# Designs that fly:

## Evaluating the aeronautics analogy for design research in Education

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# INTRODUCTION

Since its introduction into the literature, the idea of design research in education has been associated with aeronautics. In their influential 1992 articles, both Collins and Brown explained the idea of design experiments by appealing to methods of experimental testing in aeronautical engineering (Brown, 1992; Collins, 1992). Despite extensive elaboration and exploration of the idea of design research in the intervening years (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; Design-Based Research Collective, 2003; Edelson, 2002; Sloane & Gorard, 2003), and a wide variety of adherents who have pushed it in different directions, recent publications continue to make the comparison between design work in education and in aeronautics (Philips, 2006). Clearly, there is something compelling in this analogy that deserves examination.

Obviously neither Brown nor Collins meant to claim that educational design can be conducted in the *same* way that aircraft design is. They took aeronautical engineering as a useful analogy, with explanatory power. We know that analogies and metaphors can be extremely powerful aids to thinking (Gentner & Jeziorski, 1979; Gentner & Stevens, 1983), yet they are not without hazards. We are wise to be mindful of the limitations of an analogy, in the way that we are wise to be mindful of the limitations of a hand tool. Just as a drill or a chisel can only take so much stress before it breaks, an analogy can similarly break down, and potentially injure us. My purpose in this article is to critically examine the aeronautics analogy for design research in education – to look closely at how it both enables *and* disadvantages thinking about educational research and design. I will do this, in part, by examining the early history of aeronautical engineering, and pointing out some of the similarities and differences it bears to current design research in education.

Before delving into the *explanatory* power of the analogy, though, I should note something about its *rhetorical* power. Aeronautical engineering makes an attractive analogue for educational researchers because it is a field with obvious, almost unpreecedented accomplishments. A mere 66 years separated the Wright brothers' first powered flight at Kitty Hawk in 1903 and the first lunar landing. Further, while it took decades to develop, commercial flight today exerts an enormous influence on how people live and work all over the developed world. While educators also accomplished great things over the past century (Tyack & Cuban, 1995), educational research could certainly do worse than to aspire to the example of aeronautics. The question remains though, *in what ways* should we aspire to match this example?

## WHAT IS DESIGN?

Before I begin, it is necessary to say a few words about the notion of design that I will follow in this paper. Design is a deep subject that has been explored by scholars in many fields, whose work I cannot do justice to within the scope of this article. Nonetheless, I will lay out my operational definition of design, for the sake of convenience and clarity.

The English word "design" derives from the Latin *designare* meaning "to mark out" and is related to the French *dessine*, "to draw." The *American Heritage Dictionary* defines design as follows:

1a. To conceive or fashion in the mind; invent.

1b. To formulate a plan for; devise.

2. To plan out in systematic, usually graphic form.

*3. To create or contrive for a particular purpose or effect.*

4. To have as a goal or purpose; intend.

5. To create or execute in an artistic or highly skilled manner. ("Design," 2000)

While all of these definitions are relevant to a discussion of DBR, to my understanding, the sense most dear to design researchers in Education is that captured in the italicized line above. Design is a task that is driven by goals. The desire to achieve some particular, preconceived objective is a crucial part of what separates design from other creative processes. Further, the act of design is constrained by trade-offs in which the attempt to achieve one end comes, inevitably, at the cost of another, or entails the production of side effects that may be undesirable (MacLean, Young, & Moran, 1989). The designer's main job is thus to *optimize* for desired effects, while *minimizing* undesired ones. For example in making knives, it is known that if steel is tempered to be very hard, it can hold a very sharp edge; but the harder it is, the more brittle.

Playing design trade-offs like these demands a working understanding of the elements of the system one is designing within, and how they interact. And here is where the aeronautics analogy starts to become useful. In both aeronautics and education, our understanding of the system we are designing within is *never* complete – it is constantly developing. For this reason, failure is highly instructive. The failures of particular designs can help us to appreciate flaws in *both* the designs themselves *and* the developing theories that they are built upon, if we are observant enough (Sandoval, 2004). This is the key premise upon which it is claimed that educational design research can make contributions *both* to educational practice (through useful new designs) *and* theory (through testing and improvement of theories *in* practice). It is this promise of “killing two birds” that continues to draw people to the idea of educational design experiments, despite our ongoing difficulties in executing and reporting them.

## THE MOST IMPORTANT MAPPING

One way in which aeronautical engineering makes a useful analogy for educators is that it highlights the nature of the interplay between design and theory in our interdisciplinary field. Specifically, theory plays a primarily *heuristic*, rather than a *prescriptive* role in both fields.

Education scholars have sometimes bemoaned the fact that teachers’ practice does not routinely follow theory. Year after year and decade after decade, scholars (including many teachers pursuing graduate credentials) have toiled to collect and examine data on student learning in a phenomenally wide array of domains. We have constructed explanations of how people accomplish skilled performance, how they learn to do so, and why some conditions are more supportive of that learning than others (Bransford, Brown, & Cocking, 2000). Over generations, we have assembled an impressive body of scholarship. It is difficult to see this knowledge ignored.

But here, the example of aeronautics is both instructive and reassuring. In aeronautics, designers have a body of theory to guide them that is arguably superior to any we have in Education. Newtonian mechanics and fluid dynamics have more impressive explanatory and predictive power than Lev Vygotsky’s sociocultural theory (Vygotsky, 1978), and a greater range of application than John Anderson’s ACT (Anderson, 1993). All the same, even in aeronautics there is a lot of relatively unconstrained creative work involved when aircraft are designed (Sutter & Spenser, 2007). As Vincenti (1990) states, quoting a British engineer speaking to the Royal Aeronautical Society:

> "Aeroplanes are not designed by science, but by art in spite of some pretence and humbug to the contrary. I do not mean to suggest for one moment that engineering can do without science, on the contrary, it stands on scientific foundations, but there is a big gap which has to be bridged by the art of the engineer." The creative, constructive knowledge of the engineer is the knowledge needed to implement that art. (p. 4)

That science does not entirely *determine* aircraft design is illustrated by the great variety of practical airframes that exist. Despite the centuries that it took to make even *one* heavier-than-air craft fly further than a few hundred feet, a surprising variety of designs *will actually fly*. Until historically recent advances were made in flight simulators, it was necessary to build scale models and test them in a wind tunnel, or build full-scale aircraft, to determine with any certainty how an airframe design would ultimately behave (Vincenti, 1990). Thus, even as enviable as it is, aeronautical engineers could not use their body of theory to *fully* predict how a given design would behave under real-world conditions. Even today, new aircraft go through rigorous flight testing.

