamic factors: (1) Wing Angle of Inclination, (2) Wing Surface Area, (3) Wing Shape, and (4) Airspeed. In the Elaborated Explanation (EE) condition, each of the four subsections contained additional challenging information over-and-above what was presented in the Unelaborated Explanation (UE) condition. The content of this section was *potentially* very different between conditions and it was therefore predicted that the Elaborated Explanation (EE) condition might be judged to be significantly more difficult than the Unelaborated Explanation (UE) condition, depending on the degree to which participants utilized the learner control affordance.

As before, the pair of difficulty estimation questions was completed immediately after reading the Main Text, and involved a Likert scale rating comparing the difficulty of the recently read text to that of the earlier practice text (i.e. (1) Much Easier, (4) Same, (7) Much Harder).

A one-way ANOVA was performed and revealed that there was no significant difference in perceived difficulty of the Main Text between conditions. The Unelaborated Explanation (UE) condition (*M* = 4.50, *SD* = 1.21) was not perceived as less difficult than the Elaborated Explanation (EE) condition (*M* = 4.94, *SD* = 1.65), *F*(1, 30) = 0.73, *p* = .40 (See first row of Table 16 below).

An independent samples *t*-test was performed and revealed that *Weak* participants found the EE (M = 4.88, SD = 1.81) condition was not significantly more difficult than the UE (M = 4.38, SD = 1.89) condition, $t(14) = 0.65$, $p = .262$ (one-tailed). An independent samples *t*-test was performed and revealed that *Strong* participants found the EE (M = 5.00, SD = 1.60) condition was not significantly more difficult than the UE (M = 4.63, SD = 1.30) condition, $t(14) = 0.51$, $p = .31$ (one-tailed). (See first row of Table 17 below).

The second difficulty estimation question was also completed immediately after reading the Main Text, and involved a Likert scale rating of how much "mental effort" was involved in reading the text (i.e. (1) Extremely low, (2) Very low, (3) Low, (4) Neither low nor high, (5) High, (6) Very high, (7) Extremely high). A one-way ANOVA was performed and revealed that there was no significant difference in perceived difficulty (i.e. "mental effort") of the Main Text between conditions. The Unelaborated Explanation (UE) condition (M = 4.63, SD = 0.96) was perceive as no less difficult (i.e. not involving less mental effort) than the Elaborated Explanation (EE) condition (M = 4.75, SD = 1.61), $F(1, 30) = 0.071$, $p = .79$ (See second row of Table 16 below).

An independent samples *t*-test was performed and revealed the *Weak* participants found the EE (M = 4.75, SD = 2.12) condition was not significantly more difficult than the UE (M = 4.63, SD = 0.92) condition, $t(14) = 0.15$, $p = .44$ (one-tailed). An independent samples *t*-test was performed and revealed the *Strong* participants found the EE (M = 4.75, SD = 1.04) condition was not significantly more difficult than the UE (M = 4.63, SD = 1.06) condition, $t(14) = 0.24$, $p = .41$ (one-tailed) (See second row of Table 17 below).

Table 16 Main Text Difficulty by Condition

	Condition: UE	Condition: EE
Main Text Difficulty Est. "Relative Difficulty"	4.50 (1.21)	4.94 (1.65)
Main Text Difficulty Est. "Mental Effort"	4.63 (0.96)	4.75 (1.61)

Note. Tables display mean scores with standard deviations in parentheses.

Table 17 Main Text Difficulty by Condition and Prior Domain Knowledge

	Condition: UE		Condition: EE	
	Weak	Strong	Weak	Strong
Main Text Difficulty Est. "Relative Difficulty"	4.38 (1.19)	4.63 (1.30)	4.88 (1.81)	5.00 (1.60)
Main Text Difficulty Est. "Mental Effort"	4.63 (0.92)	4.63 (1.06)	4.75 (2.12)	4.75 (1.04)

3.1.8. Knowledge Gains

The overall knowledge gains (i.e. recall, near inference, and far inference) for participants were examined via a two-way (Condition, Domain Knowledge) repeated measures (Time) ANOVA. As predicted, there were significant gains in knowledge over time, $F(1,28) = 123.64$, $p < .001$. The interactions of Time X Condition (UE, EE) and Time X Domain Knowledge (Weak, Strong) were not significant, $F(1, 28) = 1.12$, $p = .29$; $F(1, 28) = .64$, $p = .43$. The main effect of Condition was not significant, $F(1, 28) = .96$, $p = .34$. The main effect of Domain Knowledge was significant, $F(1, 28) = 99.9$ $p < .001$. The interaction of Condition and Domain Knowledge was not significant, $F(1,28) = 0.32$, $p = .57$. There was a (marginally) significant interaction between Time (pretest, posttest), Condition (UE, EE) and Domain Knowledge (Weak, Strong), $F(1, 28) = 2.85$, $p = .10$.

Additional analyses (i.e. independent samples *t*-tests) were performed comparing Strong and Weak participants across conditions. It was revealed that, unlike in experiment 1, Strong participants in the Elaborated Explanation (EE) ($M = 12.75$, $SD = 3.47$) condition (with Learner

Control), did not gain significantly greater knowledge compared to the Unelaborated Explanation (UE) (*M* = 11.50, *SD* = 6.57) condition, *t*(14) = 0.78 *p* = .32 (one-tailed).

Most importantly, it was hypothesized that the affordance of learner control would allow individuals to adaptively select explanations most appropriate for their ability level. Thus, the ability to control the number of elaborations viewed would allow Weak participants to regulate the difficulty of the text which would help prevent a relative decline in learning gains in the Elaborated Explanation (EE) condition relative to those in the Unelaborated Condition (UE), as was demonstrated in the first experiment. This prediction was not supported. It was revealed that, against predictions, that Weak participants again were found to have gained (marginally) significantly *less* knowledge in the Elaborated Explanation (EE) condition (*M* = 7.69, *SD* = 7.04) than in the Unelaborated Explanation (UE) condition (*M* = 13.31, *SD* = 5.26), despite the affordance of Learner Control (LC), *t*(14) = 1.81, *p* = 0.09, (See Table 18 and Figure 13 below).

Table 18 Domain Knowledge -- Pretest to Posttest Changes, by Condition and Prior Domain Knowledge

	Condition: UE		Condition: EE	
	Weak	**Strong**	**Weak**	**Strong**
Pretest Score: Domain Knowledge	7.56 (2.15)	27.13 (5.41)	11.19 (3.28)	29.56 (4.20)
Posttest Score: Domain Knowledge	20.88 (6.72)	38.63 (9.40)	18.88 (8.89)	42.31 (6.49)
Pretest-Posttest Gain Scores	13.31 (5.26)	11.55 (6.57)	7.69 (7.04)	12.75 (3.47)

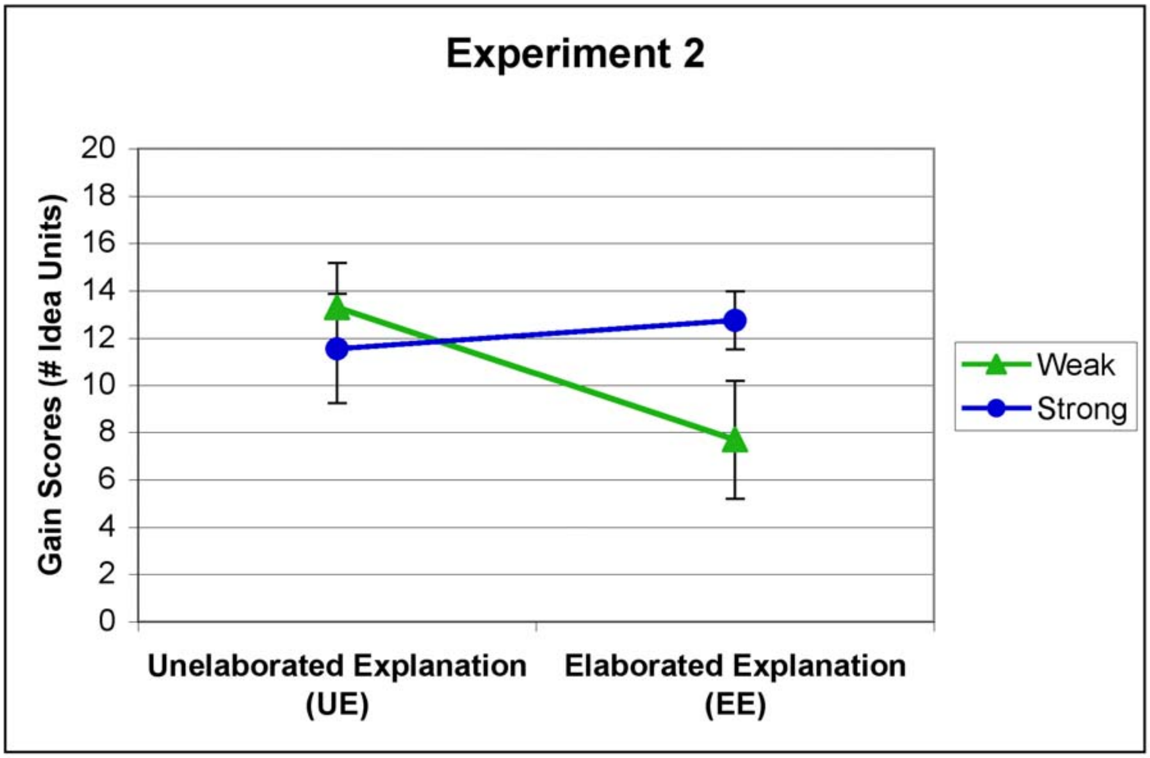

Figure 13 Gain scores by condition and level of prior domain knowledge.

3.1.8.1. Knowledge Gains - Recall

The knowledge gains involving recall for participants were examined via a two-way (Condition, Domain Knowledge) repeated measures (Time) ANOVA. As predicted, there were significant gains in knowledge over time, $F(1,28) = 106.34$, $p < .001$. The interactions of Time X Condition (UE, EE) and Time X Domain Knowledge (Weak, Strong) were not significant, $F(1, 28) = .03$, $p = .86$; $F(1, 28) = .64$, $p = .43$. The main effect of Condition was not significant, $F(1, 28) = .43$, $p = .52$. The main effect of Domain Knowledge was significant, $F(1, 28) = 66.59$ $p < .001$. The interaction of Condition and Domain Knowledge was not significant, $F(1,28) = 0.001$, $p = .98$. There was no significant interaction between Time (pretest, posttest), Condition (UE, EE) and Domain Knowledge (Weak, Strong), $F(1, 28) = 1.71$, $p = .20$.

Additional analyses (i.e. independent samples *t*-tests) were performed comparing Strong and Weak participants across conditions. It was revealed that, Strong participants in the Elaborated Explanation (EE) (M = 9.81, SD = 2.15) condition (with Learner Control), did not gain significantly greater knowledge compared to the Unelaborated Explanation (UE) (M = 8.00, SD = 4.57) condition, $t(14) = 1.02$ $p = .16$. The Weak participants were found to have *not* gained significantly less knowledge in the Elaborated Explanation (EE) condition (M = 6.56, SD = 5.33) than in the Unelaborated Explanation (UE) condition (M = 8.81, SD = 5.59) $t(14) = .82$, $p = .21$ (one tailed), which is consistent with the prediction that the affordance of Learner Control (LC), may minimize the relative decline in learning gains for Weak participants in the EE condition (See Table 19 and Figure 14 below).

Table 19 Domain Knowledge: Recall -- Pretest to Posttest Changes, by Condition and Prior Domain Knowledge

	Condition: UE		Condition: EE	
	Weak	**Strong**	**Weak**	**Strong**
Pretest Score: Domain Knowledge	5.25 (1.93)	17.81 (3.75)	7.38 (1.96)	17.94 (4.28)
Posttest Score: Domain Knowledge	14.06 (6.42)	25.81 (5.78)	13.81 (5.98)	27.75 (5.83)
Pretest-Posttest Gain Scores	8.81 (5.59)	8.00 (4.57)	6.44 (5.05)	9.81 (2.15)

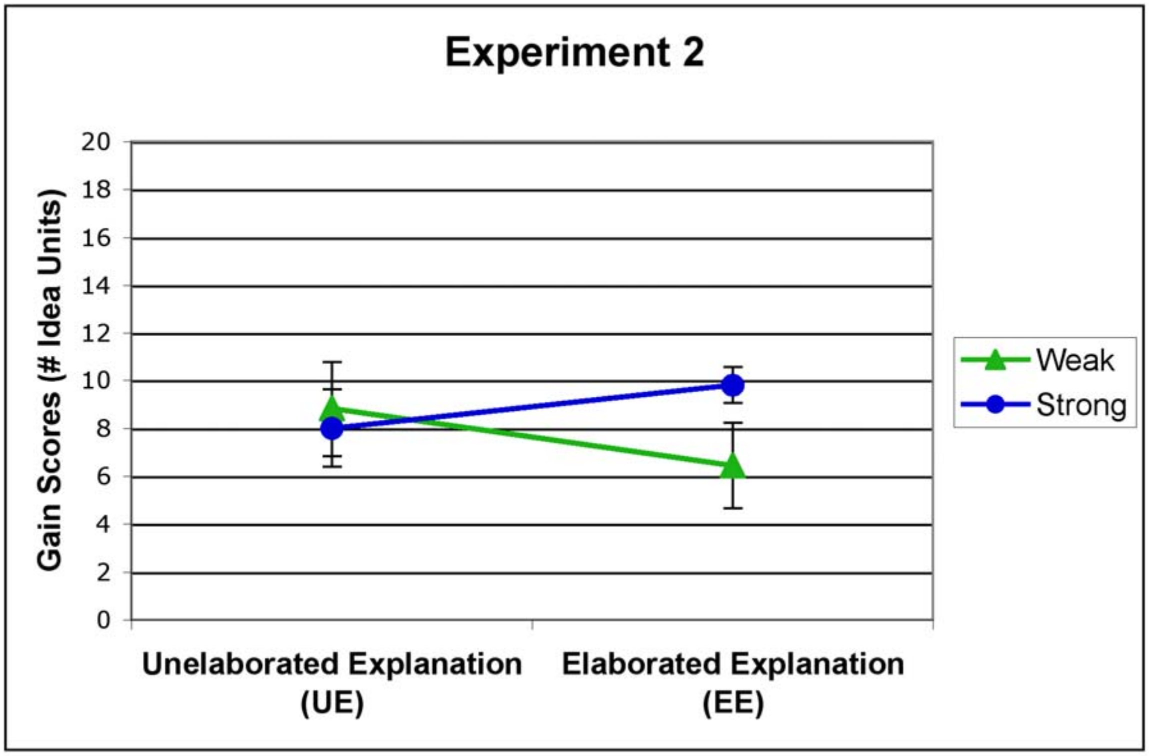

Figure 14 Knowledge Gains - Recall scores by condition and level of prior domain knowledge.

3.1.8.2. Knowledge Gains – Near Inference

The knowledge gains involving near inference for participants were examined via a two-way (Condition, Domain Knowledge) repeated measures (Time) ANOVA. There were significant gains in knowledge over time, $F(1,28) = 10.31$, $p = .003$. The interactions of Time X Condition (UE, EE) and Time X Domain Knowledge (Weak, Strong) were not significant, $F(1, 28) = 2.57$, $p = .12$; $F(1, 28) = 1.59$, $p = .22$. The main effect of Condition was not significant, $F(1, 28) = .21$, $p = .65$. The main effect of Domain Knowledge was significant, $F(1, 28) = 20.38$ $p < .001$. The interaction of Condition and Domain Knowledge was significant, $F(1,28) = 8.37$, $p = .007$. There was a (marginally) significant interaction between Time (pretest, posttest), Condition (UE, EE) and Domain Knowledge (Weak, Strong), $F(1, 28) = 2.96$, $p = .10$

Additional analyses (i.e. independent samples *t*-tests) were performed comparing Strong and Weak participants across conditions. Strong participants in the Elaborated Explanation (EE) (M = .56, SD = 1.92) condition (with Learner Control) did not gain significantly greater knowledge compared to the Unelaborated Explanation (UE) (M = .50, SD = 1.83) condition, $t(14) = .07$ p = .95). Weak participants were found to have gained significantly less knowledge in the Elaborated Explanation (EE) condition (M = .31, SD = 1.19) than in the Unelaborated Explanation (UE) condition (M = 2.13, SD = 1.03), despite the affordance of Learner Control (LC),) $t(14) = 3.26$, p = .006)**,** (See Table 20 and Figure 15 below).

Table 20 Domain Knowledge: Near Inference -- Pretest to Posttest Changes, by Condition and Prior Domain Knowledge

	Condition: UE		**Condition: EE**	
	Weak	**Strong**	**Weak**	**Strong**
Pretest Score: Domain Knowledge	0.06 (0.18)	1.31 (0.88)	0.31 (0.37)	2.19 (1.10)
Posttest Score: Domain Knowledge	2.19 (1.00)	1.81 (1.60)	0.63 (1.41)	2.75 (1.31)
Pretest-Posttest Gain Scores	2.13 (1.03)	0.50 (1.83)	0.31 (1.19)	0.56 (1.92)

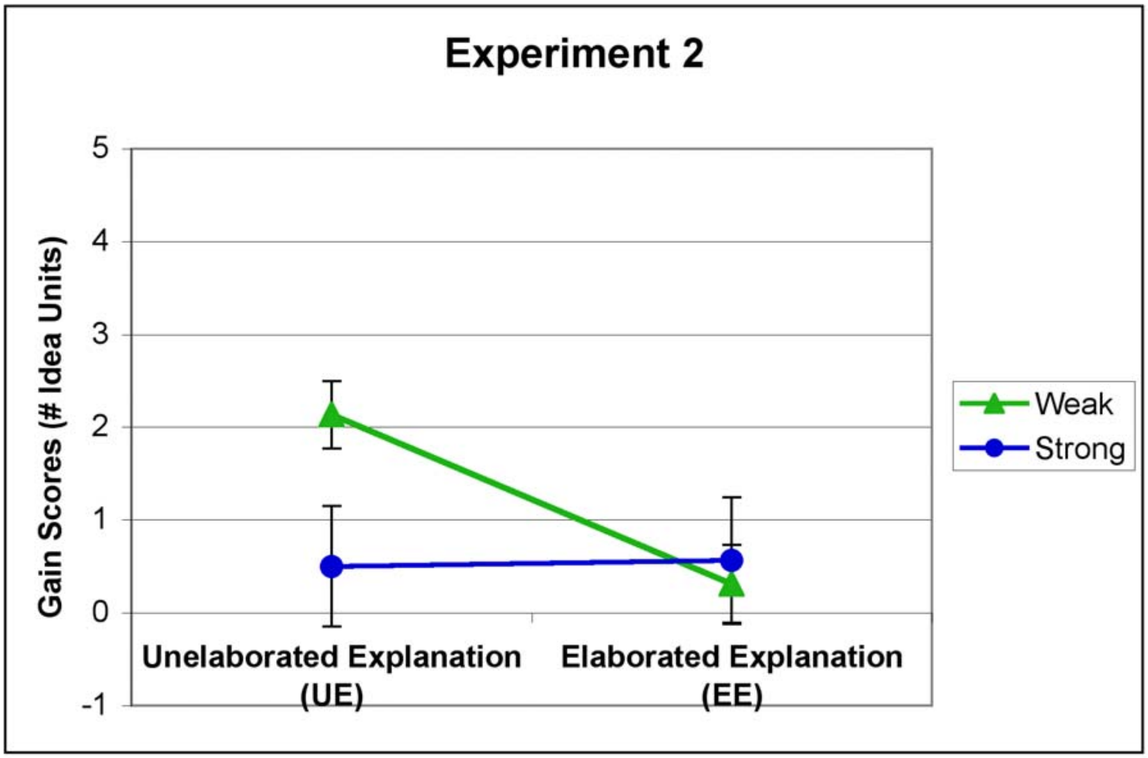

Figure 15 Knowledge Gains – Near Inference scores by condition and level of prior domain knowledge.

