Anatomy of Invention

Larry L. Howell

BYU Studies has a long history of publishing the annual lecture given by the recipient of the Karl G. Maeser Distinguished Faculty Lecturer Award, BYU's highest faculty honor. It is with great pleasure that BYU Studies Quarterly *publishes this year's lecture by Dr. Larry L. Howell, a professor of mechanical engineering. His speech was delivered as a forum address on May 17, 2016, at Brigham Young University.*

My topic today is "Anatomy of Invention." By anatomy, I mean the structure or the internal workings of something. My experiences have led me to believe that the principles of inspiration, collaboration, and exploitation are important elements of creativity and innovation. We'll start with a story that illustrates these principles then talk about each of them in more detail. Although I'll use examples from engineering, my intent is that the principles are general enough to apply to a wide range of areas, whether personal relationships, politics, art, social science, or other parts of our lives.

A Successful Failure

A few years ago, my lab was doing a research project sponsored by a large international corporation. Imagine working on something like a cool, next-generation flip phone. We looked for inspiration by studying devices with similar motions—everything from toys to switchblades. We would make sure we understood the fundamentals that enabled the motion of each device, including creating mathematical equations to describe the motion, and with that understanding we could extend that knowledge to create other systems. Some of the new devices we created were compliant mechanisms. A compliant mechanism gets its motion from parts that are flexible rather than using hinges or bearings. So when you see something that is able to move because it is flexible, that's a compliant mechanism. You've seen compliant mechanisms but may not have known them by that name—for example, an elephant's trunk, a shark, a Venus flytrap, and your heart are all examples of compliant mechanisms in nature.

The compliant mechanisms research we were doing for the company was going well—so well that they agreed to buy the patents that had come from the first round of our research, and they also agreed to fund a second round of work. We had come to verbal agreements on both the patents and the research contract, and the signature of a company vice president was the only thing needed to close the deal. It was a Monday morning when our liaison at the company was planning to get that last signature. Unfortunately, he wasn't feeling well and decided to stay home that day. Tuesday morning he went to work, and that was the day the company's European headquarters announced they were closing that entire division of the company. Suddenly everything was gone. There would be no patent sale, there would be no next round of research funding, and all of this was totally out of our control. We were just one day away—one cold virus away—from having these contracts in place, but now there was nothing. I was devastated.

Peter Halverson was one of the graduate students who had been working on the project for his master's degree. He had recently committed to continue on for a PhD with the expectation that the funding from the company would support his dissertation research, but now we had nothing. After we got over the initial disappointment, we began considering how his research could be applied beyond consumer electronics. We searched for areas where the capabilities of our new technology could offer advantages. During that process, Peter made an amazing discovery—our work had the possibility of creating dramatically improved artificial spinal discs to replace damaged or diseased discs in the human spine.

Currently, spinal fusion is a common surgical procedure to treat people who suffer from severe back or neck pain. In spinal fusion, you surgically remove the disc and grow bone to connect, or fuse, the vertebrae and take away the motion in that part of the spine. Though the fusion procedure can address some issues, you can imagine that removing flexibility from your spine can cause other problems, and it often doesn't resolve the pain. We saw that with the theory we'd developed, we could replace the damaged disc not with a fusion, but with a device that had the potential to restore the motion of the healthy human spine.

Our previous work had explored the fundamentals of the technology, but it needed a lot of research to extend it to the complex motion observed in the spine, to make it biocompatible, and to have it all be compact enough to be implanted in the disc space without injuring the spinal cord.

We read a lot of technical papers, textbooks, and other material to get up to speed on spinal biomechanics. The more we learned, the more we were convinced that not only could our technology result in a new artificial disc, but it had the potential to make a positive impact in many people's lives. Still, although members of our research group were considered world experts in compliant mechanisms, we had zero credibility in the spine world. Without that credibility, it would be hard to convince people of the value of our idea. And we really needed partners because, let's face it, you really don't want *me* messing with your spine.

In our search for partners, we once convinced the president of a spinal implant company and one of his engineers to visit our lab and learn about our work. During the meeting we were talking about some joints that connect the vertebrae, and the joint's name is spelled "f-a-c-e-t." We had used that word before in geometry, and it's pronounced "ˈfă-cet." So in the meeting we were talking about facet joints of the spine and our guests were looking at us with confused expressions. Then finally, the company president said, "Oh, you mean 'fə-ˈcet.'" It's kind of hard to have credibility when you can't even pronounce the terms.

Soon after this, a miracle occurred. Dr. Anton Bowden, a spinal biomechanics expert, joined the faculty at BYU (fig. 1). We began to collaborate, and he brought with him a wealth of knowledge about the spine and the spinal implant industry, and a network of connections throughout the world. Now we were able to do research more specifically related to the spine, test our prototypes in cadavers, and verify that the motion mimicked a healthy human spinal disc. The research moved forward at an exciting pace, but that wasn't enough. To enable it to make its full impact in helping people with severe back or neck pain, the implant needed to be an approved commercial implant, which is not the domain of the university. Enter Gary Crocker, a business-savvy venture capitalist who had successfully started several previous biotech companies. He started a company based on the spinal implant technology, hired an experienced president and employed Peter after he finished his PhD. But even this skilled team couldn't surgically implant the discs, so they

Figure 1. Anton Bowden *(left)* and Larry Howell collaborating on the development of an artificial disc to replace damaged or diseased discs in the human spine. Photograph by Mark A. Philbrick, courtesy Brigham Young University.

created a surgeon advisory board made up of neurosurgeon experts from around the world.