In Education of course, our theories tend more toward the descriptive and explanatory than the predictive. Some of the theory that we find most inspirational today (for example, sociocultural theory) points toward new *possibilities* for design, but is not complete and predictive enough to inform all the decisions that *must* be made in order to complete a full-fledged design. (It is an open question as to whether educational theory can *ever* be complete enough to satisfy these purposes.) The implication for educational designers is that, once one has adopted a goal and followed theoretical inspiration as far as it can go, one is still left with quite a few decisions to make. In this fact resides the fundamental similarity between aeronautics and education, as I understand it.

In the next sections, I will share three historical case studies that help tease out the ways in which the aeronautics analogy does and does not map to design research in education.

## CASE 1: THE GUPPY

I have felt for some years that the purpose of the aeronautics analogy in Brown and Collins' articles was not merely to *explain*, but also to *scientize* educational design work – that is, to lend it greater legitimacy it for an audience intolerant of "soft science." In this way however, I feel that the analogy is a bit deceptive. For when aeronautical engineering is conducted in a way much akin to what we do in Education, it has a "seat-of-the-pants" quality that is not generally understood to be the case in aeronautics. This seat-of-the-pants quality is captured well in the story of the Guppy, the aircraft used since the Apollo era to carry NASA rocket stages and other oversized aerospace components around the US (see Figure 1). In order to open up the aeronautics analogy a bit, I will share the story of the Guppy in some detail here.


Figure 1: The Guppy

I first encountered the story of the Guppy one day in 2002, when I found myself in the small town of Mission, British Columbia. I had driven two hours inland from my home in Vancouver to do some work in a school there, where a seasoned history teacher had expressed keen interest in the kind of design experimentation I wanted to do in my latest grant. On this particular day, I had arrived in town early and had a few minutes for lunch before attending the teacher's afternoon Social Studies class. In my haste to arrive on time, I had not brought any reading material along, and was facing lunch alone at the local café without anything to occupy my mind. In some desperation, I wandered into a smoke shop across the street and found a copy of *Invention & Technology* magazine containing a cover story (Tripp, 2002) that began as follows:

> The first time the Pregnant Guppy…took off from California's Mojave Airport under its maximum weight of 141,000 pounds, in the spring of 1963, it did manage to get aloft, but just barely. After the usual long, lumbering ground run, the landing gear was retracted, but the ship could climb no faster than the hilly ground was rising in front of it. The air speed seemed locked at 128 knots. An awed and expectant silence prevailed in the cockpit, even as the engines and

> propellers churned away at their noisiest level.
>
> The town of Boron loomed dead ahead. It looked as if the Guppy's crew would clean it out if they didn't turn, but a turn might sink them back into the ground. The flight engineer saw that the right inboard engine was giving them trouble. He told the pilot, "Number three is overheating. Can I pull it back?"
>
> "Don't touch it."
>
> "But it will burn up!"
>
> "Let it burn."
>
> To this day some crew members swear that the burning of fuel, with its consequent lightening of the plane, was the only reason the Guppy finally managed to climb. They say a string of skeletons from jackrabbits that died of pure fright runs from Mojave to Boron. After that flight the engineers and pilots agreed to decrease the plane's maximum weight by 8,000 pounds before anyone took it up again. (Trip 2002, p. 31)

The story of the Guppy's design encapsulated a sense of risk that was absent in anything I had read about educational design experiments. My interest was captured instantly, because this was the kind of design risk (minus jackrabbits) that I felt I was taking on in my own work. On a daily basis, I lived in fear that my latest design would "crash." The software might fail. The network might go down at an inopportune moment, wasting a precious class period. Our activity structures might prove impractical, or our newly-designed materials uninterpretable. Students and teachers might balk. While none of my designs held any remote threat to life or limb, as I read the story of the Guppy, the parallels to design work in Education felt ever stronger.

The Guppy was designed and built by Aero Spacelines, a small company created to cope with a peculiar problem of the Apollo space program. Building the hardware to get a man to the moon was a job too big for any one aerospace company; so the stages of the Saturn rocket had to be built in far-flung facilities and integrated at the launch site. This meant that very large stages had to somehow be transported from manufacturing facilities as far away as California to the NASA launch site in Cape Canaveral, Florida. Before the Guppy was created, the only practical way to was to ship them by barge through the Panama Canal. As Tripp explains,

> …that took 15 days and required the constant attendance of five engineers, and even so, the parts arrived banged up and corroded from the weather. They were designed to stand vertically and be filled with fuel. When empty, they were like a shell of aluminum foil. (Tripp 2002, p. 34)

This was the design challenge for the Guppy. The ambitions were lofty, the time and budget limited -- and the standards necessarily flexible. *How like design work in Education!*

As Tripp explains it, the design and testing process for the Guppy was about as pragmatic as one could imagine:

> The idea for the Pregnant Guppy came from Lee Mansdorf, a businessman who bought and sold aircraft…. Mansdorf had been buying up surplus B-377 Stratocruisers and KC-97 Stratotankers [at this time the longest aircraft in the

> world], both made by Boeing, and it looked as if they could be altered or recycled to create the plane he envisioned.
>
> They had only three days to prepare for a meeting with Wernher von Braun, NASA's rocketry chief, but von Braun expressed interest …so they started serious work on the design. …A Stratocruiser was flown in to be converted into the Pregnant Guppy's main airframe, along with another one to provide parts.
>
> The plan had three phases. First, lengthen the Stratocruiser's fuselage by 16 feet 8 inches with segments from the second airplane and test-fly the result. Second, build the enlarged fuselage, 19 feet 6 inches in diameter with internal bracing, over the old one and test-fly that. Third, take out the bracing and cut away the old fuselage. (Tripp 2002, p. 34)

Like a great deal of design work in education, the Guppy project involved the creative re-use and adaptation of existing pieces. Also like educational design work, the highly pragmatic plan for the Guppy faced inevitable complications. These were managed by Jack Conroy, Mansdorf's business partner and a former USAF test pilot:

> When the first test flight revealed that retracting the flaps caused buffeting, Conroy hired Irv Culver, a well-known aerodynamicist, to design a fix to smooth the flow at the wing-fuselage juncture. According to Sandy Friezner, a consulting engineer on vibration testing, "Irv knew Jack's stubbornness and penchant for going at things his own way, so he told Jack, 'If you don't do what I tell you, I will charge you a lot of money. If you do, the price goes down.' Since there was not nearly enough money to do a wind-tunnel test program, Irv took a model with silk strings attached and put it in front of a fan. Using cardboard and modeling

> putty, he came up with a shape that was then drawn and used.
>
> This was a classic example of how things got done at Aero Spacelines. An expression often used by designers describes this type of work: “Build to fit. Draw to match. Paint to cover.” Conroy was fond of saying, “It’s amazing what you can do without paperwork… . On most aerospace projects, any of our planes would have taken three years.” (Tripp 2002, pp. 34-35)

The Guppy made its first payload flight for NASA only *one year* after its initial test flight. This was a remarkable achievement, especially considering what followed. Before it was retired in 1974, the Guppy logged more than 6000 flight hours. Without the plane, Tripp claims that NASA could never have gotten to the moon before the end of the 1960s.