3.1.8.3. Knowledge Gains – Far Inference

The knowledge gains involving far inference for participants were examined via a two-way (Condition, Domain Knowledge) repeated measures (Time) ANOVA. As predicted, there were significant gains in knowledge over time, $F(1,28) = 28.18$, $p < .001$. The interactions of Time X Condition (UE, EE) and Time X Domain Knowledge (Weak, Strong) were not significant, $F(1, 28) = 1.59$, $p = .22$; $F(1, 28) = 1.59$, $p = .22$. The main effect of Condition was not significant, $F(1, 28) = .94$, $p = .34$. The main effect of Domain Knowledge was significant, $F(1, 28) = 55.36$ $p < .001$. The interaction of Condition and Domain Knowledge was not significant, $F(1,28) = 0.12$, $p = .73$. There was no significant interaction between Time (pretest, posttest), Condition (UE, EE) and Domain Knowledge (Weak, Strong), $F(1, 28) = .25$, $p = .62$.

Additional analyses (i.e. independent samples *t*-tests) were performed comparing Strong and Weak participants across conditions. It was revealed that, Strong participants in the Elaborated Explanation (EE) (M = 2.38, SD = 2.18) condition (with Learner Control), did not gain significantly greater knowledge compared to the Unelaborated Explanation (UE) (M = 3.00 SD = 2.36) condition, $t(14)$ = .55 p = .30 (one-tailed).

Weak participants were found to have not gained significantly less knowledge in the Elaborated Explanation (EE) condition (M = .94, SD = 2.56) than in the Unelaborated Explanation (UE) condition (M = 2.38, SD = 2.13), $t(14)$ = 1.22, p = .12 (one-tailed), which is consistent with the prediction that the affordance of Learner Control (LC), may minimize the relative decline in learning gains for Weak participants in the EE condition (See Table 21 and Figure 16 below).

Table 21 Domain Knowledge: Far Inference -- Pretest to Posttest Changes, by Condition and Prior Domain Knowledge

	Condition: UE		**Condition: EE**	
	Weak	**Strong**	**Weak**	**Strong**
Pretest Score: Domain Knowledge	2.25 (0.71)	8.00 (2.76)	3.50 (1.67)	9.44 (3.57)
Posttest Score: Domain Knowledge	4.63 (0.82)	11.00 (3.20)	4.44 (2.91)	11.81 (3.13)
Pretest-Posttest Gain Scores	2.38 (2.13)	3.00 (2.36)	0.94 (2.56)	2.38 (2.18)

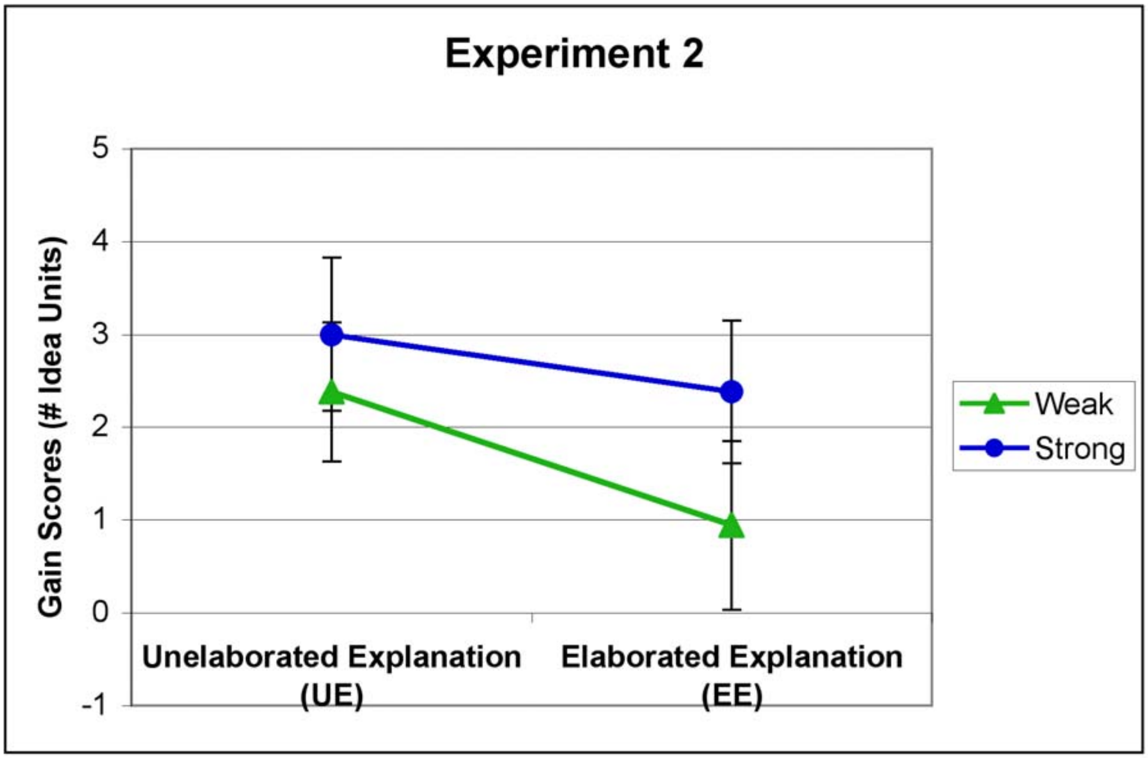

Figure 16 Knowledge Gains – Far Inference scores by condition and level of prior domain knowledge.

3.1.9. Intentional Learning

An examination of the direct relationship between intentional learning and knowledge gains failed to find a significant correlation for the Unelaborated Explanation (UE) condition ($r(16) = .08$, $p = .77$). However there was a highly significant correlation between intentional learning and knowledge gains for the participants in the Elaborated Explanation (EE) condition ($r(16) = .68$, $p = .004$ (the correlation was still significant after controlling for the number of elaborations viewed, $r(13) = .67$, $p = .006$).

A reexamination of the study hypothesis (i.e. that the affordance of Learner Control would allow participants to adaptively select explanations most appropriate for their ability level, minimizing the differential effect of ability level) was performed after the exclusion of 4 participants whose average score on the Learning Goals and Strategies measurement was below the designated midpoint cutoff (i.e. means less than 4.0). The knowledge gains for participants were examined via a two-way (Condition, Domain Knowledge) repeated measures (Time) ANOVA. As originally predicted, there were significant gains in knowledge over time, $F(1, 23) = 108.32$, $p < .001$. The interactions of Time X Condition (UE, EE) and Time X Domain Knowledge (Weak, Strong) were not significant, $F(1, 23) = 0.54$, $p = .47$; $F(1, 23) = 1.06$, $p = .31$. The main effect of Condition was not significant, $F(1, 23) = .97$, $p = .34$. The main effect of Domain Knowledge was significant, $F(1, 23) = 86.49$, $p < .001$. The interaction of Condition and Domain Knowledge was not significant, $F(1, 23) < .001$, $p = .99$. There was no significant interaction between Time (pretest, posttest), Condition (UE, EE) and Domain Knowledge (Weak, Strong), $F(1, 23) = .89$, $p = .36$.

Additional analyses (i.e. independent samples *t*-tests) were performed comparing Strong and Weak participants across conditions. It was revealed that, unlike in experiment 1, Strong participants in the Elaborated Explanation (EE) ($M = 12.75$, $SD = 3.47$) condition (with Learner Control), did not gain significantly greater knowledge compared to the Unelaborated Explanation (UE) ($M = 12.29$, $SD = 6.69$) condition, $t(13) = 0.17$, $p = .43$ (one-tailed).

Most importantly, it was hypothesized that the affordance of learner control would allow individuals to adaptively select explanations most appropriate for their ability level. Thus, the ability to control the number of elaborations viewed would allow Weak participants to regulate the difficulty of the text, which would help prevent a relative decline in learning gains in the Elaborated Explanation (EE) condition relative to those in the Unelaborated Explanation (UE) condition, as was demonstrated in the first experiment. Weak participants did not have significantly lower knowledge gains in the Elaborated Explanation (EE) condition ($M = 8.43$, *SD*

= 7.26) than in the Unelaborated Explanation (UE) condition (M = 12.10, SD = 3.65), $t(10)$ = 1.03, p = .16, which was consistent with study predictions (See Table 22 and Figure 17 below).

Table 22 Domain Knowledge -- Pretest to Posttest Changes, by Condition and Prior Domain Knowledge (with Intentional Learning constraint)

	Condition: UE		Condition: EE	
	Weak	Strong	Weak	Strong
Pretest Score: Domain Knowledge	7.90 (2.30) (n=5)	27.71 (5.56) (n=7)	11.86 (2.90) (n=7)	29.56 (4.20) (n=8)
Posttest Score: Domain Knowledge	20.0 (5.22) (n=5)	40.00 (9.24) (n=7)	20.29 (8.58) (n=7)	42.31 (6.49) (n=8)
Pretest-Posttest Gain Scores	12.10 (3.65) (n=5)	12.29 (6.68) (n=7)	8.43 (7.26) (n=7)	12.75 (3.47) (n=8)

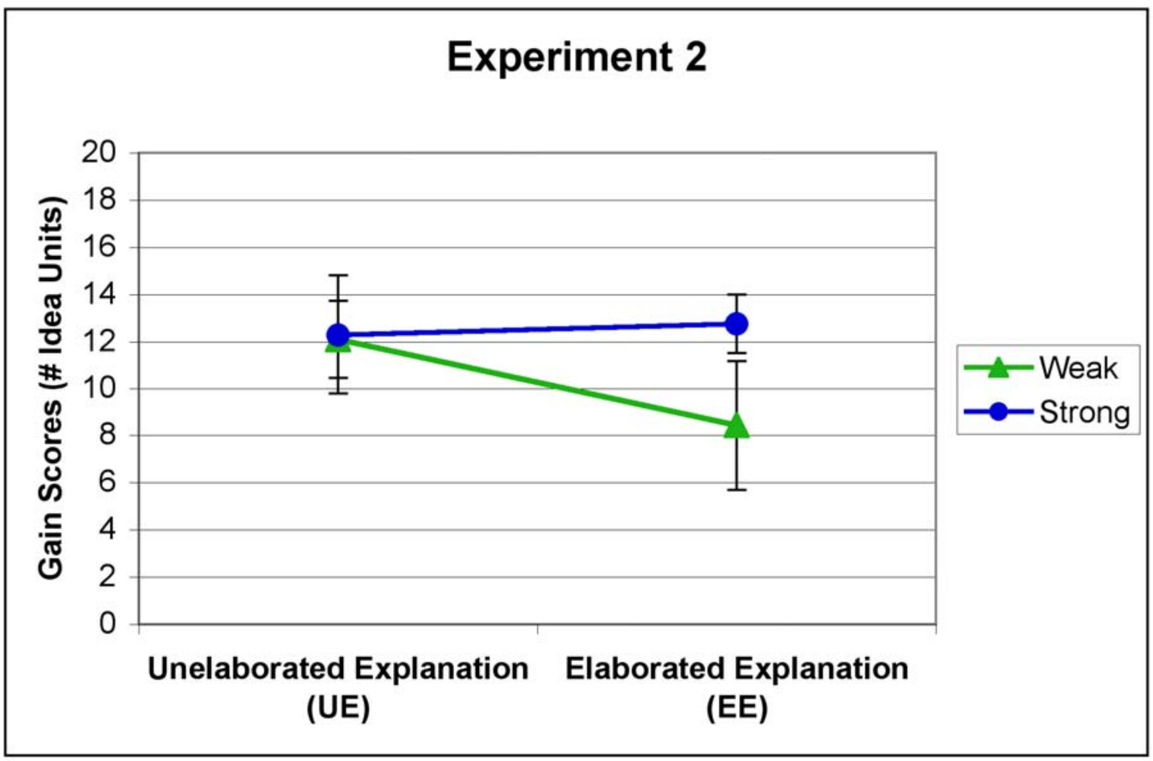

Figure 17 17. Gain scores by condition and level of prior domain knowledge (with Intentional Learning constraint).

3.1.9.1. Knowledge Gains – Recall (Intentional Learning)

The knowledge gains involving recall for participants were examined via a two-way (Condition, Domain Knowledge) repeated measures (Time) ANOVA. As predicted, there were significant gains in knowledge over time, $F(1,23) = 117.46$, $p < .001$. The interaction of Time X Condition (UE, EE) was not significant, $F(1, 23) = .14$, $p = .71$. The interaction of Time X Domain Knowledge (Weak, Strong) was marginally significant, $F(1, 23) = 2.96$, $p = .10$. The main effect of Condition was not significant, $F(1, 23) = .88$, $p = .36$. The main effect of Domain Knowledge was significant, $F(1, 23) = 61.24$ $p < .001$. The interaction of Condition and Domain Knowledge was not significant, $F(1,23) = 0.4$, $p = .53$. There was no significant interaction between Time (pretest, posttest), Condition (UE, EE) and Domain Knowledge (Weak, Strong), $F(1, 23) = .07$, $p = .79$.

Additional analyses (i.e. independent samples *t*-tests) were performed comparing Strong and Weak participants across conditions. It was revealed that Strong participants in the Elaborated Explanation (EE) ($M = 9.81$, $SD = 2.15$) condition (with Learner Control), did not gain significantly greater knowledge compared to the Unelaborated Explanation (UE) ($M = 8.86$, $SD = 4.18$) condition, $t(13) = .57$ $p = .29$ (one-tailed). The Weak participants were found to have not gained significantly less knowledge in the Elaborated Explanation (EE) condition ($M = 7.00$, $SD = 5.61$) than in the Unelaborated Explanation (UE) condition ($M = 6.70$, $SD = 2.61$), $t(10) = .11$, $p = .46$ (one-tailed), which is consistent with the prediction that the affordance of Learner Control (LC), may minimize the relative decline in learning gains for Weak participants in the EE condition (See Table 23 and Figure 18 below).

Table 23 Domain Knowledge: Recall -- Pretest to Posttest Changes, by Condition and Prior Domain Knowledge (with Intentional Learning Constraint)

	Condition: UE		Condition: EE	
	Weak	Strong	Weak	Strong
Pretest Score: Domain Knowledge	5.50 (2.26)	17.93 (4.04)	7.93 (1.27)	17.94 (4.28)
Posttest Score: Domain Knowledge	12.20 (3.62)	26.79 (5.48)	14.79 (5.74)	27.75 (5.83)
Pretest-Posttest Gain Scores	6.70 (2.61)	8.86 (4.18)	6.86 (5.30)	9.81 (2.15)

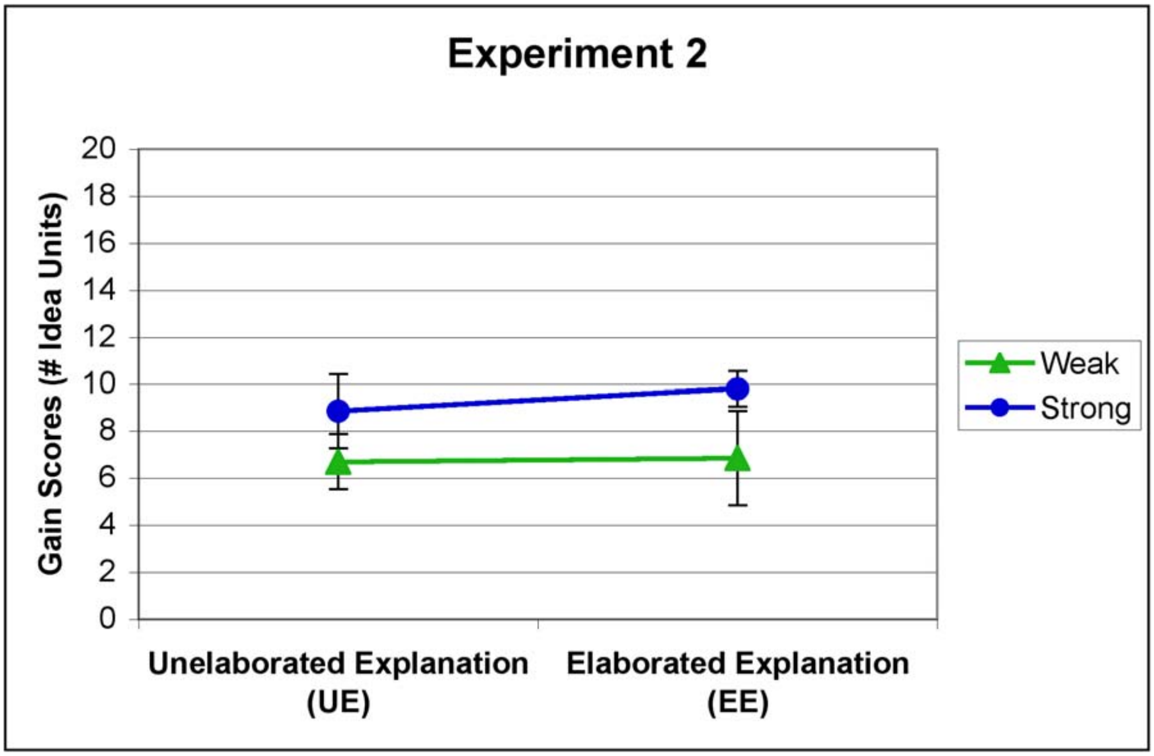

Figure 18 Knowledge Gains - Recall scores by condition and level of prior domain knowledge (with Intentional Learning constrain).

3.1.9.2. Knowledge Gains – Near Inference (Intentional Learning)

The knowledge gains involving near inference for participants were examined via a two-way (Condition, Domain Knowledge) repeated measures (Time) ANOVA. There were significant gains in knowledge over time, $F(1,23) = 5.76$, $p = .025$. The interactions of Time X Condition

(UE, EE) and Time X Domain Knowledge (Weak, Strong) were not significant, $F(1, 23) = .94$, $p = .34$; $F(1, 23) = .41$, $p = .53$. The main effect of Condition was not significant, $F(1, 23) = .91$, $p = .35$. The main effect of Domain Knowledge was significant, $F(1, 23) = 15.92$ $p = .001$. The interaction of Condition and Domain Knowledge was significant, $F(1,23) = 4.41$, $p = .05$. There was no significant interaction between Time (pretest, posttest), Condition (UE, EE) and Domain Knowledge (Weak, Strong), $F(1, 23) = .92$, $p = .35$

Additional analyses (i.e. independent samples *t*-tests) were performed comparing Strong and Weak participants across conditions. Strong participants in the Elaborated Explanation (EE) ($M = .56$, $SD = 1.92$) condition (with Learner Control), did not gain significantly greater knowledge compared to the Unelaborated Explanation (UE) ($M = .57$, $SD = 1.97$) condition, $t(13) = .01$ $p = .99$.

Weak participants were found to have gained significantly less knowledge in the Elaborated Explanation (EE) condition ($M = .1.13$, $SD = 1.35$) than in the Unelaborated Explanation (UE) condition ($M = .25$, $SD = .34$), despite the affordance of Learner Control (LC), $t(11) = 2.34$, $p = .02$ (one-tailed), (See Table 24 and Figure 19 below).

Table 24 Domain Knowledge: Near Inference -- Pretest to Posttest Changes, by Condition and Prior Domain Knowledge (with Intentional Learning Constraint)

	Condition: UE		**Condition: EE**	
	Weak	**Strong**	**Weak**	**Strong**
Pretest Score: Domain Knowledge	0.10 (0.22) (n=5)	1.21 (0.91) (n=7)	0.36 (0.38) (n=7)	2.19 (1.10) (n=8)
Posttest Score: Domain Knowledge	1.70 (0.97) (n=5)	1.79 (1.73) (n=7)	0.71 (1.50) (n=7)	2.75 (1.31) (n=8)
Pretest-Posttest Gain Scores	1.60 (0.96) (n=5)	0.57 (1.97) (n=7)	0.36 (1.28) (n=7)	0.56 (1.92) (n=8)

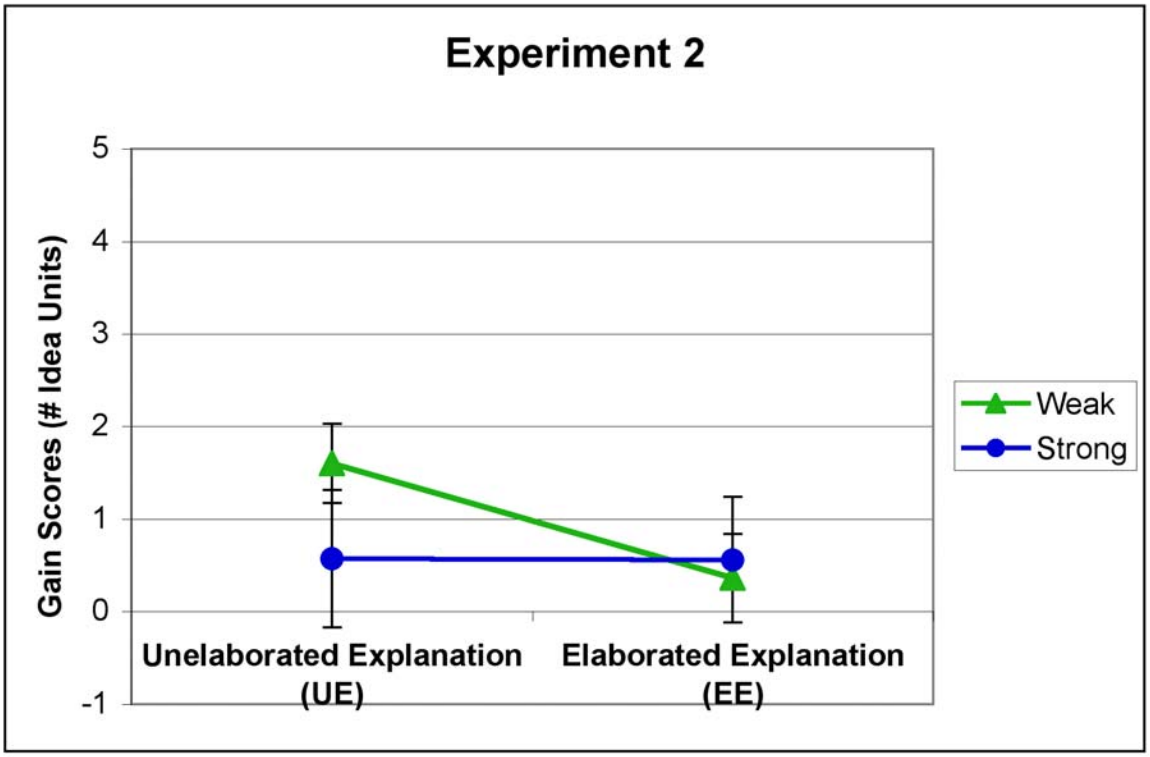

Figure 19 Knowledge Gains – Near Inference scores by condition and level of prior domain knowledge (with Intentional Learning Constraint).

3.1.9.3. Knowledge Gains – Far Inference (Intentional Learning)

The knowledge gains involving far inference for participants were examined via a two-way (Condition, Domain Knowledge) repeated measures (Time) ANOVA. As predicted, there were significant gains in knowledge over time, $F(1,23) = 33.81$, $p < .001$. The interaction of Time X Condition (UE, EE) was (marginally) significant, $F(1, 23) = 3.03$, $p = .10$. The interaction of Time X Domain Knowledge (Weak, Strong) was not significant, $F(1, 23) = .02$, $p = .90$. The main effect of Condition was not significant, $F(1, 23) = .1$, $p = .76$. The main effect of Domain Knowledge was significant, $F(1, 23) = 41.1$ $p < .001$. The interaction of Condition and Domain Knowledge was not significant, $F(1,23) = 0.12$, $p = .74$. There was no significant interaction between Time (pretest, posttest), Condition (UE, EE) and Domain Knowledge (Weak, Strong), $F(1, 23) = 1.43$, $p = .25$.

Additional analyses (i.e. independent samples *t*-tests) were performed comparing Strong and Weak participants across conditions. It was revealed that, Strong participants in the Elaborated Explanation (EE) ($M = 2.38$, $SD = 2.18$) condition (with Learner Control), did not gain significantly greater knowledge compared to the Unelaborated Explanation (UE) ($M = 2.86$ $SD = 2.51$) condition, $t(13) = .40$ $p = .35$ (one-tailed).

Weak participants were found to have gained significantly less knowledge in the Elaborated Explanation (EE) condition ($M = .94$, $SD = 2.56$) than in the Unelaborated Explanation (UE) condition ($M = 2.38$, $SD = 2.13$), $t(10) = 2.07$, $p = .03$ (one-tailed), despite the affordance of Learner Control (LC), (See Table 25 and Figure 20 below).

Table 25 Domain Knowledge: Far Inference -- Pretest to Posttest Changes, by Condition and Prior Domain Knowledge (with Intentional Learning Constraint)

	Condition: UE		**Condition: EE**	
	Weak	**Strong**	**Weak**	**Strong**
Pretest Score: Domain Knowledge	2.30 (0.57)	8.57 (2.42)	3.57 (1.79)	9.44 (3.57)
Posttest Score: Domain Knowledge	6.10 (1.24)	11.43 (3.19)	4.79 (2.96)	11.81 (3.13)
Pretest-Posttest Gain Scores	3.80 (1.04)	2.86 (2.51)	1.21 (2.63)	2.38 (2.18)

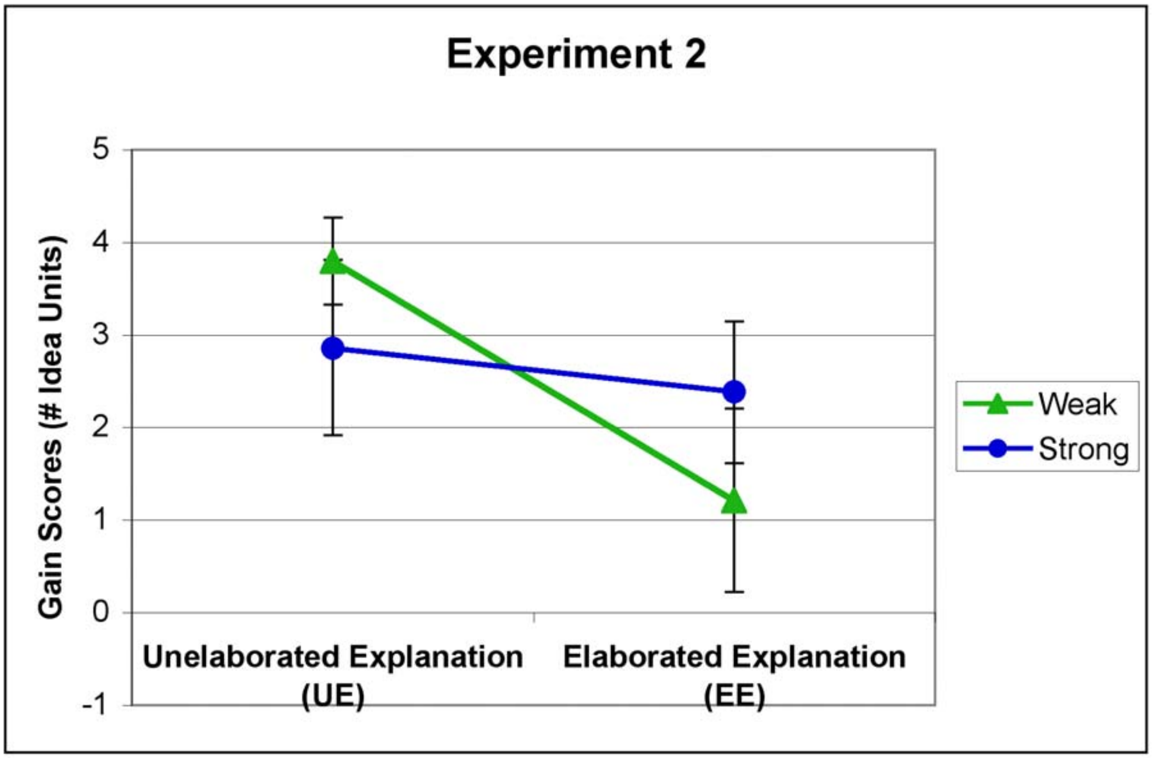

Figure 20 Knowledge Gains – Far Inference scores by condition and level of prior domain knowledge (with Intentional Learning Constraint).

3.1.10. Topic Interest and Learning Gains

Interest in a particular topic of study has the potential to play an important role in learning, particularly in cases in which individuals have a degree of learner control, such as in this experiment. As in experiment 1, before reading the texts, the degree of participant interest in science and aerodynamics (i.e. the science of flight) was measured by two Likert scale ratings (1 = Very Boring, 4 = Neutral, 7 = Very Interesting).[14]

There were several general findings involving Topic Interest itself. A paired *t*-test revealed that overall, interest in Science (*M* = 5.16, *SD* = 1.87) was significantly higher than that in Aerodynamics (*M* = 4.25, *SD* = 1.74), *t*(31) = 2.09, *p* =.045. An independent samples *t*-test

[14] Two open-ended questions about the amount of free time participants would like to spend learning about science and aerodynamics proved to be extremely variable and therefore are not included here (see Table 5 in Appendix C for these scores).

revealed that Strong participants (*M* = 6.00, *SD* = 1.10) had significantly more interest in Science than Weak participants (*M* = 4.31, *SD* = 2.12), $t(30) = 2.83$, $p = .008$. Similarly, an independent samples *t*-test revealed a significant difference in interest in Aerodynamics between Strong participants (*M* = 4.88, *SD* = 1.03) and weak participants (*M* = 3.63, *SD* = 2.09), $t(30) = 2.15$, $p = .04$, (see Tables 26 and 27 below).

Table 26 Topic Interest in Science and Aerodynamics by Condition

	Condition: UE	**Condition: EE**
Interest in Science	5.25 (1.69)	5.06 (2.08)
Interest in Aerodynamics	4.13 (1.82)	4.38 (1.71)

Table 27 Topic Interest in Science and Aerodynamics by Condition and Prior Domain Knowledge

	Condition: UE		**Condition: EE**	
	Weak	*Strong*	*Weak*	*Strong*
Interest in Science	4.50 (1.93)	6.00 (1.07)	4.13 (2.42)	6.00 (1.20)
Interest in Aerodynamics	3.25 (2.05)	5.00 (1.07)	4.00 (2.20)	4.75 (1.04)

Participant interest was examined with respect to learning gains. Unlike the first experiment, in this case there were significant correlations between an interest in Science and learning gains, $r(32) = .44$, $p = .01$ (Recall: $r(32) = .38$, $p = .03$, Near Inference: $r(32) = .03$, $p = .86$, Far Inference: $r(32) = 37$, $p = .04$).

A closer examination revealed that in the Unelaborated Explanation (UE) condition, there was virtually no relationship between interest in Science and learning gains, $r(16) = .001$, $p = .97$. In contrast, in the Elaborated Explanation (EE) condition in which learners had control over the content viewed, there was a *highly significant correlation* between interest in Science and learning gains, $r(16) = .79$, $p < .001$ (Recall: r(16) = .81, p <.001, Near Inference: $r(16) = .16$, $p = .56$, Far Inference: $r(16) = .44$, $p = .09$.). This relationship was still highly significant after statistically controlling for the number of elaborations viewed, $r(13) = .77$, $p = .001$.

With respect to interest in Aerodynamics, there was no significant correlation with learning gains, $r(32) = 0.07$, $p = .72$ (Recall: $r(32) = .03$, $p = .86$, Near Inference: $r(32) = -.12$, $p = .52$, Far Inference: $r(32) = .18$, $p = .34$).

Elaboration Selection

The Elaborated Explanation (EE) condition is of particular interest because it afforded Learner Control to participants in that they were able to *choose* which elaborations to read. It was predicted that there would be a significant interaction between the participants' domain knowledge (i.e. Strong vs. Weak) and the number of elaborations (from 0 to 4) selected and read, with the Strong participants expected to read greater numbers of these optional elaborations. A One-way ANOVA was performed, and as predicted Strong participants ($M = 2.25$, $SD = 0.89$) viewed significantly more elaborations than Weak participants ($M = 0.63$, $SD = 0.92$), $F(1, 14) = 13.0$, $p = .003$. More specifically, there was a highly significant correlation between participants' prior domain knowledge and the number of elaborations read, $r(16) = .69$, $p = .002$. This relationship still held even after controlling for participants' interest in Science ($r(13) = .69$, $p = .002$) and Aerodynamics ($r(13) = .66$, $p = .004$).

Relatedly, the direct relationship between topic interest and the number of elaborations selected was investigated. Neither participants' interest in science ($r(16) = .25$, $p = .17$) nor aerodynamics ($r(16) = .27$, $p = .16$) was significantly related to the number of elaborations selected.

An analysis was also performed examining the relationship between the number of elaborations chosen and participants' degree of intentional learning. Not surprisingly, for Strong participants there was a positive, although non-significant correlation ($r(8) = .45$, $p = .13$), but when controlling for the participants' interest in science, the correlation between intentional learning and the number of elaborations viewed becomes marginally significant, $r(5) = .57$, $p = .09$. For weak participants there was a *negative,* although again non-significant correlation ($r(7) = -.36$, $p = .19$), between the degree of intentional learning and the number of elaborations viewed (interest in science did not significantly change this correlation – $r(5) = -.34$, $p = .23$). This result seemed somewhat counter-intuitive at first. However, this may be resolved upon consideration of the possibility that Weak participants with greater intentional learning goals may have recognized their already high level of cognitive load and thus chosen to forego viewing additional elaborations.

Discussion

This experiment was concerned with how the affordance of learner control, an inherent aspect of the Web (e.g. Marchionini, 1988), would interact with the proposed unifying framework of the Region of Proximal Learning (Metcalfe, 2002; Son & Metcalfe, 2000).

While similar to the first experiment, the second experiment was characterized by the critical distinction of providing participants in the Elaborated Explanation (EE) condition with control over whether or not to read the elaborations. The addition of learner control (i.e. hypertext) to this study allowed for a more realistic mirroring of actual web-based learning environments. However, this added dimension greatly reduced experimental control, making predictions for participants in this condition more difficult. Individual factors such as learning goals and topic interest appeared to play a greater role in this situation. It was predicted that the affordance of learner control would allow individuals to adaptively select explanations most appropriate for their ability level.

There are two key pieces of evidence that support the claim that the availability of learner control allowed participants to adaptively select the number of elaborations viewed based upon their individual ability. First, while it might be speculated that the selection of elaborations is merely a random process or influenced solely by individuals' interests, study results showed that greater prior domain knowledge was highly correlated with increased numbers of elaborations viewed. Thus, consistent with the RPL framework, individuals appeared to be regulating the number of elaborations they viewed based on their current domain knowledge. In other words, it appears that individuals selected instructional materials that had a difficulty level commensurate with their abilities – i.e. within their Region of Proximal Learning. Thus, in the current study this would suggest that Strong individuals (i.e. higher in prior domain knowledge) would be expected to seek more difficult instructional materials as the basic information alone would be too easy. Similarly, this would suggest that Weak individuals (i.e. lower in prior domain knowledge) would be expected to seek less difficult instructional material (i.e. unelaborated explanations). This is precisely what was found – Strong participants chose to read significantly greater numbers of elaborated explanations (e.g. 86% chose to read two or more elaborations) than Weak individuals (e.g. 63 % chose not read any elaborations).

Second, there was an interesting trend such that for Strong participants, there was a positive (though non-significant) correlation between the strength of their intentional learning goals (Bereiter & Scardamalia, 1989) and the number of elaborations viewed. Conversely, there was the opposite trend for Weak participants with a negative (though non-significant) correlation between the strength of their intentional learning goals and the number of elaborations viewed. One can speculate that the participants with stronger intentional learning goals and strategies were more adaptively selecting the appropriate number of elaborations for themselves. That is to say, higher domain knowledge participants with high intentional learning goals may have chosen to view more elaborations because they realized that they were not in danger of cognitive overload. In contrast, Weak participants with high intentional learning goals may have recognized their already high level of cognitive load, and therefore wisely chose to bypass the reading of additional challenging materials. This speculation will be explored more below in terms of difficulty ratings.

4. GENERAL DISCUSSION

The cognitive load perspective (e.g. Chandler & Sweller, 1991; Sweller & Chandler, 1994; Sweller et al., 1998) suggests that the simplification of instructional material can enhance learning. However, research from the active processing perspective (e.g. Chan et al., 1992; Chi et al., 1989, 1994; Mannes & Kintsch, 1987; McNamara et al., 1996; Slamecka & Graf, 1978) makes the opposite prediction. The first experiment conducted herein found evidence that this apparent contradiction may be accounted for by the fact that increasing (or decreasing) the difficulty of an explanation may move it either into or out of an individual's region of proximal learning (Metcalfe, 2002; Son & Metcalfe, 2000). More specifically, it was found that individuals higher in prior domain knowledge (i.e. Strong) acquired significantly more information when given additional challenging elaborated explanations. In contrast, individuals lower in prior domain knowledge (i.e. Weak) acquired significantly *less* information in such a situation.

The diminished learning of Weak individuals when given additional challenging materials is troubling from a pedagogical perspective. It was speculated that the affordance of learner control might help to mitigate this problem. More specifically, it was hoped that individuals (particularly the Weak) would adaptively select the elaborated explanations appropriate for their ability level. The second experiment found evidence that individuals do in fact choose materials of appropriate difficulty, presumably within their personal region of proximal learning. However, the addition of learner control was not found to reduce the relative decline in performance when Weak individuals were provided with even the *option* of viewing more difficult elaborated explanations. One useful way of examing this issue is by taking the previously presented results from each experiment and then combining them into a single representation, which is shown below in Figure 21.