I do not mean to make too much of the parallels between educational design work and the engineering process for the Guppy. One may object that the Guppy is an unusual type of airplane, requiring an unusual design process. It may be said that more often, design progress in aeronautics is slow, methodical, and done to high standards. This may be so, but I will argue that to the extent this is true, aeronautics differs (indeed, *must* differ) from the majority of design work in Education. Thinking of Jack Conroy, I find myself asking:  is educational design research an attempt to produce working knowledge “without all the paperwork?”

## CASES FROM EARLY AERONAUTICS: SOME BACKGROUND

My hope for this paper is to shed light on our developing tradition of Educational design research by examining a tradition that is already well established. However, to find aeronautical design work that bears more than a passing resemblance to the general run of design work in Education, one has to go back pretty far. In fact, I will hazard to say that aside from rare stories like that of the Guppy, Educational design work bears more of a resemblance to the aeronautics of the early 1900s than that of the early 2000s. In the following sections, I will open up some of the differences at play in educational design work by examining the exploits of some very different aviation pioneers:  The famous Wright Brothers, and a lesser-known Frenchman named Louis Bleriot.

Americans are taught from an early age that the first powered flight by a human being took place at Kitty Hawk, NC on December 17, 1903. It was conducted by the Wright brothers, with only a local lifeboat crew looking on (Hoffman, 2003). However, according to aviation historians, the story is not quite as simple as that (Schneider, 2003). The Wright brothers were certainly distinguished innovators, and their achievement is undeniable; but it is not so singular as some would lead us to believe.

There is a long history of experimentation with manned flight, going back further than 1519 and Leonardo da Vinci's obsession with flapping-wing machines, or ornithopers (Gibbs-Smith, 1970). However, for hundreds of years the field was occupied by a succession of daring but naïve innovators who did not have either the proper knowledge or orientation to the problem to achieve success. Close to the end of the 19th century, scientific authorities like Lord Kelvin continued to insist that manned flight was impossible (Hoffman, 2003). But as Gibbs-Smith (1970) documents, the work continued with scattered and halting progress until the early 1890s, when Otto Lilienthal undertook successful experiments with manned gliders in Germany. Lilienthal tested numerous kite designs using an ingenious conical hill that he had constructed so that he could launch himself into the wind no matter what direction it blew from.

Gibbs-Smith declares that “Lilienthal…was the first man to fly practical heavier-than-air aircraft consistently and successfully.” (p. 80) His published work became the basis of some of the Wrights’ first gliders. The Wrights also gained a great deal from the advice of Samuel Langley (who was head of the Smithsonian and a fellow experimenter with powered flight) as well as from Octave Chanute, a French-born Chicago engineer who became a sort of one-man, self-appointed clearinghouse (and sometime granting agency) for work on flying machines (Crouch, 1981).

By the early 1900s, innovators like the Wrights, Glen Hammond Curtiss, Louis Bleriot and Alberto Santos-Dumont had built airplanes that showed some promising performance; and of course they had nascent theories about lift and control. But these machines and the theories behind them were still primitive by today’s standards. Exploring the possibilities for improving flying machines was a lurching, grasping process in which they followed a working theory as far as it would go, made up the rest as was necessary to complete the design, then tested it and attempted to understand its performance in a fairly intuitive way. As I discuss in the next two sections, the methods they followed were determined partly by the status of applicable theory at the time, and partly by their own personal character as designers.

## CASE 2: THE WRIGHT METHOD

The Wright brothers were the sons of a minister, neither of whom completed high school. After developing a successful bicycle manufacturing business in Dayton, Ohio, they were inspired to take on the problem of manned flight after Otto Lilienthal died in a routine flight of one of his gliders. They received some early assistance from Samuel Langley, an eminent astronomer who was director of the Smithsonian Institution and was also experimenting with powered flight. They also received ongoing advice from Octave Chanute. However, according to aviation historians, the Wrights stood apart from their contemporaries in their methodical pursuit of the problem. They were among the first in history, for example, to construct and use a wind tunnel to test the lift generated by differently shaped airfoils (Gibbs-Smith, 1970).

While their means were quite limited in comparison to many of their European contemporaries, and despite not having the government grants that Samuel Langley did, the Wrights' more efficient methods of inquiry[1] allowed them to make unparalleled progress in a short span of time. Among the minority of experimenters in their day, they used unpowered, unmanned kites to test their ideas before building manned gliders, then full-scale, powered machines. Figures 2, 3 and 4 illustrate the striking similarity of their designs at each phase of their testing and refinement.