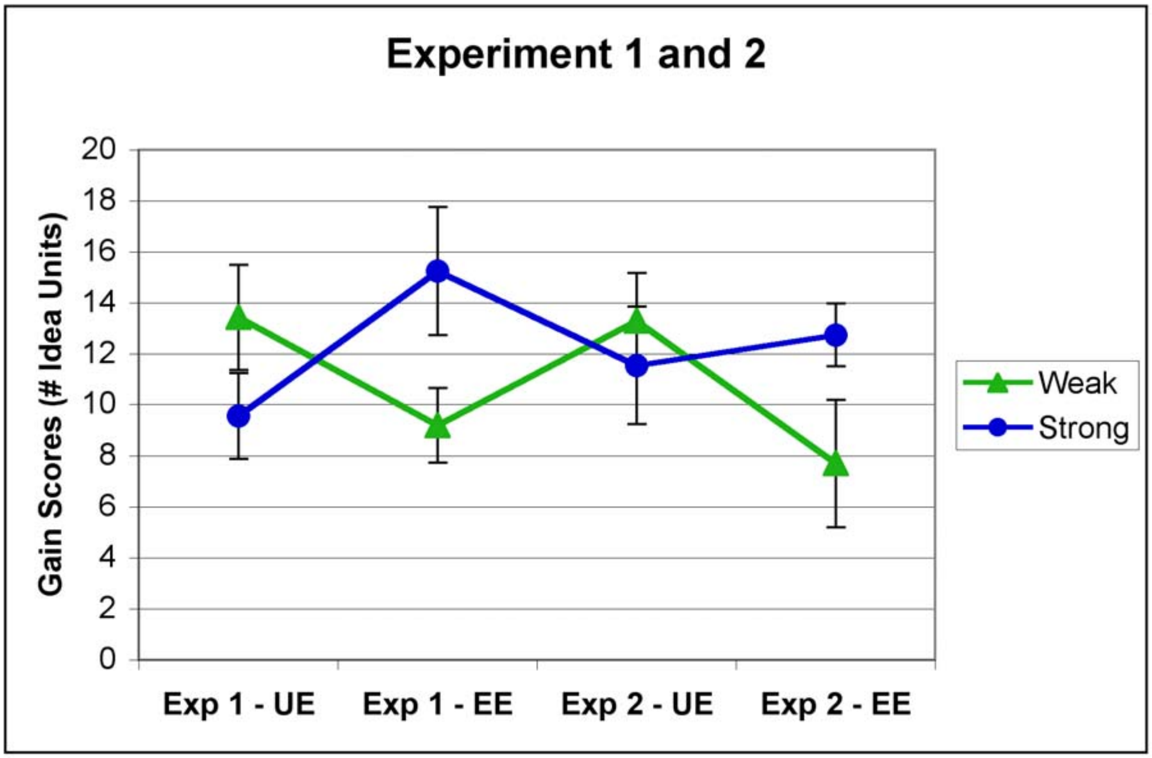

Figure 21 Gain scores between experiments and conditions for Weak and Strong participants.

As is shown above in figure 21, there was little evidence that providing Weak individuals with control over the viewing of the elaborations provided any advantage in learning over simply requiring the elaborations to be read (i.e. Condition EE in Experiment 2 (LC) versus in Experiment 1 (No LC)). Perhaps the reason for the lack of improvement for Weak participants with increased learner control was that given their already taxed cognitive resources, the cognitive load from being forced to read additional challenging information was not significantly different from having to deal with the cognitive load of making decisions about whether or not to view such information. An examination of the participants' "mental effort" difficulty ratings (see figure 22 below) may be interpreted as consistent with this speculation[15]. However, this issue is far from resolved and deserves further study.

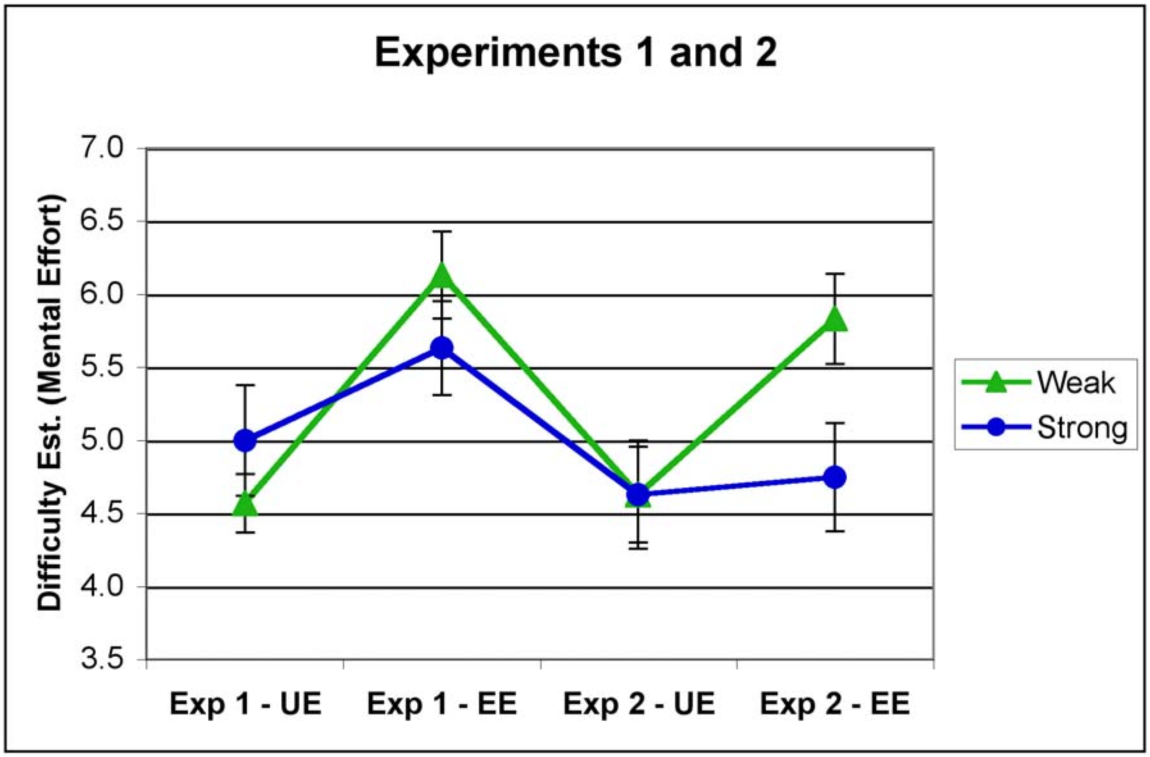

Figure 22 Difficulty Estimations ("Mental Effort") between experiments and conditions for Weak and Strong participants.

Two additional findings related to learner control are worth highlighting. First, in instances without learner control such as the UE and EE conditions in experiment 1 and the UE condition in experiment 2, there were no significant correlations between *intentional learning* and knowledge gains. In contrast, in the EE condition of experiment 2, in which participants had

[15] Three outliers were removed, resulting in an n = 59 for the data displayed figure 22.

more control, there was a highly significant correlation ($r = 0.69$) between intentional learning and knowledge gains, even after controlling for the number of elaborations viewed ($r = 0.68$). Thus, the possession of sufficiently strong intentional learning goals is especially important in situations with greater learner control, such as in the case of informal learning on the Web.

A second notable finding involves the factor of *topic interest*. Previous research (e.g. Alexander et al. 1994; Hidi, 1990; Krapp et al., 1992; Schiefele et al., 1992) has indicated that correlations between *interest* and student achievement (e.g. knowledge acquisition, grades, etc.) range from 0.09 to 0.67 with the average being approximately 0.30 for learning across different subject domains and age groups. Furthermore, the relationship between interest and learning is held to be independent of text length, reading ability, prior knowledge, and text difficulty (Schiefele, 1999). In the first experiment, reported above, the relationship between topic interest (e.g. science) and learning ($r = 0.14$) was on the lower end of the range established in previous research and was not statistically significant. In contrast, in the Elaborated Explanation (EE) condition in which participants had greater learner control over this experience, there was a highly significant correlation between topic interest and learning gains ($r = 0.72$). This relationship remained highly significant (r = 0.70) even after controlling for the number of elaborations viewed. Thus it appears that topic interest might play a critical role primarily in situations in which there is a significant degree of learner control, like informal learning on the Web.

There were a number of weaknesses and limitations in these studies that need to be addressed. First, while the sample size was sufficient for running statistical analyses in three of the four experimental conditions, the complexity of the learner control condition (EE condition of study 2) necessitated a greater number of participants for adequate power than had been anticipated, thereby limiting the range of statistical analyses that could be performed. This is because whereas participants in the first three conditions were either presented with 0 or 4 elaborations, participants in the Elaborated Explanations condition of study 2 had the option of choosing anywhere from 0 to 4 elaborations, thereby dividing these participants into multiple subgroupings for which statistical analyses were at times problematic. For example, only one Strong participant chose a low number of elaborations, thereby precluding the calculation of a standard deviation for this subgrouping. Another limitation was that several key study assessments (i.e. interest ratings, difficulty ratings, and intentional learning goals) were based on self-report measures constructed by the study investigator. While this was deemed necessary since there were no existing standardized measures that targeted the specific questions of interest to this study, the newly created measures are limited in terms of lacking established reliability and validity data. In addition, the use of more objectively measured behavioral assessments would increase the strength of these findings. Possibilities for doing so are discussed below.

Future research should be conducted to help remedy these weaknesses. To address the first problem, that is, the lack of sufficient participants, a follow-up study should be performed in which additional participants are run in the learner control condition (i.e. experiment 2, EE condition). To address the second limitation – the lack of key objective behavioral measures – verbal protocol analyses could be performed with the video recordings of participants reading the text during the intervention phase of the experiment. For instance, episodes of comprehension breakdown could be coded and analyzed to provide another measure of the learner's perception of the text difficulty. Similarly, episodes in which participants relate the text content to their prior knowledge could be coded to provide another measure of their intentional learning goals and strategies.

In addition to the inclusion of a process measure of moment-by-moment cognitive processes, a more fine-grained analysis of domain knowledge might be useful. For instance, the analyses herein did not address the issue of misconceptions. Many participants began the study with misconceptions about aerodynamics. These problematic misconceptions were not analyzed, potentially leading to an underestimation of changes in participants' learning gains.

Stepping back in order to view the larger picture, we see that informal learning environments, such as found in museums and via the Web (e.g. Crowley & Jacobs, 2002; Crowley, Leinhardt, & Chang, 2001; Leinhardt, et al., 2002), are important areas of instruction that are only now beginning to receive proper study by cognitive scientists. As noted by Graesser et al. (2002), despite the widespread use of the Web, there has been very little empirical research on its instructional effectiveness; hence this is an area in which additional research is greatly needed. The U.S. government's task force on this topic (Web-based Education Commission, 2000) has called for the building of a new national research framework to better understand how people learn from the Web. Furthermore, they state that, "A vastly expanded, revitalized, and reconfigured educational research, development, and innovation program is imperative" (p. iv). It is held by the author that both the specific experimental findings as well as the new research approaches employed and suggested herein have the potential to meaningfully contribute towards achieving these goals.

APPENDIX A

Assessment Materials

CONFIDENTIAL

Data Cover Sheet

[Remove and store in locked file cabinet]

Participant Name: ____

Study Date: _____/____/_____ Study Start Time: ________________

[Do not write below this line]

Participant ID Code: ___________________

Study: 1 (ST) EE / UE 2 (HT) EE / UE

Data Cover Sheet

Participant ID Code: __________ Study: 1 (ST) EE/ UE 2 (HT) EE / UE

Study Date: _____/_____/_____ Study Start Time: ________________

Nelson-Denny: __________ *MARSI:* ____________ *Domain Knowledge:*_________

Pretest

- Nelson-Denny Start Time: ______+15 Stop Time: ___________
- Assessments Start Time: ________ Stop Time: ___________
- Practice (Video Rec.) Start Time: ________ Stop Time: ___________

---------------------------------------[*BREAK for Participant*]---

Intervention (Video Rec.)

- Reading Main Text Start Time: _______ Midpoint: _______ Stop Time: ________
  - HT Condition: Opened Elaboration Window: 1 2 3 4

---------------------------------------[*BREAK for Participant*]---

Posttest

- Assessments Start Time: ________ Stop Time: ___________

Notes:

Web Experience Questionnaire

1. How long have you been using the Web?

   - __________ years

2. On average, how much time per week do you spend using the Web?

   - __________ hours

3. Of this, about what percentage of time do you spend reading educational or instruction materials?

   - __________ %

4. Please list any education or instruction websites that you repeatedly visit

   - Site: ___________________________________ Average # visits per week _____
   - Site: ___________________________________ Average # visits per week _____
   - Site: ___________________________________ Average # visits per week _____
   - Site: ___________________________________ Average # visits per week _____
   - Site: ___________________________________ Average # visits per week _____

Interest Rating

1. In general, do you find science to be:

1	2	3	4	5	6	7
Very Boring			Neutral			Very Interesting

2. About how much of your free time during the next week do you think you'd like to spend learning about science?

   - ____________ %

3. In general, do you find aerodynamics (i.e. the science of flight) to be:

1	2	3	4	5	6	7
Very Boring			Neutral			Very Interesting

4. About how much of your free time during the next week do you think you'd like to spend learning about aerodynamics?

   - ___________ %

Academic and Science Background Questionnaire

1. Please list any Science courses (also including the grade received) that you've taken in high school and college:

- High School:
    - o ____
    - o ____
    - o ____
    - o ____
- College:
    - o ____
    - o ____
    - o ____
    - o ____

2. Major: ______________________________ GPA: _____________ SAT: _____________

   Class Year: ___________________________ Age: ________________________________

Domain Knowledge Assessment:

-Please write NEATLY (i.e. so that it is legible to others)
-Provide written (i.e. prose) answers and/or diagrams wherever appropriate

1. Write a brief explanation of the important scientific principles that govern the flight of an airplane.

2. Provide a brief definition (with examples) of:

   -Fluids

   -Mass

   -Speed

   -Pressure

   -Viscosity

3. Define these forces and explain how they influence how an airplane flies:

   -Thrust

   -Drag

   -Weight

   -Lift

4. When a quarterback throws a football, what force does the football exert on him?

5. What is the pressure of air *below* a wing compared to that of the surrounding air? If it is different, explain why.

6. Does the bottom surface of the wing significantly contribute to generating lift? If so, how?

7. What is the pressure of air *above* a wing compared to that of the surrounding air? If it is different, explain why.

8. Does the top surface of the wing significantly contribute to generating lift? If so, how?

9. Describe and explain how the angle of the wing, with respect to the air, influences how the air flows over a wing.

10. Draw and label a diagram of the flow of air around a wing with:

    -No Lift

    -Significant Lift

11. Describe and explain some ways in which a fluid can flow over a surface. What different forces can be involved?

12. What is the common cause of a “stall” in which a wing undergoes a sudden loss of lift?

13. How does the *surface area* of a wing influence how an airplane flies?

14. How does the *shape* of a wing influence how an airplane flies?

15. How does *airspeed* influence how an airplane flies?

16. What happens to a fluid’s speed when moving from an area of low pressure into an area of high pressure?

17. Draw the flow of water around this boat. Explain any differences in pressure both *in front of* and *behind* it, compared to that of the surrounding water.

18. At higher altitude, the air is thinner (i.e. less dense). Explain how this would affect the flight of an airplane.

19. The flow of air above these cars influences the amount of traction the wheels will have with the surface of the road. Explain why a specific car would have the *most* traction. Also explain why a specific car would have the *least* traction:

-The most traction:

-The least traction:

20. Chris is trying to make a wing for a model airplane, but only has a piece of flat, rigid cardboard. Will he be able to make an airplane with the cardboard that generates lift? Why or why not?

21. Two people are arguing about how to increase an airplane's lift. Sarah suggests using bigger wings, doubling their size. Aaron suggests using a more powerful engine, doubling the plane's speed. Which plan will lead to greater lift and why?

-Sarah's (i.e. bigger wings)

-Aaron's (i.e. bigger engine)

-No Difference

-Can't tell

22. Airplanes are launched off an aircraft carrier by a machine called a "catapult" that rapidly accelerates the planes forward helping them takeoff. If there is a strong wind blowing from the North, which way should the ship be pointed to generate more lift for takeoff, and why?

-South (away from wind)

-North (into the wind)

-No Difference

-Can't Tell

Stop

Wait for instructions before proceeding

Difficulty Estimation

1. Compared to the initial practice text on bridges, how difficult was the recent text to understand:

1	2	3	4	5	6	7
Much Easier			Same			Much Harder

2. How much of your "mental effort" was involved in reading the recent text:

1	2	3	4	5	6	7
Extremely low	Very low	Low	Neither low nor high	High	Very high	Extremely high

Once completed, return to reading on-line text

Difficulty Estimation

1. Compared to the initial practice text on bridges, how difficult was the recent text (i.e. second section) to understand:

1	2	3	4	5	6	7
Much Easier			Same			Much Harder

2. How much of your "mental effort" was involved in reading the recent text (i.e. second section):

1	2	3	4	5	6	7
Extremely low	Very low	Low	Neither low nor high	High	Very high	Extremely high

Stop

Wait for instructions before proceeding

Domain Knowledge Assessment:

-Please write NEATLY (i.e. so that it is legible to others)
-Provide written (i.e. prose) answers and/or diagrams wherever appropriate

1) Write a brief explanation of the important scientific principles that govern the flight of an airplane.

2) Provide a brief definition (with examples) of:

-Fluids

-Mass

-Speed

-Pressure

-Viscosity

3) Define these forces and explain how they influence how an airplane flies:

-Thrust

-Drag

-Weight

-Lift

4) When a quarterback throws a football, what force does the football exert on him?

5) What is the pressure of air *below* a wing compared to that of the surrounding air? If it is different, explain why.

6) Does the bottom surface of the wing significantly contribute to generating lift? If so, how?

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8) Does the top surface of the wing significantly contribute to generating lift? If so, how?

9) Describe and explain how the angle of the wing, with respect to the air, influences how the air flows over a wing.

10) Draw and label a diagram of the flow of air around a wing with:

-No Lift

-Significant Lift

11) Describe and explain some ways in which a fluid can flow over a surface. What different forces can be involved?

12) What is the common cause of a “stall” in which a wing undergoes a sudden loss of lift?

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17) Draw the flow of water around this boat. Explain any differences in pressure both *in front of* and *behind* it, compared to that of the surrounding water.

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-The most traction:

-The least traction:

20) Chris is trying to make a wing for a model airplane, but only has a piece of flat, rigid cardboard. Will he be able to make an airplane with the cardboard that generates lift? Why or why not?

21) Two people are arguing about how to increase an airplane's lift. Sarah suggests using bigger wings, doubling their size. Aaron suggests using a more powerful engine, doubling the plane's speed. Which plan will lead to greater lift and why?

-Sarah's (i.e. bigger wings)

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22) Airplanes are launched off an aircraft carrier by a machine called a "catapult" that rapidly accelerates the planes forward helping them takeoff. If there is a strong wind blowing from the North, which way should the ship be pointed to generate more lift for takeoff, and why?

-South (away from wind)

-North (into the wind)

-No Difference

-Can't Tell

Learning Goals and Strategies Measurement

When you read the text, what were your main goals?

1. Enjoying the material

1	2	3	4	5	6	7
Not at all			Somewhat			Definitely

2. Doing as little "work" as possible

1	2	3	4	5	6	7
Not at all			Somewhat			Definitely

3. Connecting the material to things that you already knew about

1	2	3	4	5	6	7
Not at all			Somewhat			Definitely

4. Memorizing the material

1	2	3	4	5	6	7
Not at all			Somewhat			Definitely

5. Skimming the material for the main points

1	2	3	4	5	6	7
Not at all			Somewhat			Definitely

6. Building a "mental picture" of the material

1	2	3	4	5	6	7
Not at all			Somewhat			Definitely

7. Searching the material for answers to the earlier questions

1	2	3	4	5	6	7
Not at all			Somewhat			Definitely

8. Maximizing how much you would learn

1	2	3	4	5	6	7
Not at all			Somewhat			Definitely

9. Connecting the various facts and ideas to each other

1	2	3	4	5	6	7
Not at all			Somewhat			Definitely

APPENDIX B

Study Text (Elaborations are Highlighted)

Introduction: What Makes an Airplane Fly?

Almost everyone today has flown in an airplane. Many ask the simple question "what makes an airplane fly?" To answer this, we'll look at some of the simpler areas of aerodynamics, which is a science that deals with the motion of solid objects in fluids.

Basic Science Concepts

One important idea to understand is that gases (like air) and liquids (like water) are both considered to be fluids. In a fluid, the molecules are free to move around, unlike those in a solid object.

Fluids have a number of important properties such as mass, speed, pressure, and viscosity.

The *mass* of something is basically the amount of matter it contains (i.e. the number of molecules). This is what determines its weight.

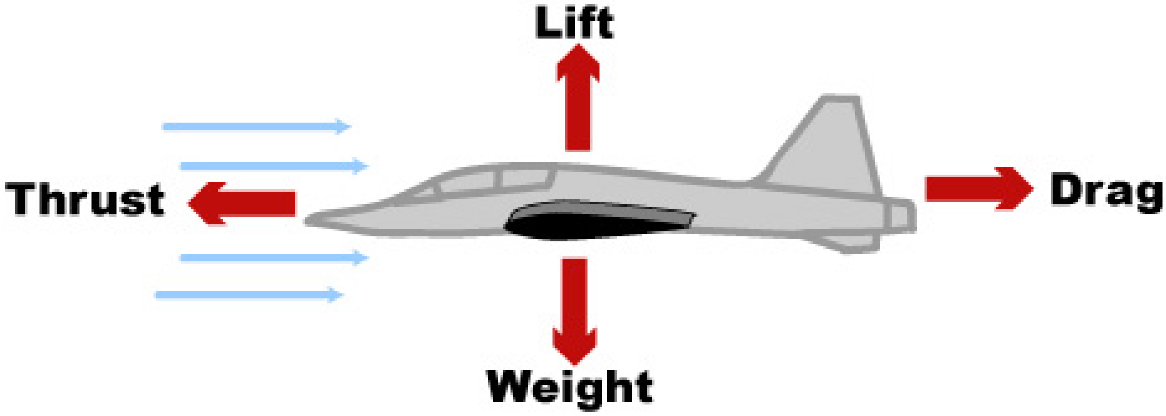
The *speed* of something is how quickly it is moving with respect to another object or objects (e.g. a plane relative to the air). You can think about this in terms of the distance an object travels within a certain period of time (e.g. miles per hour).

The *pressure* of a fluid is the amount of force or “push” it directly applies to a surface of a specific area (e.g. pounds per square inch).

The *viscosity* of a fluid is a measure of how much the fluid resists flowing. Air, water, and even pancake syrup all flow at different rates. They may seem to behave very differently, but they are actually quite similar, except in terms of viscosity – air having a low viscosity, water having an intermediate viscosity, and syrup having a high viscosity.

Forces on an Airplane

Before we delve into how wings keep airplanes up in the air, it is important that we take a quick look at four basic aerodynamic forces: lift, weight, thrust and drag.



Straight and Level Flight
In order for an airplane to fly straight and level, the following relationships must be true:

- Thrust = Drag
- Lift = Weight

If the amount of drag becomes larger than the amount of thrust, the plane will slow down. If the thrust is increased so that it is greater than the drag, the plane will speed up.

Similarly, if the amount of lift drops below the weight of the airplane, the plane will descend. If the lift is increased so that it is greater than the weight, the plane will rise.

Thrust
Thrust is an aerodynamic force produced by an engine (e.g. propeller or jet). It is directed forward along the axis of the engine (which is usually more or less parallel to the long axis of the airplane).

Drag
Drag acts parallel to, and resists, the motion of an object through a fluid. If you stick your hand out of a moving car window, you'll experience the air pushing against your hand, which is the force called drag. The amount of drag that your hand creates basically depends on a few factors, such as the size or surface area of your hand pointing into the wind and the speed of the car.

Weight
Weight is the force directed downward from an object towards the center of the earth and is proportional to the mass of the object.

Every object on earth has weight including air – a cubic yard of air at sea level weighs about 2 pounds.

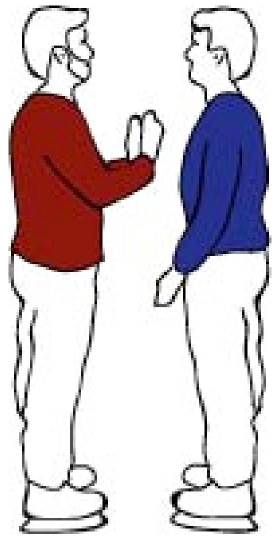
Lift

Lift acts perpendicular to the motion of an object moving through a fluid. This force is usually directed upwards, in the opposite direction of the object's weight. A simple demonstration of this effect can be experienced if you stick your hand out of a moving car window and turn it so its leading edge (i.e. the one pointed into the wind) is now higher than the trailing edge (i.e. the one pointed away from the wind). Turning your hand this way results in an upward force on your hand which is called "lift".

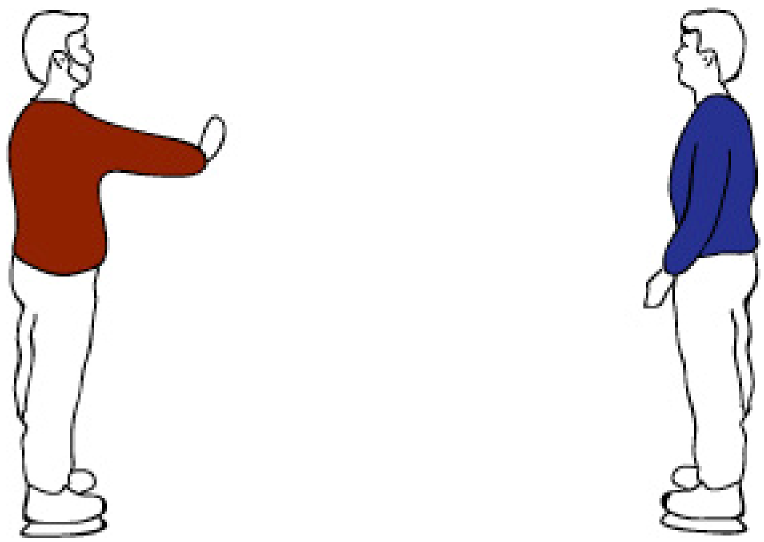
Forces on a Wing

Action/Reaction

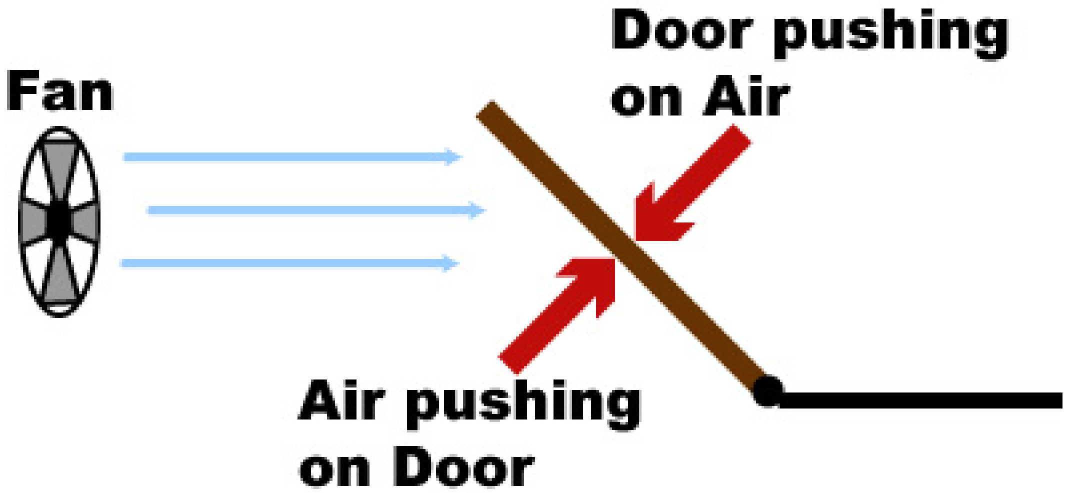
An important idea is that when one object pushes on something (action), the second object "pushes back" (reaction). For example, in the picture below, two skaters are standing next to each other at an ice rink.



If the skater on the left pushes on the skater on the right, they both move in opposite directions.



Imagine a fan blowing air at a partially open door as seen in the picture below (a "top view" looking downward at the door).



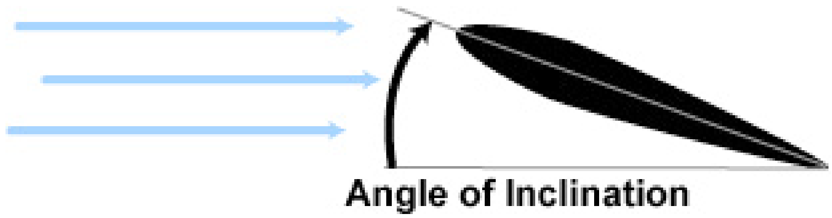
The air hits and pushes against the door. At the same time, the door pushes back against the air. Similarly, if a wing pushes air downward, the air will “push back” on the wing, sending it upward. This can be seen more clearly in the picture below of a side view or cross-section of a wing.

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Now we’ll just look at how a fluid such as air pushes on a surface.

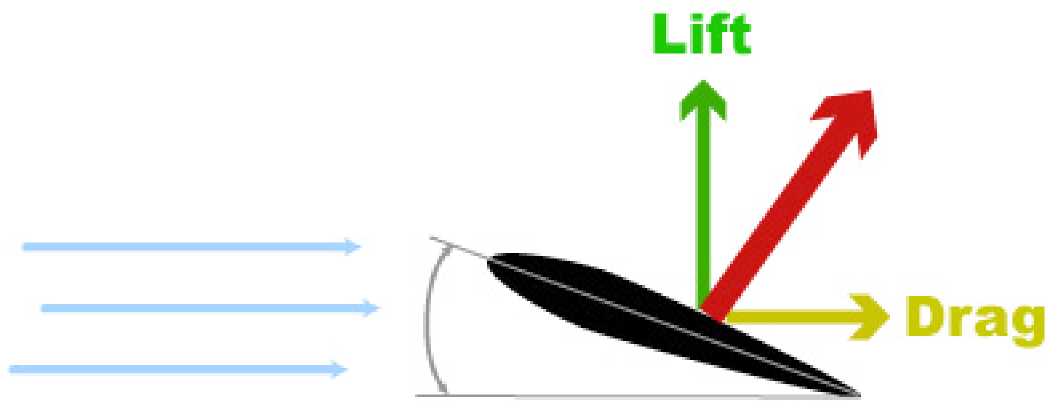
Angle of Inclination

One important thing to consider is the *angle of inclination* or “tilt” a surface or a wing makes with respect to the flow of a fluid.



If a wing is pointed directly into the wind, we can say that its angle of inclination is zero. In cases such as this, all the force of the air pushes horizontally on the surface and just causes drag.

In the picture below, we can see the force of the air (red arrow) on the wing. We can think about the overall force of the air (red arrow) on the surface as being made up of two parts: one part that points *straight up* (green arrow) and is perpendicular to the wind, and another part that points *straight across* (yellow arrow) and is parallel to the wind.



The force pointing straight up is the force on the surface that is called *Lift*, and is what lifts the airplane up. The force pointing to the right is the force on the surface that is called *Drag*, and is what slows the airplane down.

Deflecting Air – Wing Surfaces

In order for a wing to generate lift, it needs to *deflect air downward*. So how does a wing deflect the air flowing around it? The top and bottom surfaces both play a role.

Bottom Surface of Wing

When the air approaches the bottom surface of a wing with a positive angle of inclination, such as in the picture below, it is deflected downward along the bottom surface of the wing. Basically, the bottom surface of the wing pushes the air downward. This leads to higher pressure below the wing.

Top Surface of Wing

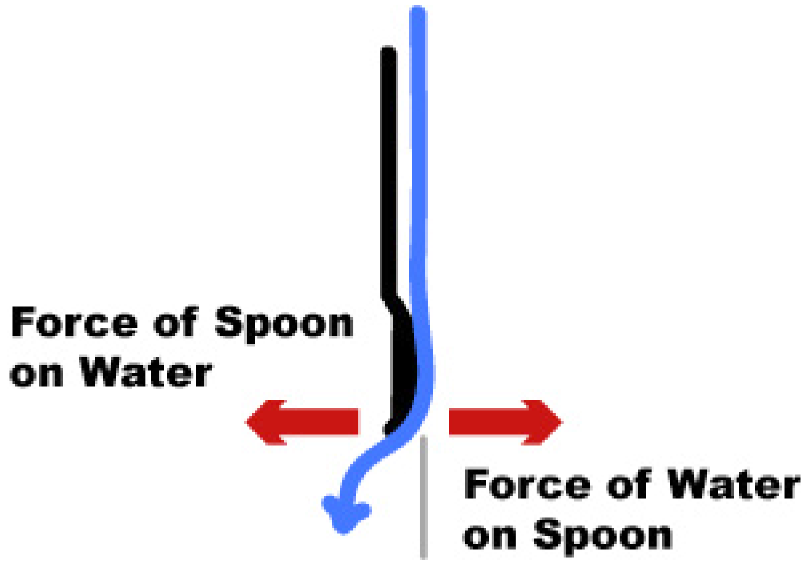
When the air approaches the top surface of a wing with a positive angle of inclination, such as in the picture below, it is deflected downward along the top surface of the wing. Basically, the top surface of the wing *pulls* the air downward. This leads to lower pressure above the wing.

A wing is able to “pull” the air above it downward because when a moving fluid, such as air or water, comes into contact with a surface it will *try to follow that surface*. This is called the Coanda effect.

As a fluid flows past a surface, the fluid’s viscosity causes it to “stick” to the surface and change the direction of its flow. It is this change in direction of the fluid flow that helps generate lift.

You can see an example of this effect if you hold a spoon under a faucet with a small stream of water that just touches the side of the spoon.

As you can see in the picture below, the spoon deflects the flow of water as it follows the spoon’s curved surface. The spoon applies a force on the water (action) and the water applies a force in the opposite direction (reaction).



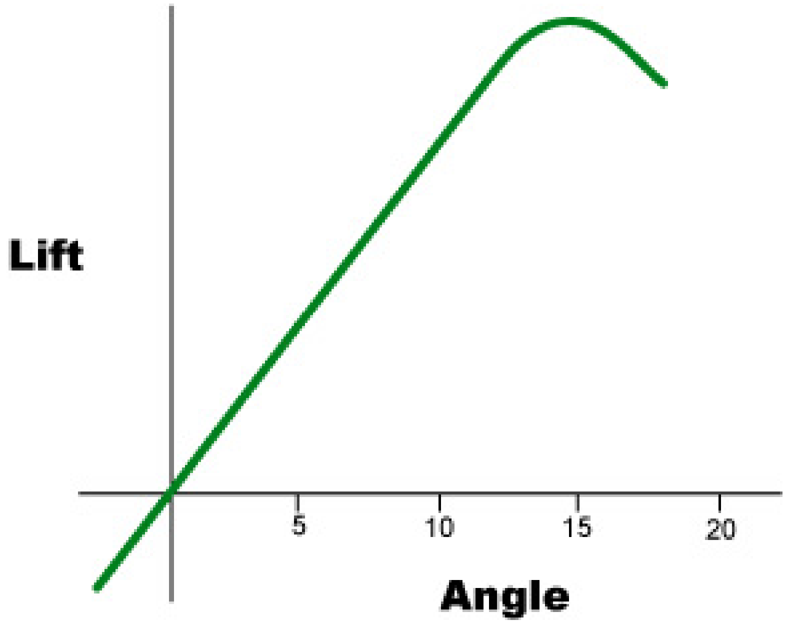
Now please open your blue binder, turn to the next page,

and then answer the "difficulty estimation" questions

Wing Angle of Inclination

There are several major factors that influence lift. One factor, discussed above, is the wing's angle of inclination. Within a certain range, as you increase the angle of inclination the lift is increased proportionately.

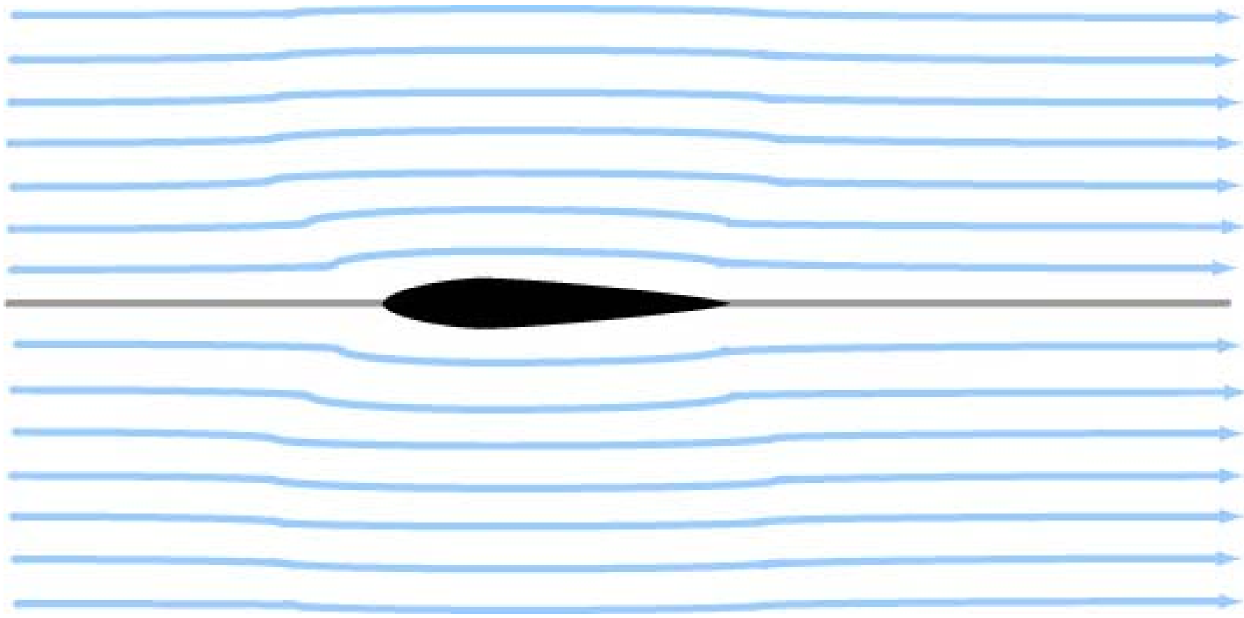
The picture below shows the lift of a typical wing, as a function of the angle of inclination. A similar lift versus angle of inclination relationship is found for wings in general, from the wing of a 747 or your hand out the car window.



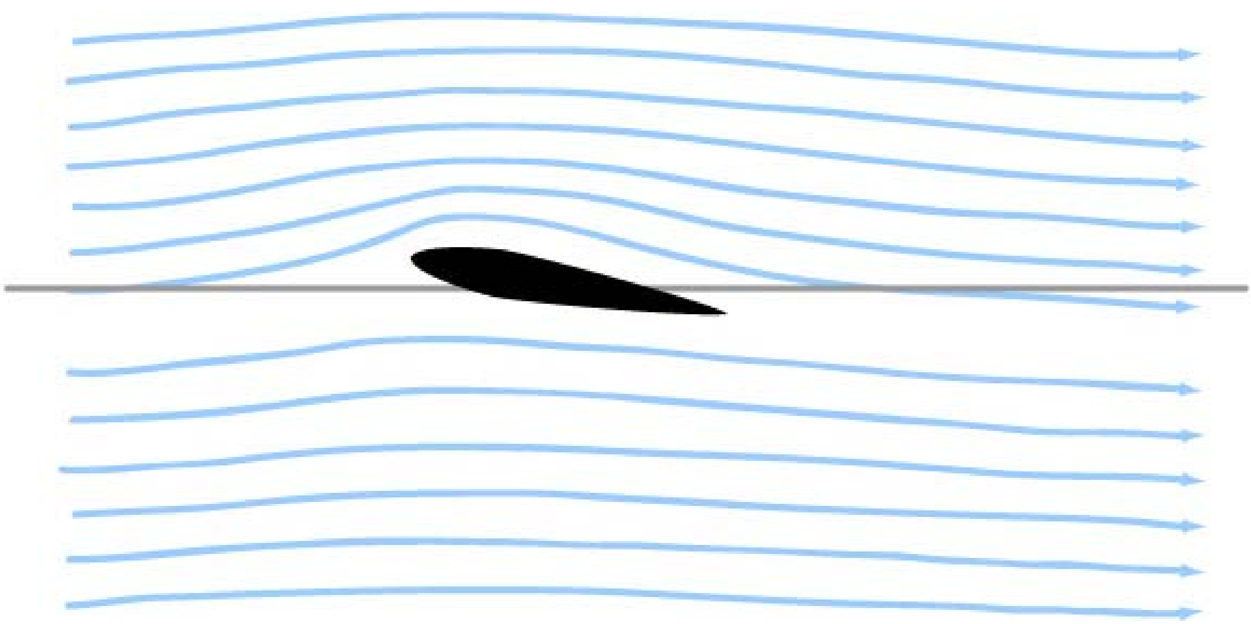
As the angle of inclination increases, the lift increases until it eventually reaches a point where it levels off and begins to decrease. This happens because when the angle of inclination becomes too great, the air can't smoothly bend around the top surface of the wing. When this happens to an airplane, the lift is decreased and the plane is in what is called a "stall". To understand why this occurs, we need to look at how the air flows around a wing.