[1] along with their single-minded commitment – neither ever married

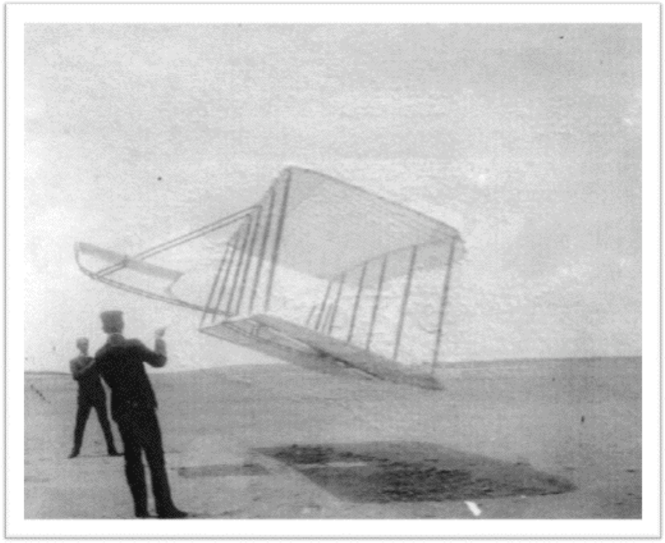

Figure 2: The Wright Brothers testing a biplane kite at Kitty Hawk, 1901

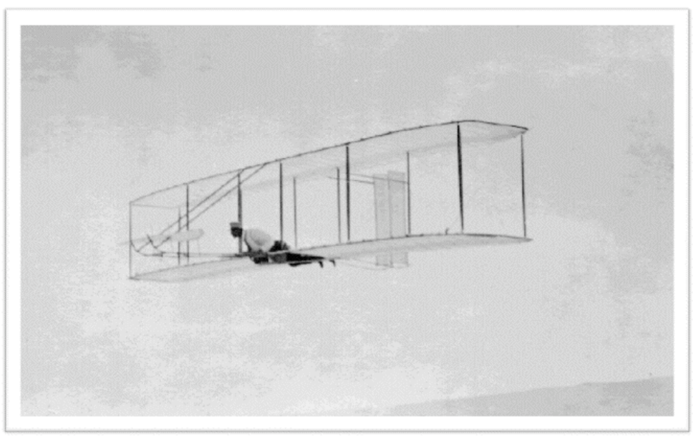

Figure 3: A Wright manned glider, 1902

Figure 4: A powered Wright Flyer, 1909

While this approach seems so sensible as to be obvious, years after the Wrights' 1903 flights, Europeans like Gabriel Voisin, Henri Farman and Louis Bleriot continued to test their new designs by building full-scale, powered machines of relatively primitive design -- and risking their necks in them in full view of one another and the public (Josephy, 1962). It appears that in the European cohort, only Santos Dumont ever had the idea of testing the aerodynamics a heavier-than-air craft other than by flying it under power (Hoffman, 2003). (He is known to have tested his first heavier-than-air design by having a donkey pull it along an iron cable suspended in air.)

The Wrights also appear to be some of the first serious experimenters to have understood the necessity of controlling the roll of an aircraft, in addition to its pitch and yaw (Crouch, 1981). While the Europeans sought to make airplanes inherently stable in the air, it is argued that the Wrights, as bicycle makers, realized that balancing an aircraft would need to be a constant effort – as it is in riding a bike. Their unique solution to the problem of roll control was termed "wing warping." Cables running through the flexible wood-and-cloth wings of the Wright Flyer allowed the pilot to twist them during flight. This increased the lift of one wing and decreased that of the other, allowing the plane to roll left or right[2].

A final important difference between the Wrights and their French contemporaries lay in their appetite for publicity. They had none. Historians suggest that the Wrights' shyness stemmed from their desire to achieve a legal monopoly on the airplane (Hoffman, 2003; Shulman, 2002). So, while it may have galled them to have fellow American and French aviators doubt their achievements of 1903, they were not about to reveal the details of their innovations until their patent rights were secure. With this achieved, they proceeded to take out injunctions to prevent European aviators from flying in America. They also undertook a lengthy and bitter legal dispute with Glenn Hammond Curtiss over the aircraft that he was producing at his plant in upstate New York (Shulman, 2002). In the end, however, the Wrights were not very successful businessmen. After years of ugly disputes over patent rights and the death of his brother Wilbur, Orville Wright was forced to merge the Wright Aeronautical Company with rival Curtiss in 1929.

From our historical distance we can see that while they made some vital discoveries, the Wrights also suffered from a degree of fixedness in their thinking about aircraft design (Spenser, 2008). After producing their first successful design and securing patents for it, they stuck to this basic configuration until surprisingly late in the game. Crouch (1981) argues that their stable design configuration was an advantage in the early

[2] Bereiter provides an analysis of the progress of the Wright Brothers' ideas about control in roll (Berieter, 2008). Spenser also provides a detailed account (Spenser, 2008).

going; but by 1909, the Wrights' biplanes with their pusher propellers and forward elevator looked out of place in a field containing monoplanes with "tractor" configurations (in which the propellor pulls from ahead of the main wing, and the rudder and elevator trail behind). The Wright machines' performance was relatively weak as well. Because the dual wings of a biplane produce substantially more drag, their top speed and range are lower than those of a similarly-powered monoplane.

## CASE 3: THE BLERIOT METHOD

Louis Bleriot was, like many of his fellow aviators in France, a wealthy man. An engineer by training, he made his fortune by inventing (and successfully marketing) a bright headlight for use on automobiles. With his fortune seemingly secure, he embarked on his own years-long program of design research into powered flight.

Bleriot had the advantage of living in Paris, which most of the world then considered the capital of aviation. After years of witnessing flights in balloons and dirigibles, the public in Paris had grown accustomed to (and appreciative of) seeing brave aviators testing their rickety contraptions. Alberto Santos-Dumont, one of Bleriot's contemporaries, was well known and surprisingly well loved for flitting about Paris in his hydrogen-filled dirigibles, which he would land (or sometimes crash) at cafés, in the city streets, or on the property of wealthy people he had never met (Hoffman, 2003). Issy-les-Moulineaux, a makeshift airfield near the Eiffel tower where Bleriot and others experimented with heavier-than-air machines, became a popular place to go for entertainment (Charlson, 2005).

This atmosphere of enthusiasm and design ferment may have led Bleriot and his compatriots to be overly optimistic about their prospects for heavier-than-air flight.

Bleriot's approach, like that of experimenters before him, now seems impatient. Month after month, Bleriot and his French contemporaries powered themselves into the air in machines that were barely in control at all. Bleriot's crashes were so frequent, and drew such public attention as to demand reassurance that he was not putting himself at unnecessary risk. The press branded him "the prince of bad luck", because they had seen him crash so often (Charlson, 2005).

Bleriot's approach was also, by comparison to the Wrights', quite improvisational. Before meeting with substantial success he developed no fewer than *eight* designs, each quite different from the last. Beginning with bird-imitating ornithopters like da Vinci had envisioned, Bleriot moved rapidly through a series of radically different designs – each one not a scale model, but a full-scale, powered machine that he piloted himself:

> After two unsuccessful biplanes in 1906, Bleriot in 1907 built in rapid order – or, better, disorder – a monoplane with a canard ("tail-first") horizontal surface and pusher propellor (similar to the machine of Samuel P. Langley in the United States), and a tractor monoplane with aft tail. The last put him on the road finally to a practical airplane. No other method being apparent to them, Bleriot and the others tested their ideas by attempting to fly, sometimes with disastrous results (but, fortunately, no fatalities until 1909). (Vincenti 1990, p. 243)

It is difficult to appreciate just how different Bleriot's designs were from one another without examining photographs of them. See Figures 5, 6 and 7.