Airflow

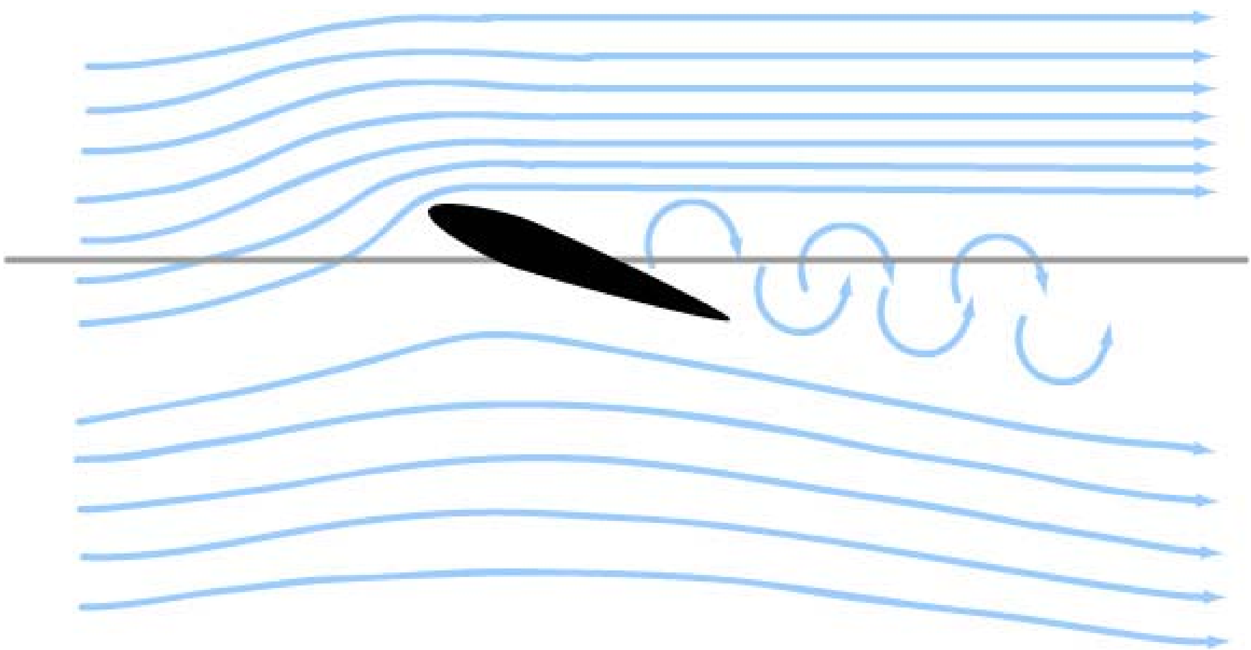
In the picture below, the blue lines represent the flow of streams of air as they move from left to right and flow over and under the wing.



With a small angle of inclination, as in the picture below, the flow of air above the wing is now different from that below the wing, but it is still flowing smoothly over the wing.

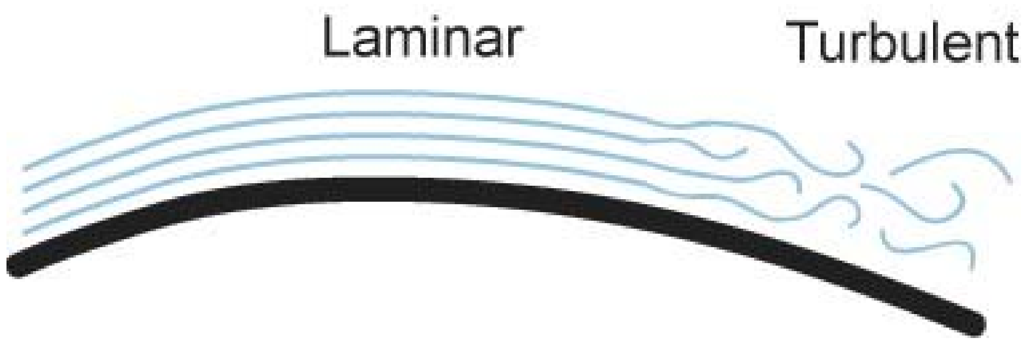


However, if the angle of inclination becomes too large, the air on the top of the wing becomes turbulent and it no longer flows smoothly, as you can see in the picture below.



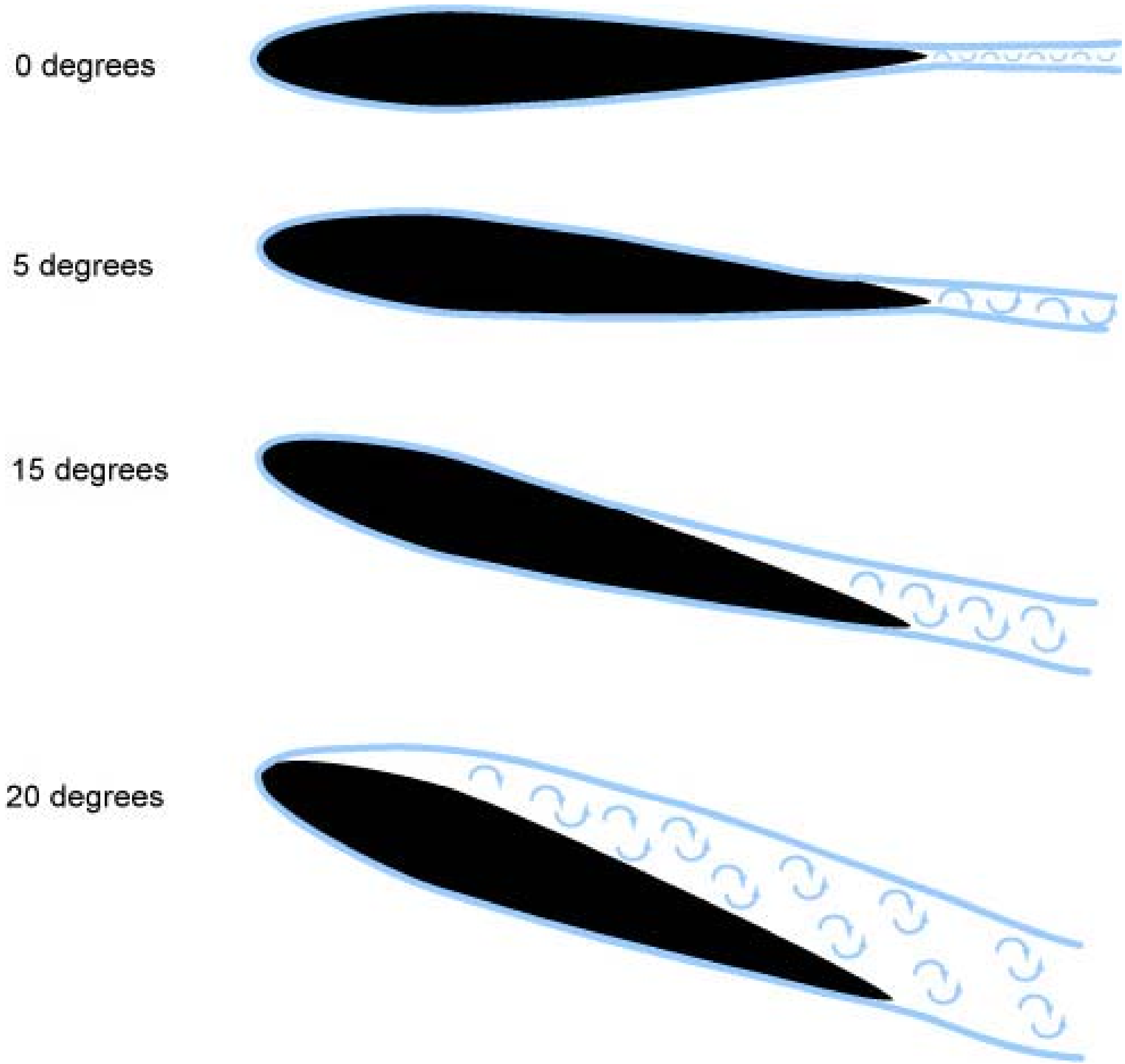
While the smooth flow of air over the wing is fairly straightforward, the *turbulent* flow is complex and often unpredictable.

When the air flows smoothly over a surface, this is called "Laminar" flow. In the picture below we see air flowing over a surface. At first it is flowing smoothly over the surface, but further along the surface, the flow becomes progressively disorganized and turbulent. In turbulent flow, secondary random motions are superimposed or added to the principle flow.



What causes the change from laminar to turbulent flow? There is a thin layer of slower moving air around the surface of the wing that is called the *boundary layer*. The external flow is the flow beyond the boundary layer. As the angle of inclination increases, the boundary layer flow changes from laminar to turbulent. The boundary layer adheres to the surface because of viscosity, but as the angle of inclination increases, the boundary layer separates.

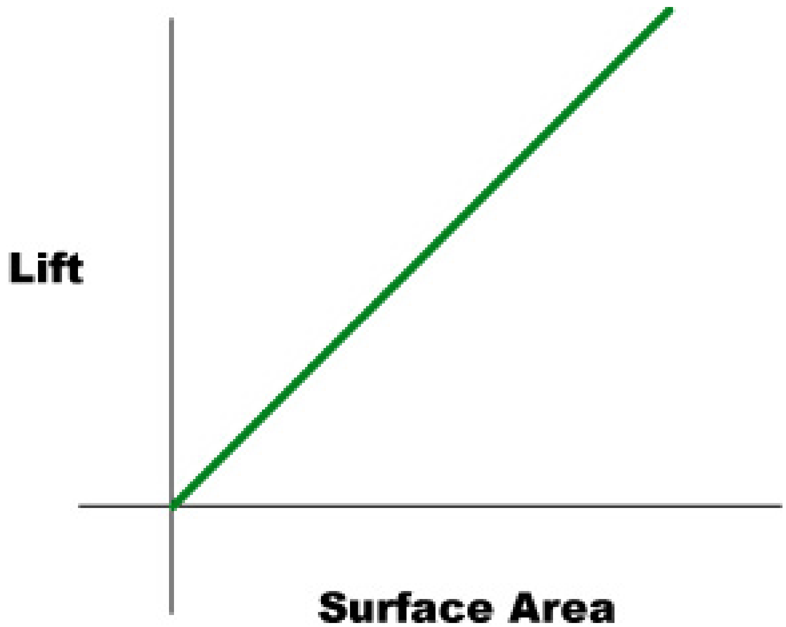
Flow separation occurs because of a transition from laminar to turbulent flow, and is the reason for wing stall at high angle of inclination. As shown in the series of pictures below, as the angle is increased, the point of separation moves closer to the leading edge of the wing.



Wing Structure

Another important set of related factors is the wing's surface area and shape.

Surface Area
Increasing the surface area of a wing allows more air to be deflected, proportionately increasing the lift. So if you double the surface area, you double the lift (as shown below).



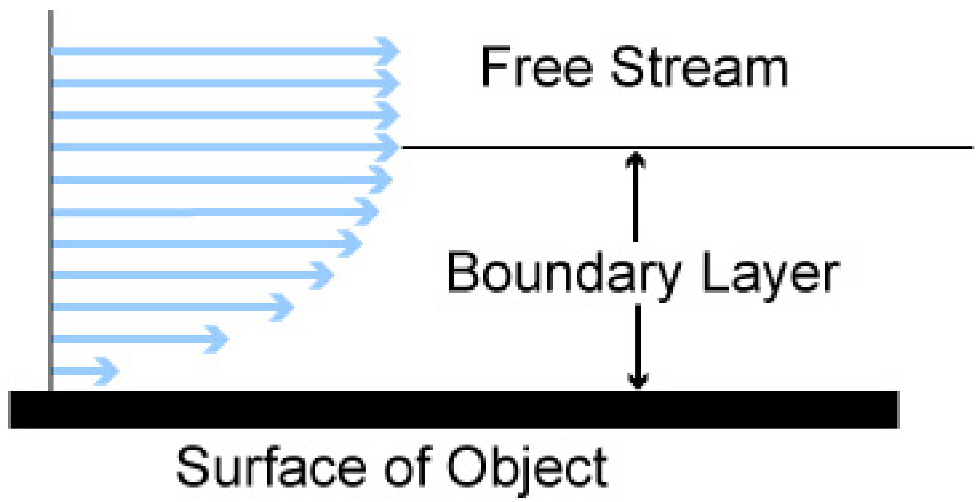
However, increasing the surface area also causes an increase in drag. One type of drag is called *friction drag* and is the result of the friction between the fluid and the surface of the object.

This friction is determined in part by the fluid's *viscosity,* which is a measure of how resistant it is to flow.

The absolute viscosity of a fluid is a measure of its resistance to shear stresses, which act tangentially to the object's surface. Viscosity can be thought of as an "internal friction" of a fluid, which is determined by its composition (i.e. the intermolecular forces between the molecules). Greater viscosity (i.e. more resistant to flow), results in greater frictional drag.

Consider a fluid flowing over a surface as illustrated in the picture below. Due to viscosity, the film of fluid next to the surface will be sticking to it and will, therefore, have zero velocity. Fluid further away from the surface will slip over the fluid beneath it as it moves to the right. Since each successive layer of fluid will slip over the layer below it, the velocity of the fluid will increase with the distance from the surface over which the fluid is flowing.

This creates a thin layer of fluid near the surface in which the velocity changes from zero at the surface to the free stream value away from the surface. This layer is called the *boundary layer* because it occurs on the boundary of the fluid.



So for a specific fluid, such as air, the greater the surface area, the greater the drag will be. However, unlike lift, if you double the surface area, there will only be a small increase in its drag.

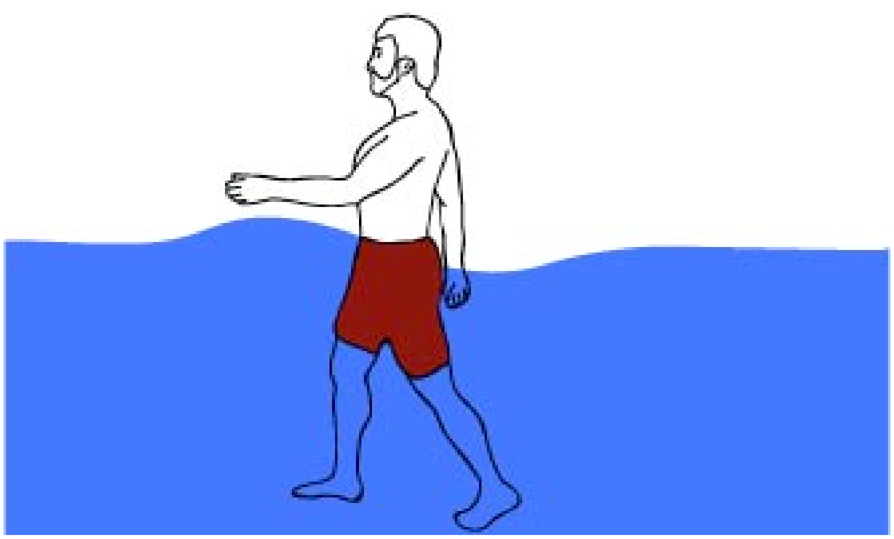
Shape

The shape of a wing is another important factor in terms of a wing's drag.

In order to reduce a wing's drag, airplane designers change the shape of the wing so that it is rounded and thicker in the front and narrower in the back (see pictures below).

The second picture shows a more streamlined wing, which has a lower amount of drag. This is because as an object moves through a fluid, there is a net difference between the high pressure in front of the object and the low pressure behind the object.

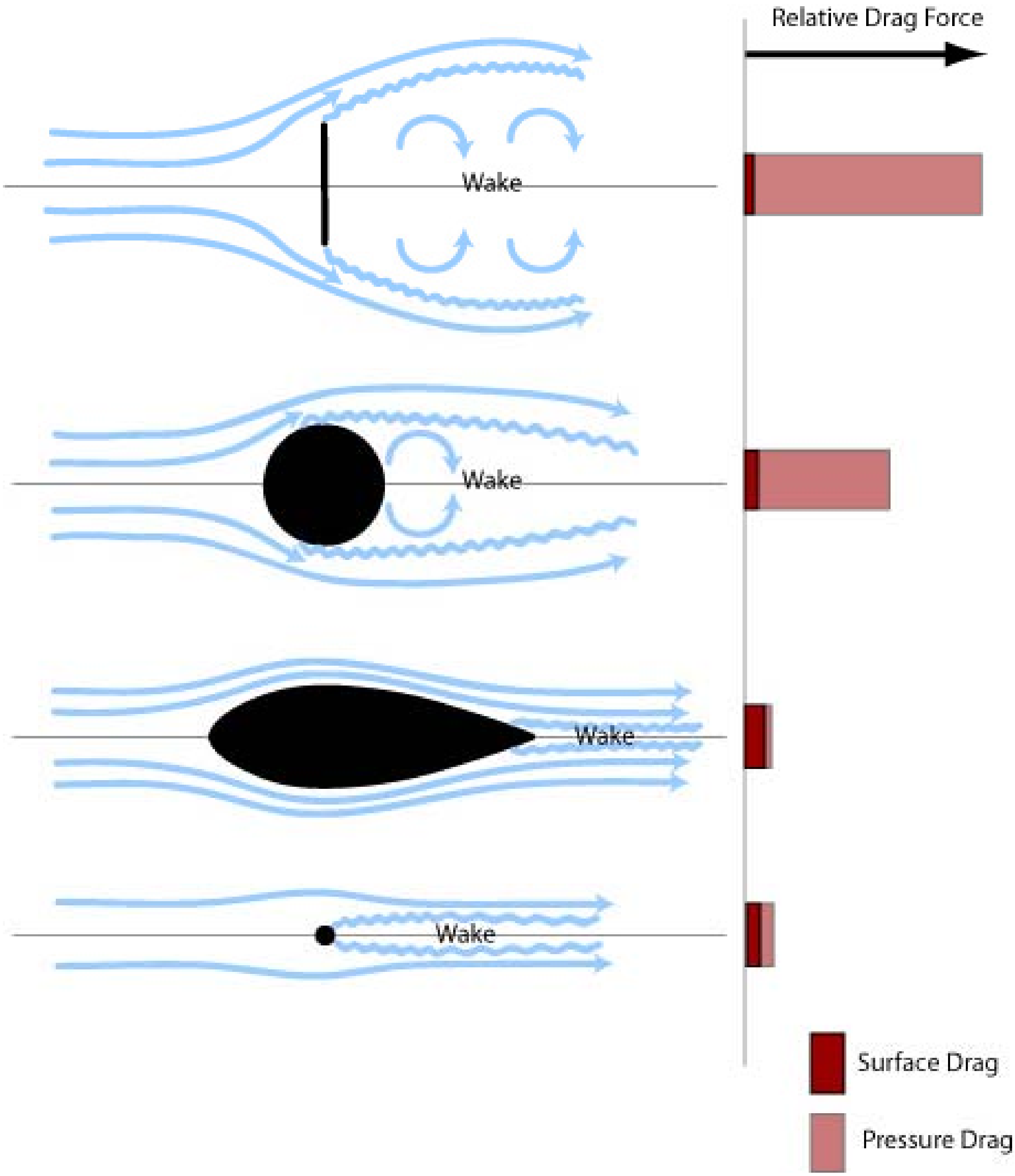
You can see this effect if you walk through the water of a swimming pool (see picture below). As you walk through the water you will feel yourself being held back, this is due in large part because there is a build-up of pressure in front of you, and the decrease in pressure behind you, which can be seen in the picture below with the rising wave in front of the person and the depression in the water behind him. This difference in pressure is called *pressure drag*.