Figure 5: The Bleriot V, a bird-like pusher monoplane with forward elevator and rudder

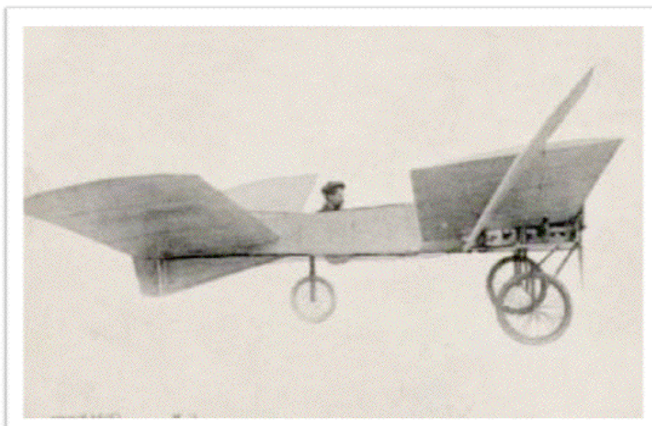

Figure 6: The Bleriot VI, a tractor monoplane with "tandem" wings of nearly equal size fore and aft

Figure 7: The Bleriot XI, the prototype for all small, single-engine propeller-driven airplanes

Vincenti argues that Bleriot's seemingly haphazard approach was not as unproductive as it seemed:

> These unsystematic efforts led to only modest achievement by 1908, but the body of experience and community of designers and fliers that resulted put the French in position to forge ahead rapidly once Wilbur Wright had shown them how truly successful flight could be accomplished. From the French work (mainly) came the engine-forward, tail-aft biplane (and occasionally monoplane) configuration that became normal in airplane design by the beginning of World War I. (Vincenti 1990, p. 243)

Ultimately, in his model XI monoplane (which adopted the Wrights' wing-warping technology for control in roll), Bleriot gambled his life and won. In July of 1909 he became the first person in history to fly a heavier-than-air craft across the English Channel, claiming a prize of 1,000 pounds offered by the London Daily Mail newspaper. The psychological effect of this achievement was on the public was astounding, bringing

Bleriot instant fame. The Bleriot XI became the biggest-selling airplane in the world, and set Bleriot on a path to create aircraft essential to the French and British efforts in World War I (Charlson, 2005).

A number of lessons may be drawn from Bleriot's experience. Here, I will note only that his example shows us what great things can be achieved through integrating bold, creative experimentation with the results of methodical, stepwise work. I will have much more to say about this in the following sections.

## WHERE DOES THE ANALOGY MAP?
## LESSONS FOR EDUCATIONAL DESIGN RESEARCH

A large number of innovators were active in the early days of aviation, often dedicating enormous effort to make small, but important discoveries (Bereiter, 2008). Here I have deliberately focused my narrative on the efforts of Bleriot and the Wrights, in order to emphasize a set of contrasts that are important to assessing the aeronautical engineering analogy for design research in education. Here, I try to draw out of these cases some lessons that design researchers in Education will hopefully find useful.

### *Lesson 1: Systematic variation isn't everything*

It seems clear that orderly, systematic variation (like the Wrights did) can be extremely helpful in speeding up progress on key sub-problems when a design requires new knowledge. For example, without their innovative wind-tunnel work on airfoil shapes, the Wrights would certainly have taken much longer to refine their gliders, and in turn their powered craft. They were later able to further capitalize on their wind tunnel data by using it to create very efficient propellers, which gave their planes more effective thrust than ones with more powerful engines (Axelrod, 2003).

However, Bleriot's ultimate success, both in crossing the Channel and in his business affairs, suggests that the Wrights' cautious, systematic approach may not be adequate to produce larger creative leaps. As Vincenti discusses, in design innovation action must occasionally *preceed* theoretical understanding. In some sense, it cannot help but do so, since as mentioned earlier, both in aeronautics and education, our body of theory is in some ways of merely heuristic value. Vincenti, an aeronautical engineer himself, describes design innovation as "blind." He explains:

> …any variation that leads to truly new knowledge – knowledge that has not been attained before – must be blind in the sense of going "beyond the limits of foresight or prescience." It is important to be clear here…that "blind" (in this sense) does not mean "random" or "unpremeditated" or "unconstrained." It simply denotes…that the outcome of the variation cannot be foreseen or predicted…. If it could, the knowledge obtained would not be new. (Vincenti 1999, p. 242)

I will return to this issue of blindness in later sections. Here I will simply note that many early aviators benefited in important ways from intuition and serendipitous discoveries. The Wrights' chief American rival, Glenn Curtiss, provides a dramatic example. On the eve of the flight that won him the Scientific American trophy for the first officially observed flight of more than a kilometer in the United States, Curtiss seriously damaged his plane the June Bug. During a test flight, he crashed it into the ground nose-first. After staying up all night to repair it on time for the arrival of the official observers, he found that it handled *better* than before. The reason? While re-building his Wright-style forward elevator, he had run short of materials, and was forced to make the replacement *smaller* than the original. The larger, original elevator was more sensitive, and may have been partly responsible for his crash (Shulman, 2002).

There is a school of thought in Education research that appears to take experimental methods as *the only* true way to produce valid knowledge (Kirschner, Sweller, & Clark, 2006). One problem with this approach is that it relies on careful, premeditated and exhaustive work to put design variations on trial. In the course of goal-directed design work, however, this can come to seem horribly inefficient. Despite their famously meticulous methods, even the Wrights relied upon intuition at times (Crouch pp. 233-234), and on my reading, history appears to show the Bleriot method to be equally essential to success.

*Lesson 2: If at first you don't succeed, fail, fail again*

Another important lesson that the early aeronauts have for design researchers in Education is that it can take a *lot* of carefully scrutinized failure in order to achieve to success. In part, the number of failures necessary is explained by the lack of good theory to direct observation during design trials, and to provide coherent explanations for failures. The early aviators at Issy les Moulineaux were in the unenviable position of trying to learn about the shortcomings of their designs without the benefit of either sound theory or systematic observations by third-party observers. They must have done a great deal by the feel of the aircraft alone.

In a similar way, every day in the field of Education, teachers and researchers try new things. If we have not been able to learn what we could have from our failures, it may be because we have not been willing or able to study them carefully enough. However, it is heartening to consider that early aeronautics and education are not unique with regard to the frequency of failure. The majority of high-tech startups also fail, and the great successes – the designs that create new markets, for instance -- result from careful analysis of previous failures (Moore, 1991).

*Lesson 3: Openness is good for innovation*

The last, and possibly most important "mapping" lesson that early aviation provides for design researchers is that openness is good for innovation. Turn-of-the-century aviators in France had risked much, and spent a great deal of money to accomplish only a few short hops (Gibbs-Smith, 1970; Hoffman, 2003). Without a proper means for control in roll, their craft were easily blown off course and sunk to the ground by the tiniest crosswinds. The Europeans had experimented with ailerons for controlling roll, but the wood-and-cloth wings of the day were not rigid enough to make this approach very workable. However, as soon as they understood the Wright Brothers' approach to the problem, the large community of French aviators, who exchanged ideas openly, was able to quickly surpass the Americans' efforts (Spenser, 2008).

Orville and Wilbur preferred to fly solo. The Aero Club of America and the press tried many times between 1903 and 1908 to convince them to exhibit their machines. Glenn Curtiss tried vainly to engage them in a business partnership, but the Wrights weren't interested, despite the fact that Curtiss produced the most powerful lightweight engines of the time and had a lot to contribute to their work (Shulman, 2002). Chanute, widely regarded as one of the most patient and giving figures in early aviation, became estranged from the Wrights as they aggressively used their patent rights to try to drive

Curtiss and their other competitors out of business. In the end, Curtiss won out by building more innovative aircraft, and selling more of them (Hoffman, 2003).

The ultimate revelation of the secret of the Wrights' success was certainly a boon to French aviation. But the reason it catalyzed such great success is that the French had always been open about their failures. I will return to this subject later.

*Lesson 4: The public will not demand the future*

An anonymous reviewer for this conference suggested to me that one of the largest *differences* between Education and other fields is the source from which demands for new designs emerge. As it was put:

> …(in other fields) customers ASK for new medicines, new cars, new gadgets. In Education, we have to *convince* the customers they want our new stuff, then hope we can teach them to use it right.

This is well put and worth careful consideration, because it has a definite resonance with those of us who have experience of design experimentation "on the ground." We share a common experience of having to persuade practitioners that our new toys, materials, and ways of thinking are worth the effort to learn about and use.

However, I believe that distinctions of granularity are quite important here. At a high level of granularity, the general public certainly demands new medicines, cars and gadgets with a frequency that seems to outstrip the demands placed on educational researchers. However at the level of *design features*, it is a different story. GM and Ford probably received very few (if any) letters asking for disc brakes, side-impact airbags, shock absorbers or heated seats; though they *must* have faced some degree of consumer demand for greater safety and comfort. Similarly, Educational researchers are *not* asked by the public for innovations that will produce deep learning or far transfer; though the public clearly does expect their children to be prepared for life in an uncertain world.

As we know from the field of software development, requirements gathering is a very tricky process (Chin, Rosson, & Carroll, 1997, March). Users struggle to articulate their *real* needs, and when asked directly, are likely to come up with some irrelevant claptrap in answer. The job is even harder when you are trying to come up with an unprecedented product.

Returning to my historical cases, clients were decidedly *not* begging for aircraft in the early 1900s. The Wrights traveled the world looking for a buyer for their airplane, and despite their current reputation as all-American innovators, they were not being particularly picky about buyers. They were willing to sell the airplane to *any* world government that would pay a fair price. Still, it took a long time for them even to get military trials in the U.S.

The lesson I draw here is that one can never rely upon the public to demand the future. True, the field of Education is essentially conservative (Tyack & Cuban, 1995); but despite this, in my view Education researchers don't have a qualitatively different set of challenges to face in "selling" our innovations than other innovators do. Promoting a new vision of the future is never easy work, no matter what your field (Rogers, 1995).

## WHERE DOES THE ANALOGY NOT MAP? MORE LESSONS

Analogies can be instructive both when they map and when they don't. Below, I will unpack several of the more important differences that separate education and aeronautics as fields of design and theory development.

### *Lesson 5: Who knows when we've flown?*

As I mentioned above, there are *still* arguments about who was the "first in flight", and what that means. Gibbs-Smith might give the honor to Otto Lilienthal, as the first to make repeated, controlled flights – even though his machines were not powered. Many Brazilians claim the honor for their countryman, Santos-Dumont, who in 1906 hopped 722 feet in his plane "14-bis", under the watchful eye of officials from the Aero Club de France (Hoffman, 2003). Finally, as I mentioned earlier, Glenn Curtiss was awarded the Scientific American Trophy in 1908 by the Aero Club of America for being the first to make an *officially observed* flight of more than one kilometer in the United States.

If such arguments can take place in aeronautics, it is no surprise that more intense ones should take place in Education. After all, with aircraft there are only a few key outcomes, all consensually agreed upon and (relative to outcomes in Education) easily measured:  speed, acceleration, altitude, distance, etc. With educational innovations, people care about myriad outcomes, which are involved in design trade-offs but are not so easily observed. Depth of understanding, transfer, and equity are so problematic to operationalize that it is far less clear when an educational design "flies." To my mind, this goes beyond the observation that education and educational research are value-laden (Towne & Shavelson, 2002). If we are wise, we envy the early aviators because their success was far more demonstrable than ours, and more visible to the public.

*Lesson 6: A wind tunnel is not like a classroom*

While it is tempting to think of design trials in classrooms as akin to wind tunnel tests, this misrepresents the kind of knowledge that classroom trials produce. While the results of wind tunnel tests on scale models do not scale infallibly to full-size aircraft (Vincenti, 1990), they do not involve nearly the level of indeterminacy that a classroom does. For one thing, each air molecule in the wind tunnel does not have its own mind, intentions, motivations, etc. (as students do). As Labaree writes, “These billiard balls are likely to change direction between the cue ball and the corner pocket” (Labaree, 1998, p. 5).

What is more, air molecules do not behave according to their understanding and appreciation of the aircraft designer’s intentions. With educational designs, students and teachers usually must understand and “buy into” our plans if they are to work. Finally, with aircraft, generalizability is almost a non-issue. A plane that will fly in one location will pretty much fly anywhere else on earth -- with a few limitations. This is clearly not so with educational designs, where it can be a major challenge to *understand* (let alone reproduce) the conditions that are needed to make an innovative design work at the level of a classroom, school, and district.

*Lesson 7: We cannot keep our failures to ourselves*

For some time, fear of ridicule led many aviation enthusiasts to keep their experiments private. At the 1886 meeting of the American Association for the Advancement of Science, Octave Chanute witnessed a roomful of scientists laughing and jeering at a presenter who claimed to have flown scale models for as long as fifteen minutes at a time (Hoffman, 2003). The situation was scarcely improved in 1900 when Wilbur Wright, in the opening line of his first-ever letter to Chanute, described his interest in manned flight as a kind of affliction (Crouch, 1981).

Today, educators are similarly reticent to be seen at their worst. A student in one of the first graduate classes I ever taught captured this reticence perfectly when he said, “as teachers, we can’t go around advertising our failures.” (He was responding to a rare published article on a failed design experiment (Radinsky, Bouillion, Lento, & Gomez, 2001).) This is more than unfortunate, since as I discussed above, some of the greatest ferment in early aviation resulted when the French pioneers developed an eager audience for their developing work. While they were nearly all failures, the early French experiments were, in that time and place, viewed as brave sacrifices for the cause of science. Important to the crowd’s enthusiasm, it seems, was that every new machine was flown by its own designer. There was a well-rewarded bravado involved in risking one’s neck.