The picture below shows four objects in which the air is flowing from the left to the right.

The flat plate, placed broadside to the flow, has a large wake (i.e. turbulent area of lower pressure) with separation points at the plate edge. A large pressure drag is the result, the friction drag being a relatively small component.

The cylinder has a smaller wake and the boundary layer separation occurs, in this case, before the “shoulders” (i.e. widest point) of the cylinder. The friction drag is a little larger in this case than for the plate, but is still smaller than the pressure drag. Overall, the total drag has been reduced from that of the flat plate, so some effects of streamlining are already evident.

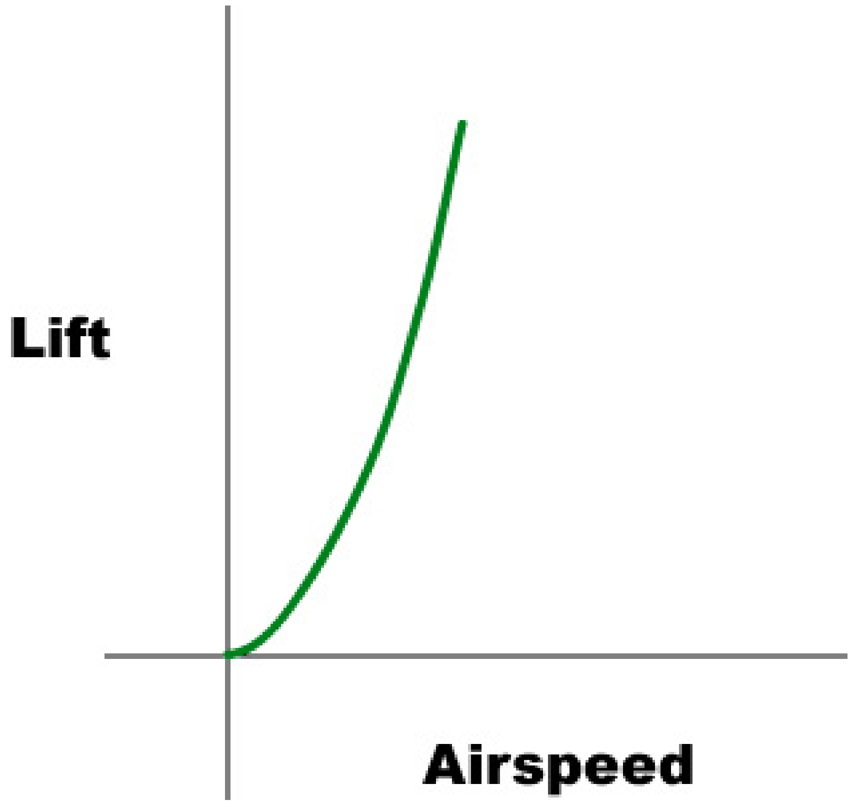


The streamlined shape has almost no boundary layer separation and the wake is very small. The friction drag now is the dominant component and the pressure drag is very small. Even more noticeable is the very large reduction in overall drag compared with the cylinder or plate. This has been accomplished by greatly reducing the pressure drag. The friction drag has been increased due to the fact that the streamlined body has more area exposed to the flow and thus has a greater area over which the boundary layer may act.

Finally, the fourth object is a small cylinder approximately 1/10th the diameter of the streamlined shape, in thickness. Surprisingly it has the same overall drag as the much larger streamlined shape because of its high pressure drag.

Air Speed

A third factor influencing lift is airspeed. In general the greater the speed of the wing relative to the air, the greater the lift will be. More specifically the lift is proportional to the square of the airspeed so that if you double the airspeed, you quadruple the lift.



The lift and drag generated by a wing are proportional to both its *speed* relative to the air and the *mass* of the air.

When the wing deflects the air downward, the force generated is determined by the change in *momentum* of the air. The momentum of any object is proportional to the object's speed, multiplied by the object's mass. A useful way of calculating momentum is to first find out the density of an object.

So if we have a wing that deflects a certain volume of air downward, then its lift will depend on the density of the air. Air of higher density has more mass in a fixed volume, and since momentum is determined by both the speed and mass of an object, when the density of the air is increased, there will be an increase in its momentum (per unit volume) and the resulting lift.

Lastly, the speed of a fluid's flow is also closely related to its *pressure*. In general, the speed of flow will increase when moving from an area of high pressure to one of low pressure.

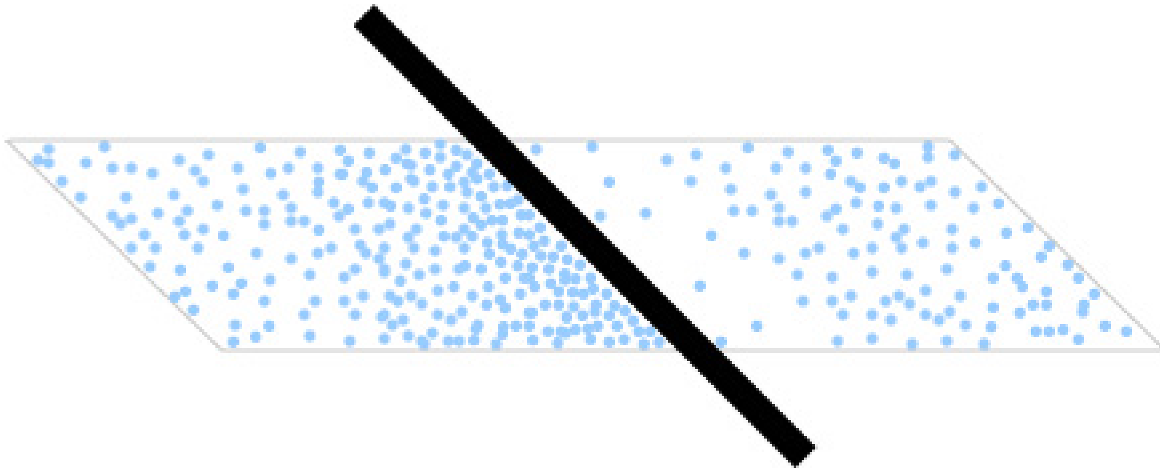
Speed and Pressure
In order to understand the specific reasons why the speed of the flow of air changes across different parts of the wing, we first need to look at the concept of pressure in terms of the action of individual molecules.

In a gas, the molecules are in constant, random motion and frequently collide with each other and with the surface of any nearby object. As the gas molecules collide with an object, they impart momentum to it, producing a force perpendicular to the surface. The sum of the forces due to the random motion of the molecules striking the surface is defined as the *static pressure*. If, in addition to the random motion, the molecules are moving (on average) toward or away from a surface, this added force perpendicular to the surface is called the *dynamic pressure*. The sum of the static pressure and dynamic pressure is called the *total pressure*.

We can look at how the pressure differs on the surfaces of a wing. The picture below shows the air molecules around a simplified wing that is moving from the right to the left. The far left and far right represent the molecules in the normal, ambient air.

The motion of the wing has *compressed* the arrangement of air molecules just in front of it so that they occupy less space, creating *greater total pressure* on the bottom surface of the wing.

The motion of the wing has also *decompressed* the arrangement of air molecules just behind it so that they occupy more space, creating *lower total pressure* on the top surface of the wing. This results in a net difference in pressure between the top and bottom wing surfaces.



These differences in pressure are what cause the air to move at *different speeds* along the surfaces of the wing.

Air molecules move an average distance before hitting another object – usually another air molecule – and this is called the mean free path. When air is compressed the molecules are more closely packed together and have smaller mean free paths, meaning that they don't move as far before hitting and bouncing off another object. Conversely, when air is decompressed, the molecules have larger mean free paths and can travel longer distances before hitting and bouncing off other objects.

So when air approaches a wing and becomes compressed, the air molecules become more crowded (i.e. increased pressure) and the molecules cannot move as easily in the direction of the airflow since there is more "congestion" in that direction. So whenever there is an *increase* in pressure due to molecules becoming more compressed, there will be a *decrease* in their overall speed in the direction of flow. Conversely, when there is a *decrease* in pressure (i.e. less "congestion"), there will be an *increase* in the speed of the fluid flow.

Conclusion

So now you've learned about the main forces on an airplane and how they allow airplanes to fly!

Again, please open your blue binder, turn to the next page, and then answer another set of "difficulty estimation" questions

APPENDIX C

Supplementary Results

Table 1
Excluded Middle Third of Tripartite Split

	Experiment 1		Experiment 2	
	Condition: UE	Condition: EE	Condition: UE	Condition: EE
	Intermediate	*Intermediate*	*Intermediate*	*Intermediate*
Pretest Score: Domain Knowledge	21.13 (2.49)	18.38 (2.76)	17.88 (2.71)	21.06 (2.24)
Posttest Score: Domain Knowledge	32.44 (7.34)	32.69 (4.94)	27.31 (9.04)	35.63 (8.49)
Pretest-Posttest Gain Scores	11.31 (7.75)	14.31 (6.29)	9.56 (9.00)	14.56 (8.35)
Repeat-Measures ANOVA	$F(1, 7) = 17.02$, $p = .004$	$F(1, 7) = 41.42$, $p < .001$	$F(1, 7) = 8.39$, $p = .023$	$F(1, 7) = 24.35$, $p = .002$

Table 2
Difficulty Estimations

	Experiment 1				Experiment 2			
	Condition: UE		Condition: EE		Condition: UE		Condition: EE	
	Weak	*Strong*	*Weak*	*Strong*	*Weak*	*Strong*	*Weak*	*Strong*
Difficulty Est. 1-1	4.13 (0.99)	3.62 (1.30)	4.25 (1.17)	4.00 (0.93)	4.38 (1.69)	3.88 (1.13)	4.25 (0.89)	3.13 (0.99)
Difficulty Est. 1-2	4.38 (0.92)	4.38 (0.52)	5.38 (0.52)	4.13 (1.64)	5.00 (0.54)	4.25 (1.17)	4.50 (1.31)	4.63 (1.06)
Difficulty Est. 2-1	4.63 (1.60)	4.63 (1.19)	5.75 (1.28)	5.63 (0.74)	4.38 (1.19)	4.63 (1.30)	4.88 (1.81)	5.00 (1.60)
Difficulty Est. 2-2	4.88 (0.99)	5.00 (1.07)	6.13 (0.84)	5.63 (1.06)	4.63 (0.92)	4.63 (1.06)	4.75 (2.12)	4.75 (1.04)

Table 3
Reading Duration Measurements

	Experiment 1				Experiment 2			
	Condition: UE		Condition: EE		Condition: UE		Condition: EE	
	Weak	*Strong*	*Weak*	*Strong*	*Weak*	*Strong*	*Weak*	*Strong*
Reading Duration (Part 1)	9.36 (1.52)	9.73 (2.85)	10.57 (2.81	10.79 (3.34	9.24 (1.77)	10.14 (2.33)	10.34 (4.51)	8.64 (2.02)
Reading Duration (Part 2)	5.93 (0.69)	6.29 (1.54)	15.33 (3.82)	17.41 (5.60)	5.49 (0.76)	6.66 (1.73)	7.55 (2.82)	11.10 (3.75)

Reading Duration (Part 1):

- Study – $F(1, 56) = 0.56$, $p = .46$
- Condition – $F(1, 56) = 0.45$, $p = .51$
- Domain Knowledge – F(1, 56) = 0.005, p = .94

Reading Duration (Part 2):

- Study – $F(1, 56) = 21.60$, $p < .001$ [Study 1 takes longer due to the required reading of the Elaborated Explanations versus Study 2 in which they are optional]
- Condition – $F(1, 56) = 78.56$, $p < .001$ [The Elaborated Explanation text takes longer reading duration than the Unelaborated text]
- Domain Knowledge – $F(1, 56) = 5.50$, $p = .02$ [Somewhat surprisingly, Strong Ss took significantly longer]

Table 4

Baseline Equivalence Measurements

	Experiment 1				**Experiment 2**			
	Condition: UE		**Condition: EE**		**Condition: UE**		**Condition: EE**	
	Weak	*Strong*	*Weak*	*Strong*	*Weak*	*Strong*	*Weak*	*Strong*
Nelson Denny	2.00 (0.76)	2.25 (0.71)	2.13 (0.84)	2.25 (0.46)	2.13 (0.64)	2.25 (0.89)	2.13 (0.64)	2.50 (0.54)
MARSI	3.20 (0.47)	3.28 (0.71)	3.27 (0.45)	3.30 (0.35)	3.48 (0.25)	3.22 (0.16)	3.38 (0.52)	3.42 (0.41)
NFC	58.13 (10.68)	73.63 (4.41)	64.00 (5.29)	70.75 (10.87)	64.38 (10.16)	70.62 (11.39)	60.50 (17.52)	71.62 (11.20)

Nelson-Denny Reading Comprehension Categorization

- Study – $F(1, 56) = 0.29$, $p = .59$
- Condition – $F(1, 56) = 0.29$, $p = .59$
- Domain Knowledge – $F(1, 56) = 1.58$, $p = .21$

MARSI

- Study – $F(1, 56) = 1.00$, $p = .32$
- Condition – $F(1, 56) = 0.16$, $p = .69$
- Domain Knowledge – $F(1, 56) = 0.05$, $p = .82$

NFC

- Study – $F(1, 56) = 0.003$, $p = .95$
- Condition – $F(1, 56) = 0.0$, $p = .99$
- Domain Knowledge – $F(1, 56) = 13.29$, $p = .001$ [Strong participants had much higher Need for Cognition]

Table 5

Baseline Equivalence Measurements - Interest

	Experiment 1				**Experiment 2**			
	Condition: UE		**Condition: EE**		**Condition: UE**		**Condition: EE**	
	Weak	*Strong*	*Weak*	*Strong*	*Weak*	*Strong*	*Weak*	*Strong*
Interest Q1	5.38 (0.74)	6.62 (0.52)	4.88 (1.13)	6.63 (0.52)	4.50 (1.93)	6.00 (1.07)	4.13 (2.42)	6.00 (1.20)
Interest Q2	18.13 (16.89)	32.50 (22.04)	11.88 (11.93)	39.25 (38.15)	28.13 (31.39)	30.63 (20.43)	26.50 (32.81)	31.56 (24.67)
Interest Q3	3.63 (1.41)	4.88 (1.13)	5.13 (0.99)	5.13 (0.84)	3.25 (2.05)	5.00 (1.07)	4.00 (2.20)	4.75 (1.04)

Interest Q4	3.75 (4.43)	5.58 (7.77)	5.38 (8.68)	14.62 (27.30)	10.63 (15.68)	11.88 (20.69)	8.38 (13.98)	6.00 (4.50)

Interest – Question 1 [See Results section for description and analyses of Interest measures]
- Study – $F(1, 56) = 4.57$, $p = < .001$
- Condition – $F(1, 56) = 0.42$, $p = .52$
- Domain Knowledge – $F(1, 56) = 22.45$, $p < .001$

Interest – Question 2:
- Study – $F(1, 56) = 0.33$, $p = .57$
- Condition – $F(1, 56) = .00$, $p = .99$
- Domain Knowledge – $F(1, 56) = 3.57$, $p = .06$

Interest – Question 3:
- Study – $F(1, 56) = 1.51$, $p = .22$
- Condition – $F(1, 56) = 2.50$, $p = .12$
- Domain Knowledge – $F(1, 56) = 6.94$, $p = .011$

Interest – Question 4:
- Study – $F(1, 56) = 0.24$, $p = .63$
- Condition – $F(1, 56) = 0.02$, $p = .88$
- Domain Knowledge – $F(1, 56) = 0.47$, $p = .50$

Table 6
Baseline Equivalence Measurements – Academic Background

	Experiment 1				**Experiment 2**			
	Condition: UE		**Condition: EE**		**Condition: UE**		**Condition: EE**	
	Weak	*Strong*	*Weak*	*Strong*	*Weak*	*Strong*	*Weak*	*Strong*
Science Courses	6.63 (2.62)	8.75 (3.15)	5.50 (1.93)	9.38 (5.93)	5.25 (1.91)	10.13 (7.55)	7.25 (4.71)	9.50 (5.18)
College GPA	2.43 (0.82)	3.12 (0.71)	2.80 (0.59)	3.34 (0.62)	3.12 (0.48)	3.56 (0.32)	2.43 (1.18)	3.36 (0.40)
SAT	1094 (155)	1330 (116)	1071 (290)	1332 (101)	1111 (146)	1274 (153)	1112 (160)	1304 (120)

Science Courses [i.e. High School & College, included Social Sciences and Physical Sciences]
- Study – $F(1, 56) = 0.17$, $p = .68$
- Condition – $F(1, 56) = 0.04$, $p = .85$
- Domain Knowledge – $F(1, 56) = 8.34$, $p = .006$ [More science courses corresponded to greater domain knowledge]

College GPA
- Study – $F(1, 53) = 1.13$, $p = .29$
- Condition – $F(1, 53) = 0.18$, $p = .67$

- Domain Knowledge – $F(1, 53) = 13.14$, $p < .001$ [Higher GPAs corresponded to greater domain knowledge]

SAT

- Study – $F(1, 53) = 0.02$, $p = .88$
- Condition – $F(1, 53) = 0.004$, $p = .95$
- Domain Knowledge – $F(1, 53) = 22.77$, $p < .001$ [Higher SATs corresponded to greater domain knowledge]

Table 7

Baseline Equivalence Measurements – Web Background

	Experiment 1				**Experiment 2**			
	Condition: UE		**Condition: EE**		**Condition: UE**		**Condition: EE**	
	Weak	*Strong*	*Weak*	*Strong*	*Weak*	*Strong*	*Weak*	*Strong*
Web Exper.	6.00 (0.76)	8.25 (1.67)	8.75 (1.98)	8.13 (2.10)	7.63 (1.30)	6.75 (1.17)	6.87 (1.96)	7.37 (2.50)
Average Web Use	9,33 (6.40)	17.06 (9.59)	9.94 (7.86)	24.38 (23.83)	17.19 (20.07)	15.00 (11.92)	16.00 (11.63)	19.00 (10.34)

Web Experience:

- Study – $F(1, 56) = 2.01$, $p = .16$
- Condition – $F(1, 56) = 2.01$, $p = .16$
- Domain Knowledge – $F(1, 56) = .5$, $p = 0.48$

Average Web Use:

- Study – $F(1, 56) = .21$, $p = .65$
- Condition – $F(1, 56) = 0.58$, $p = .45$
- Domain Knowledge – $F(1, 56) = 2.70$, $p = .11$

Table 8

Baseline Equivalence Measurements – Learning Goals

	Experiment 1				**Experiment 2**			
	Condition: UE		**Condition: EE**		**Condition: UE**		**Condition: EE**	
	Weak	*Strong*	*Weak*	*Strong*	*Weak*	*Strong*	*Weak*	*Strong*
Goals: Q1	3.50 (1.31)	3.88 (1.64)	3.00 (1.51)	3.88 (1.64)	2.88 (2.03)	3.50 (0.76)	3.25 (1.58)	4.00 (1.51)
Goals: Q2	3.13 (1.55)	2.50 (1.41)	1.50 (0.76)	2.50 (1.41)	3.38 (1.19)	2.38 (1.19)	3.13 (1.36)	3.00 (1.31)
Goals: Q3	4.50 (0.93)	5.25 (1.39)	5.38 (1.19)	5.38 (1.59)	4.50 (1.07)	5.38 (1.19)	5.00 (1.20)	5.88 (0.64)
Goals: Q4	3.25 (1.40)	4.00 (1.60)	4.25 (1.04)	3.75 (2.05)	3.25 (1.98)	3.25 (1.28)	4.25 (1.49)	3.88 (2.10)
Goals: Q5	4.63 (1.85)	3.62 (1.79)	2.50 (1.69)	3.38 (1.69)	4.63 (1.30)	3.25 (1.04)	3.75 (1.49)	3.63 (1.85)
Goals: Q6	4.00 (0.93)	5.25 (1.67)	5.25 (1.67)	5.25 (1.04)	4.75 (2.05)	5.00 (1.31)	5.25 (1.67)	5.25 (0.89)
Goals: Q7	4.38 (1.41)	5.75 (1.28)	4.75 (1.83)	4.25 (2.77)	4.75 (1.98)	4.88 (1.36)	4.75 (1.98)	4.63 (2.13)
Goals: Q8	4.50	4.75	4.50	4.25	3.63	4.75	4.38	4.50

	(1.69)	(2.19)	(0.93)	(1.98)	(1.41)	(1.28)	(1.41)	(1.31)
Goals: Q9	4.63 (0.92)	5.63 (1.60)	4.50 (1.77)	5.63 (1.51)	4.38 (1.30)	5.25 (1.17)	4.75 (1.17)	5.50 (1.41)

Goals - Q1:

- Study – $F(1, 56) = 0.17$, $p = .69$
- Condition – $F(1, 56) = 0.06$, $p = .81$
- Domain Knowledge – $F(1, 56) = 2.92$, $p = .09$

Goals – Q2:

- Study – $F(1, 56) = 3.03$, $p = .09$
- Condition – $F(1, 56) = 0.94$, $p = .34$
- Domain Knowledge – $F(1, 56) = 0.34$, $p = .56$

Goals – Q3:

- Study – $F(1, 56) = 0.5$, $p = .83$
- Condition – $F(1, 56) = 2.87$, $p = .10$
- Domain Knowledge – $F(1, 56) = 4.49$, $p = .04$ [Goal corresponded to increased knowledge]

Goals – Q4:

- Study – $F(1, 56) = 0.14$, $p = .71$
- Condition – $F(1, 56) = 2.05$, $p = .16$
- Domain Knowledge – $F(1, 56) = .006$, $p = .94$

Goals – Q5:

- Study – $F(1, 56) = 0.49$, $p = .49$
- Condition – $F(1, 56) = 3.21$, $p = .08$
- Domain Knowledge – $F(1, 56) = 1.02$, $p = .32$

Goals – Q6:

- Study – $F(1, 56) = 0.07$, $p = .80$
- Condition – $F(1, 56) = 1.62$, $p = .21$
- Domain Knowledge – $F(1, 56) = 1.22$, $p = .27$

Goals – Q7:

- Study – $F(1, 56) = 0.004$, $p = .95$
- Condition – $F(1, 56) = 0.52$, $p = .47$
- Domain Knowledge – $F(1, 56) = 0.21$, $p = .68$

Goals – Q8:

- Study – $F(1, 56) = 0.23$, $p = .64$
- Condition – $F(1, 56) = 0.0$, $p = 1.0$
- Domain Knowledge – $F(1, 56) = .63$, $p = .43$

Goals – Q9:

- Study – $F(1, 56) = 0.13$, $p = .72$
- Condition – $F(1, 56) = 0.13$, $p = .72$
- Domain Knowledge – $F(1, 56) = 7.39$, $p = 0.009$ [Goal corresponded to increased knowledge]

Table 9

Experiment 1 – Correlation Matrix of Weak and Strong Participants

	Prior Domain Knowledge	Nelson Denny	MARSI	Need for Cognition	Web Usage	Interest (Science)	Interest (Aero.)	Science Courses	GPA	SAT	Difficulty Est. (Main Txt)	Dif Est 1 Main	Difficulty Est. (Elab Txt)	Difficulty Est. Effort	Intentional Learning
Prior Domain Knowledge	–														
Nelson Denny	.15	–													
MARSI	.04	.00	–												
Need for Cognition	**.53**	.00	.31	–											
Web Usage	**.43**	-.04	.26	**.42**	–										
Interest (Science)	**.69**	-.20	.33	**.65**	**.43**	–									
Interest (Aero.)	.21	.14	.21	.32	.13	.21	–								
Science Courses	.28	.16	.17	**.35**	.17	**.48**	.07	–							
GPA	**.51**	.32	.19	**.47**	.21	.34	.33	.26	–						
SAT	**.69**	.36	.14	.35	.37	.35	.25	.31	**.65**	–					
Difficulty Est. (Main Txt)	-.16	.18	.15	.05	.22	-.11	-.05	.07	.04	.08	–				
Difficulty Est. Effort (Main Txt)	-.31	.05	-.14	-.18	**-.39**	-.33	**.36**	.24	.10	-.18	.11	–			
Difficulty Est. (Elab Txt)	.00	-.07	-.05	.08	.11	-.01	.03	-.06	.17	.08	**.55**	-.02	–		
Difficulty Est. Effort (Elab Txt)	-.06	.04	-.05	-.14	-.02	-.12	.32	.13	.30	.04	.34	**.55**	**.37**	–	
Intentional Learning	.27	-.10	**.54**	**.44**	.17	**.50**	**.42**	.02	.24	.09	-.17	-.09	-.06	.10	–

Note: Significant correlations in bold.

Table 10

Experiment 1 – Correlation Matrix of Weak Participants

	Prior Domain Knowledge	**Nelson Denny**	**MARSI**	**Need for Cognition**	**Web Usage**	**Interest (Science)**	**Interest (Aero.)**	**Science Courses**	**GPA**	**SAT**	**Difficulty Est. (Main Txt)**	**Dif Est 1 Main Text**	**Difficulty Est. (Elab Txt)**	**Difficulty Est. Effort**	**Intentional Learning**
Prior Domain Knowledge	–														
Nelson Denny	.12	–													
MARSI	-.09	-.20	–												
Need for Cognition	.12	-.39	.20	–											
Web Usage	.17	-.36	.20	.30	–										
Interest (Science)	.18	**-.64**	.36	.31	.13	–									
Interest (Aero.)	.09	.10	.21	.22	.31	.13	–								
Science Courses	.07	-.12	.24	-.10	.23	.30	-.21	–							
GPA	.44	.32	.13	.36	.01	-.08	.40	-.12	–						
SAT	**.68**	.23	.18	-.22	.20	-.26	.14	.00	.44	–					
Difficulty Est. (Main Txt)	.22	.15	-.10	.27	.22	-.16	.22	.05	.25	.17	–				
Difficulty Est. Effort (Main Txt)	.04	.11	-.07	.30	.42	-.30	**.63**	.20	.35	.01	.39	–			
Difficulty Est. (Elab Txt)	.04	-.13	-.04	.29	.05	.08	.34	.04	.34	.06	**.73**	.42	–		
Difficulty Est. Effort (Elab Txt)	.00	.12	.31	.26	.16	-.06	**.69**	.17	.41	.16	**.49**	**.69**	**.62**	–	
Intentional Learning	-.06	-.25	**.68**	.29	-.03	**.53**	**.50**	-.03	.31	-.13	-.36	.06	-.01	.36	–

Note: Significant correlations in bold.

Table 11

Experiment 1 – Correlation Matrix of Strong Participants

	Prior Domain Knowledge	**Nelson Denny**	**MARSI**	**Need for Cognition**	**Web Usage**	**Interest (Science)**	**Interest (Aero.)**	**Science Courses**	**GPA**	**SAT**	**Difficulty Est. (Main Txt)**	**Dif Est. 1 Main**	**Difficulty Est. (Elab Txt)**	**Difficulty Est. Effort**	**Intentional Learning**
Prior Domain Knowledge	–														
Nelson Denny	-.04	–													
MARSI	.00	.21	–												
Need for Cognition	-.16	.32	.45	–											
Web Usage	.26	.00	.30	.30	–										
Interest (Science)	-.16	.12	**.57**	**.72**	.44	–									
Interest (Aero.)	-.41	.12	.20	.23	-.11	.28	–								
Science Courses	**-.51**	.30	.13	.33	-.02	.48	.09	–							
GPA	.29	.26	.23	.25	.08	.35	.02	.26	–						
SAT	.06	**.68**	.37	**.55**	.36	.48	.17	.34	**.68**	–					
Difficulty Est. (Main Txt)	-.16	.29	.36	.10	.39	.35	-.31	.21	.01	.28	–				
Difficulty Est. Effort (Main Txt)	-.24	.10	-.16	-.28	**-.53**	-.06	.35	.49	.18	-.01	-.17	–			
Difficulty Est. (Elab Txt)	.13	.05	-.06	-.15	.21	-.15	**-.57**	-.14	-.02	.00	.35	-.49	–		
Difficulty Est. Effort (Elab Txt)	.17	-.03	-.34	**-.51**	-.04	-.14	-.13	.20	.35	.14	.16	.46	.02	–	
Intentional Learning	.22	.00	.44	.45	.12	.41	.22	-.13	-.02	.11	.09	-.07	-.13	-.12	–

Note: Significant correlations in bold.

Table 12
Experiment 2 – Correlation Matrix of Weak and Strong Participants

	Prior Domain Knowledge	Nelson Denny	MARSI	Need for Cognition	Web Usage	Interest (Science)	Interest (Aero.)	Science Courses	GPA	SAT	Difficulty Est. (Main Txt)	Dif Est 1 Main	Difficulty Est. (Elab Txt)	Difficulty Est. Effort	Intentional Learning
Prior Domain Knowledge	–														
Nelson Denny	.26	–													
MARSI	-.12	-.03	–												
Need for Cognition	**.42**	**.48**	.31	–											
Web Usage	.04	-.15	.17	-.02	–										
Interest (Science)	**.53**	.20	.33	**.60**	.17	–									
Interest (Aero.)	**.41**	-.28	.00	.06	.20	.08	–								
Science Courses	**.40**	.07	.07	**.57**	-.13	**.49**	.32	–							
GPA	**.46**	**.52**	-.05	**.47**	-.22	**.59**	-.13	.32	–						
SAT	**.67**	**.66**	-.25	**.64**	-.24	**.42**	.04	**.40**	**.58**	–					
Difficulty Est. (Main Txt)	-.26	.07	.21	-.12	-.13	-.19	.10	-.06	-.14	-.17	–				
Difficulty Est. Effort (Main Txt)	-.09	.10	.34	.14	-.01	.05	.15	.03	.06	-.17	**.49**	–			
Difficulty Est. (Elab Txt)	.16	.21	.31	.23	.02	.29	.32	.19	.15	.19	**.40**	**.54**	–		
Difficulty Est. Effort (Elab Txt)	.06	.24	.30	**.38**	.02	.31	.19	.21	.20	.03	.24	**.78**	**.69**	–	
Intentional Learning	**.40**	.10	**.39**	**.41**	-.06	**.54**	.32	**.39**	.14	.24	.00	.19	.19	.21	–

Note: Significant correlations in bold.

Table 13
Experiment 2 – Correlation Matrix of Weak Participants

	Prior Domain Knowledge	**Nelson Denny**	**MARSI**	**Need for Cognition**	**Web Usage**	**Interest (Science)**	**Interest (Aero.)**	**Science Courses**	**GPA**	**SAT**	**Difficulty Est. (Main Txt)**	**Dif Est 1 Main**	**Difficulty Est. (Elab Txt)**	**Difficulty Est. Effort**	**Intentional Learning**
Prior Domain Knowledge	–														
Nelson Denny	.42	–													
MARSI	.33	.15	–												
Need for Cognition	.49	**.56**	**.62**	–											
Web Usage	-.06	-.09	.00	.07	–										
Interest (Science)	.35	.17	**.59**	**.65**	.20	–									
Interest (Aero.)	.21	-.37	.11	-.21	.34	-.12	–								
Science Courses	**.60**	.34	**.54**	**.60**	.12	**.69**	-.04	–							
GPA	.06	**.58**	.18	.49	-.17	**.56**	-.41	.51	–						
SAT	**.69**	**.77**	.19	**.62**	-.49	.17	-.31	.44	.47	–					
Difficulty Est. (Main Txt)	.23	.44	.32	.03	.05	-.06	.19	-.09	-.05	.26	–				
Difficulty Est. Effort (Main Txt)	.25	.27	**.55**	.43	.17	.45	.21	.24	.29	.09	.37	–			
Difficulty Est. (Elab Txt)	**.53**	.27	**.56**	.47	.23	**.56**	.46	.40	.13	.21	.37	**.60**	–		
Difficulty Est. Effort (Elab Txt)	.37	.18	**.59**	**.54**	.31	**.61**	.24	.41	.23	-.07	.15	**.88**	**.71**	–	
Intentional Learning	**.57**	.01	**.54**	.36	-.06	.48	.25	**.60**	.06	.24	.01	.23	.38	.30	–

Note: Significant correlations in bold.

Table 14
Experiment 2 – Correlation Matrix of Strong Participants

	Prior Domain Knowledge	Nelson Denny	MARSI	Need for Cognition	Web Usage	Interest (Science)	Interest (Aero.)	Science Courses	GPA	SAT	Difficulty Est. (Main Txt)	Dif Est 1 Main	Difficulty Est. (Elab Txt)	Difficulty Est. Effort	Intentional Learning
Prior Domain Knowledge	–														
Nelson Denny	.12	–													
MARSI	-.19	-.16	–												
Need for Cognition	.17	.34	.01	–											
Web Usage	.20	-.26	.47	-.19	–										
Interest (Science)	.37	.09	.15	.27	.14	–									
Interest (Aero.)	.30	-.48	-.06	.27	-.19	-.06	–								
Science Courses	.11	-.16	-.15	**.51**	-.40	.22	**.63**	–							
GPA	.16	**.67**	**-.53**	.13	-.42	.14	-.39	-.11	–						
SAT	.44	**.70**	**-.54**	.49	-.01	.24	-.19	.11	.48	–					
Difficulty Est. (Main Txt)	.06	-.17	-.07	-.05	-.46	.00	.42	.16	-.04	-.28	–				
Difficulty Est. Effort (Main Txt)	.05	.03	.08	-.04	-.23	-.39	.29	.01	-.30	-.18	**.58**	–			
Difficulty Est. (Elab Txt)	.09	.14	.01	-.12	-.32	-.21	.07	.06	-.10	.12	**.53**	**.53**	–		
Difficulty Est. Effort (Elab Txt)	-.05	.35	-.25	.12	**-.63**	-.42	.09	.10	.13	.09	.45	**.73**	**.70**	–	
Intentional Learning	.18	.09	.34	.33	-.08	.46	.20	.16	-.05	-.14	.27	-.09	-.09	.05	–

Note: Significant correlations in bold.

Table 15

Pretest Measurement Comparison between Experiments -- Weak Participants

	Experiment 1	**Experiment 2**	**Difference**
Prior Domain Knowledge (Total)	10.28 (3.87)	9.38 (3.27)	$F(30) = .51$, $p = .48$
Prior Domain Knowledge (Recall Questions)	6.81 (2.96)	6.31 (2.17)	$F(30) = .30$ $p = .59$
Prior Domain Knowledge (Near Inference Questions)	0.47 (0.59)	0.19 (0.31)	$F(30) = 2.85$, $p = .10$
Prior Domain Knowledge (Far Inference Questions)	3.00 (1.60)	2.88 (1.40)	$F(30) = 06$, $p = .82$
Nelson Denny	2.06 (0.77)	2.13 (0.62)	$F(30) = .06$, $p = .80$
MARSI	3.23 (0.44)	3.43 (0.40)	$F(30) = 1.68$, $p = .21$
Need for Cognition	61.06 (8.69)	62.44 (13.98)	$F(30) = .11$, $p = .74$
Web Usage	9.69 (6.93)	16.59 (15.85)	$F(30) = 2.55$, $p = .12$
Interest (Science)	5.13 (0.96)	4.31 (2.12)	$F(30) = 1.95$, $p = .17$
Interest (Aero.)	4.38 (1.41)	3.63 (2.09)	$F(30) = 1.41$, $p = .24$
Science Courses	6.06 (2.29)	6.25 (3.62)	$F(30) = .03$, $p = .86$
GPA	2.62 (.72)	2.72 (0.98)	$F(28) = .12$, $p = .74$
SAT	1080 (234)	1111 (145)	$F(23) = .15$, $p = .70$
Difficulty Est. (Main Txt)	4.19 (1.05)	4.31 (1.30)	$F(30) = .09$, $p = .77$
Difficulty Est. Effort (Main Txt)	4.88 (0.89)	4.75 (1.00)	$F(30) = .14$, $p = .71$
Intentional Learning	4.66 (1.01)	4.58 (1.13)	$F(30) = .04$, $p = .84$

Table 16

Pretest Measurement Comparison between Experiments -- Strong Participants

	Experiment 1	**Experiment 2**	**Difference**
Prior Domain Knowledge (Total)	30.78 (3.58)	28.34 (4.84)	$F(30) = 2.62$, $p = .12$
Prior Domain Knowledge (Recall Questions)	19.19 (3.48)	17.88 (3.89)	$F(30) = 1.01$, $p = .32$
Prior Domain Knowledge (Near Inference Questions)	1.88 (1.34)	1.75 (1.06)	$F(30) = 0.09$, $p = .77$
Prior Domain Knowledge (Far Inference Questions)	9.72 (2.50)	8.72 (3.17)	$F(30) = .98$, $p = .33$
Nelson Denny	2.25 (0.58)	2.38 (0.72)	$F(30) = .29$, $p = .59$
MARSI	3.29 (0.54)	3.32 (0.32)	$F(30) = .04$, $p = .85$
Need for Cognition	72.19 (8.15)	71.13 (10.92)	$F(30) = .10$, $p = .76$
Web Usage	20.72 (17.95)	17.0 (10.97)	$F(30) = .50$, $p = .49$
Interest (Science)	6.63 (0.50)	6.00 (1.10)	$F(30) = 4.31$, $p =$ **.05**
Interest (Aero.)	5.00 (0.97)	4.88 (1.03)	$F(30) = .13$, $p = .73$
Science Courses	9.06 (4.60)	9.81 (6.26)	$F(30) = .15$, $p = .70$
GPA	3.23 (0.65)	3.47 (0.36)	$F(29) = 1.50$, $p = .23$
SAT	1331 (105)	1289 (133)	$F(28) = .93$, $p = .34$
Difficulty Est. (Main Txt)	3.81 (1.11)	3.50 (1.10)	$F(30) = .64$, $p = .43$
Difficulty Est. Effort (Main Txt)	4.25 (1.18)	4.44 (1.09)	$F(30) = .22$, $p = .65$
Intentional Learning	5.19 (1.02)	5.19 (0.86)	$F(30) = 0.0$, $p = 1.0$

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