It may also be important that the French aviators, like the Wright Brothers, also *funded* their own work – though they did compete for financial prizes made available by wealthy benefactors. Samuel Langley, one of the most tragic figures of early aviation, was different. He had funding for his experiments from the US government, and at the age of 69, was hardly up to the job of piloting experimental aircraft. He had flown powered scale models successfully as early as 1896; but after his first full-scale man-carrying craft crashed into the waters of the Potomac in 1903, he was criticized mercilessly in the press. Rep. Joseph Robinson of the US congress famously quipped that “the only thing he ever made fly was government money.” This was untrue, but it did not matter. Langley died three years later, his scientific reputation ruined (Hoffman, 2003, p. 229).

Like Langley's efforts, much of the design experimentation in Education is funded by governments. But in our experiments we risk more than our own time, energy and reputation. To make testing a pioneer airplane resemble testing a pioneering curriculum, we would have to put thirty children aboard the plane. Design researchers in Education can be thankful that their work is not a matter of life or death, but they do need to be wary of Langley's example.

*Lesson 8: None of us will get rich*

A related difference is the nature of the incentives for innovation in aeronautics and education. Many of the early aeronauts (particularly the Wrights) toiled with the belief that if they could solve the age-old puzzle of flight, they would become fabulously wealthy, or at least famous. In contemporary Education it seems that no matter how impressive our efforts may be, there is little likelihood of fame, or a financial payoff. Thus, we tend to expect to have the costs of developing innovations covered up front.

This may be for the best, because the profit motive tends (as we have seen with the Wrights) to lead to secrecy. Given a choice, I would prefer that we take Santos-Dumont as an example. Late in his career he designed a very successful small plane called the *demoiselle*, which he refused to patent. Instead, he distributed the plans to anyone who wanted to build one (Hoffman, 2003). We might think of him as the world's first open source aircraft designer.

*Lesson 9: We are not likely to have a sudden breakthrough*

One reason that Education research doesn't look like much of a value proposition is the low likelihood of a breakthrough discovery. While many did not believe it at the time, there certainly *were* breakthrough discoveries waiting to be made in the early days of aviation. In 1902, Thomas Edison remarked at a private meeting with Santos-Dumont that when God made birds, he gave them an excellent machine to fly with, but a very small brain to control it. Surely man, with his much larger brain, must eventually achieve the goal of flight (Hoffman, 2003, p. 187). In the end Edison was right, and Lord Kelvin was wrong.

Skeptics are always vulnerable to successful counter-examples, but I will risk expressing skepticism myself here. Having reviewed the history of aviation and lived in the present of educational research, it seems incredible to me that anyone will make a breakthrough that will render the problems of teaching and learning much simpler. What we know about the challenges that teachers and students face in contemporary educational environments suggests that as we delve deeper, we are much more likely to discover further complexity than underlying simplicity. As a community, educational researchers would therefore be foolish to wait for their Wilbur Wright to arrive and show them how to achieve much greater control over childrens' learning. To the extent that it gives us false hope of such a discovery, I believe the aeronautics analogy is dangerous.

## SOME PRINCIPLES OF DESIGN EXPERIMENTATION

Despite all the important differences between design work in education and aeronautics enumerated above, I would suggest that there *are* a few principles of design research that generalize from one field to the other. I will articulate these principles below.

*Principle 1: Educational design research, like aeronautics, is "blind"*

In Education as in early aeronautics, there is substantial uncertainty about how a new design will perform. Indeed, if the design steps beyond what already accepted theory would prescribe, we are in a position of "blindness" in which there is both danger of failure *and* the potential for substantial new learning and theory generation. The two go hand in hand.

Blindness can be either partial or complete of course, and designers may cope with it in different ways. As I observed in Cases 2 and 3, both careful, systematic variation *and* intuitive leaps play important roles in pioneering design. It is doubtful that aviation would be so far advanced today if the Wright Brothers had not happened along, or if their model of engineering had been pursued *exclusively*. The world gained a great deal by having Bleriot and his French contemporaries proceed alongside the Wrights.

Bleriot's rapid shifting from one design configuration to another is a good example of what Vincenti calls "radical design":

> In radical design, how the device should be arranged or even how it works is largely unknown. The designer has never seen such a device before and has no presumption of success. The problem is to design something that *will function well enough to warrant further development*. (Vincenti 1990, p. 8, my italics)

Given the incompleteness of theory in many areas of Education, we see quite a bit of radical design. This makes the criterion of *warranting further development* a highly important one. I will discuss this further in my closing section.

*Principle 2: Failures don't prove as much as successes do*

There is an important fact of life in design research, both in Education and aeronautics, which conditions our work and our literature in far-reaching ways. Simply put: *one cannot prove that an idea will not work by going out and implementing it poorly*.

During the years between the Wrights' first flights and their first public exhibitions of their machine, Frenchmen like Ferber and Esnault-Pelterie made crude copies of the Wright biplane, which didn't fly (Gibbs-Smith, 1970; Spenser, 2008). Of course, this did *not* prove that the Wrights had not flown in 1903. But these demonstrations were convincing to many French aviators who wanted to believe that they had not fallen behind the Americans -- that the Wright Brothers, who refused to show their airplane in public, were *bluffeurs*. For those who remember their history of Educational Technology, this situation bears more than a passing resemblance to the debates about transfer of problem-solving skills from LOGO (Mitterer & Rose-Krasnor, 1986; Papert, 1987).

On the other hand, a successful trial (if demonstrably so), really does prove something; and even today, aviators continue to prove the viability of ideas once thought unworkable. In his history of aviation, Gibbs-Smith (1970) repeatedly ridicules the designers of ornithopters – the flapping-wing machines that attempt to imitate birds. For a long time, this truly did seem a bankrupt line to pursue – even Bleriot gave it up. Nevertheless in 2006, a team led by James DeLaurier at the University of Toronto demonstrated sustained flight in a full-scale, piloted ornithopter. Part of what made it possible was new, lightweight materials like kevlar (Physorg.com, 2006).

In his tough-love critique of design research, Chris Dede points out quite rightly that design researchers in Education don't always know when to give up on an idea (Dede, 1998). He describes the phenomenon of "agenda creep" in which researchers wind up undertaking large-scale reform in order to create the necessary conditions for an innovation that they should, by rights, have given up on years earlier. Perhaps to prevent such excesses, O'Donnell suggests the development of some kind of objective standard to determine when a design is promising, or should be abandoned (O'Donnell, 2004).

While I respect the intention of these suggestions, I cannot see any likelihood of them succeeding in light of how aeronautics has developed. Given that many first (even fifty-first) implementations of good ideas have been failures, it seems unreasonable to believe that there could be an objective standard according to which an educational design idea is no longer worth exploring. If they have *never* had this in aeronautics, where success and failure are relatively easy to gauge, how likely are we to develop it in Education? Further, if there were high hopes in aeronautics well before the potential was demonstrated, why should there not be much *greater* hopes in Education, where there is so much more at stake and the need is so great? The value proposition for any innovation *must* include potential impact, and it is hard to imagine greater impact than the intellectual potential of a whole generation.

This is not to say that the repeated failure of an educational design concept should be ignored. It does tell us something. Repeated failures across varied settings may tell us that the implementation of a design concept is too finicky or fragile for that concept to be of broad use – at least within the current social milieu, and with the limits of current materials, know-how, etc. However, it is worth saying that if we had applied such a criterion to aircraft, we probably would not be living in the world we have today (for better or worse).

*Principle 3: Intuition has a legitimate place in DBR*

The third principle that design-based research in Education shares with aeronautics relates to the source of our ideas for design. It is the corollary of Vincenti's observation about the "blindness" of design innovation.

The American Heritage Dictionary defines *intuition* in part as "a perceptive insight. A sense of something not evident or deducible"("Intuition," 2000). When faced with a large design space and an under-constraining body of theory, one can choose to do two things: start with past designs and make relatively small alterations (ie. tinker), or strike out into new territory on a more intuitive basis. The Wrights did the first, following the biplane configuration that Chanute had demonstrated success with previously (Crouch, 1981). Bleriot took the second approach, trying one radically different design after another based on his feel of the craft's performance in the air.

It was fair game for Bleriot to pursue intuitive leaps in his design work. He knew the chances he was taking with his own money and health, and he was as much of an authority on the building and flying of airplanes as anyone around him. It is another matter for design researchers in Education to pursue radical design in the classroom, where they risk more than their own grant money and reputation. In many respects, they are not the authorities in this setting – *the teacher is*.

There are two reasons why a solid, trusting partnership between researchers and classroom teachers is so fundamental in Educational DBR. First, this relationship provides the basis for the designer's moral authority to act in the classroom setting. Second, it provides a source of good intuitions. The teacher's understanding of what *might* work, informed by long, but not necessarily systematic or organized experience, is essential to blazing a trail through a massive design space.

If we accept this rendering of the partnership between teachers and researchers in Educational DBR, then there are implications for how we judge what is acceptable both in proposals for design research and the publication of their results. I would argue that if we expect design hypotheses to derive in a straightforward, explicable way from already accepted theory, we labour under a fundamental misconception about where design innovation comes from. One challenge we face as a research community is to articulate -- and make demonstrable -- what it means for researchers to have a satisfactorily close relationship with practitioners to justify intuitive design leaps.

## CONCLUSION

I want to make clear that am not encouraging careless experimentation. Nor am I arguing that design researchers should be given a blank checkbook to pursue their ideas. However I would like to see more reasonable expectations abroad, both with respect to how rapidly success can be seen with pioneering ideas, and about where those ideas will come from.

A colleague of mine once remarked in a half-joking way that educational psychologists suffer from an "edifice complex." He was observing that much of the theoretical language in psychology, such as "constructivism" and "scaffolding", is based on architectural metaphors. I would add further that a number of educational psychologists seem to aspire to something akin to the architect's legacy – to build an understanding of the mind that will stand as a great and lasting statement, like a great building. This, I believe, is a fundamentally different orientation to educational research than that of the design researcher.

In our metaphorical language, we design researchers have suffered from our own peculiar malady -- an *aeronautics complex*. We envy aviators (indeed deserve to) because their work is simpler than ours, and its value is more easily and more widely recognized. In this paper I have suggested that we are – like it or not -- in a stage of development with educational design research that is more similar to the aeronautics of the early 1900s than that of the early 2000s. But as a design researcher myself, I am not in the least ashamed of this. I believe we should get comfortable with seat-of-the-pants experimentation, and develop ways to report it legitimately *without* scientizing it. As Labaree has written:

> …in looking for the silver lining in the cloud of problems surrounding the production of educational knowledge, we should not ignore the significance of the cloud itself. The characteristics of educational knowledge present researchers with both advantages and disadvantages. These elements do not cancel each other out, but instead, in combination, they define a universe of working possibilities and enduring dilemmas within which educational researchers have to forge their way. (p. 11)

If we are to proceed boldly as design researchers, we need to be honest with ourselves about the nature of the conditions in which we work. If we envy aviators, it is for good reason; for in some very important ways, educational design work is fraught with more unyielding complexity than aeronautical engineering is. In the early 1900s, the public embraced the French aeronauts for their adventurous spirit and their willingness to take risks in the cause of science. If the public is to respect and admire design research in education, we must be as brave about sharing our failures as the aviators at *Issy les Moulineaux*, and our successes must be as compelling as theirs.

Harkening back to the Guppy, educational design researchers don't "Build to fit, draw to match, and paint to cover" the way the engineers did at Aero Spacelines. Rather, we build to work, theorize to explain, and narrate to make sense. For the foreseeable future, this is the best that we can do. It may be the best we can *ever* do. In my view, we can only choose to get comfortable with it.

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## IMAGE CREDITS

Figure 1: Pubic domain photograph, downloaded March 9, 2009. URL: http://en.wikipedia.org/wiki/File:Pregnant_Guppy_NASA.jpg

Figure 2: Pubic domain photograph, downloaded March 9, 2009. URL: http://en.wikipedia.org/wiki/File:WrightGlidersSideBySide.jpg

Figure 3: Pubic domain photograph, downloaded March 9, 2009. URL: http://en.wikipedia.org/wiki/File:1902_Wright_glider_fly.jpg

Figure 4: Public domain photograph, downloaded March 9, 2009. URL: http://dmc.ohiolink.edu/cgi/i/image/image-idx?rgn1=ic_all;q1=cart;size=20;c=wbc;back=back1236625799;subview=detail;resnum=4;view=entry;lastview=thumbnail;cc=wbc;entryid=x-18-5-11;viewid=18-5-11.JPG

Figure 5: Pubic domain photograph, downloaded March 9, 2009. URL: http://en.wikipedia.org/wiki/File:Bleriot_V.jpg

Figure 6: Public domain photograph, downloaded March 9, 2009. URL: http://en.wikipedia.org/wiki/File:Bleriot_VI.jpg

Figure 7: Public domain photograph, downloaded March 9, 2009. URL: http://commons.wikimedia.org/wiki/File:3c07357v.jpg