This story helps illustrate the principles of inspiration, collaboration, and exploitation that we'll now discuss in more detail.

Inspiration

The first principle we're going to talk about is finding inspiration or insight by continually observing the world around you, seeking to truly understand what you observe, and applying that knowledge to do new things. This inspiration may come from nature, art, science, products, literature, or history, which all can provide insight on how to solve new problems.

The spine story provides two examples of this principle of inspiration. First, in our research with the large company, we evaluated other products, studied their fundamentals, and created mathematical equations to describe their motion; and that knowledge enabled us to create new compliant mechanisms. A less obvious example was when our own device, designed for consumer electronics, provided insights that led to new spinal implants. We were able to take those fundamentals and apply them in a way that will hopefully make a difference in people's lives.

There is an engineer you may have heard of who taught about this principle. Let me tell you some of his engineering achievements and see how long it takes until you can guess who it is. He designed and built a hunting weapon that helped save his family from starvation. He led the team that designed and manufactured a ship capable of a transoceanic voyage that was centuries ahead of its time. He had a sword (we won't mention how he got it), that he used as a model to make other weapons to defend his people. He taught his people to work with wood and all kinds of ores and alloys. He led the design and construction of infrastructure for a new society, including a temple. That's quite a résumé! This, of course, is the prophet Nephi from the Book of Mormon (see 1 Ne. 16:23, 31; 1 Ne. 17; 2 Ne. 5:14–16). It would be hard to argue that he wasn't an amazing innovator. Now, consider the principle Nephi taught about learning from the words of Isaiah. He encouraged us to understand the fundamentals described there and apply them to other parts of our lives, or in his own words "I did liken all scriptures unto us, that it might be for our profit and learning" (1 Ne. 19:23; see also 2 Ne. 11:2, 8). When we liken the scriptures to our lives, we can become better people. And when we apply this same concept by observing the world around us and likening what we learn to help solve problems, we can become better innovators.

One surprising area where our lab has found inspiration is origami. You may be thinking, "But I did origami in elementary school; surely he can't be talking about that." But that's exactly what I'm talking about. Origami is an ancient art, and origami artists are continually expanding the art form and doing incredible things. Figure 2 shows an example of origami designed by a talented student in our lab, Matthew Gong. It's called "Mother and Child." The mother

Figure 2. "Mother and Child" designed and folded by Matthew Gong. The mother is made from a single square piece of paper using only folds—no cuts, tape, or glue. The child is also folded from a single square piece of paper. Courtesy Brigham Young University.

Figure 3. Robert Lang's origami "Yellow Jacket," Opus 624. All of the detail in this design is created by folding a single piece of paper. Courtesy Robert Lang.

Figure 4. Robert Lang's origami "Organist," Opus 363. Courtesy Robert Lang.

is made from a single, square piece of paper with no cuts, only folds. All the detail—her hair, her facial features, her fingers, her clothes, her feet, everything—is one single square piece of paper. The paper is folded with no cuts, no tape, and no glue. The child is another square piece of paper, and it also is made with only folds. Our lab collaborates with the full-time origami artist and genius Robert Lang. Figure 3 shows his yellow jacket design—again, every detail is from only folding a single piece of paper. For his organist, shown in figure 4, both the organ and the organist are from one piece of paper, and if you pull in the right place the organist moves. It's amazing—there *have* to be things that we can learn from this.

One of the first things our lab did with origami was to study what is called "action origami," which is a type of origami that moves—so a dinosaur with a chomping mouth is action origami, and an origami flower is not. We searched the world for all the action origami books and web sites we could find, and we identified literally hundreds of action origami models. We studied these models and identified what made these compliant mechanisms move. In seeking to understand the fundamentals of origami, we discovered motion and mechanisms that we would not have identified using our traditional engineering approaches.

When you study action origami, you can treat the panels as if they are rigid, like a solid door, and the creases can be treated as hinges that enable the motion. This is an important fundamental idea that helps us create mathematical equations that describe action origami motion, which then help us extend those concepts to devices that in the end won't even necessarily look like origami.

We were recently working on a project where we felt that origami could provide insight for minimally invasive surgery. The idea of minimally invasive surgery is that cameras and surgical instruments can be inserted into the patient through small incisions, and the surgeon controls the instruments from outside the body. Using small incisions can result in a faster recovery time and reduce the risk of certain complications. We wanted to develop compact forceps that could enable even smaller surgical instruments and, therefore, even smaller incisions. The mechanism used to create action origami like Venus flytraps or chomping *T. rex* jaws provided inspiration as a starting point. Because we understood how the origami worked, we could modify it to provide the motion we needed. We obviously couldn't use paper for a medical device, but other materials don't crease like paper, so it was important to understand how to extend the concept to other materials. Figure 5 (top) shows a demonstration prototype we made out of polypropylene plastic with no traditional creases but with a chomper-like motion. Figure 5 (middle) shows it in

FIGURE 5. Origami inspired forceps, or "Oriceps." *(top)* A large-scale polypropylene (plastic) demonstration prototype. Photograph by Mark Philbrick, courtesy Brigham Young University. *(middle)* A computer illustration showing it in a surgery training setup. *(bottom)* A computer illustration showing it in a surgery. Computer illustrations from animations created by Nathanael Mooth.

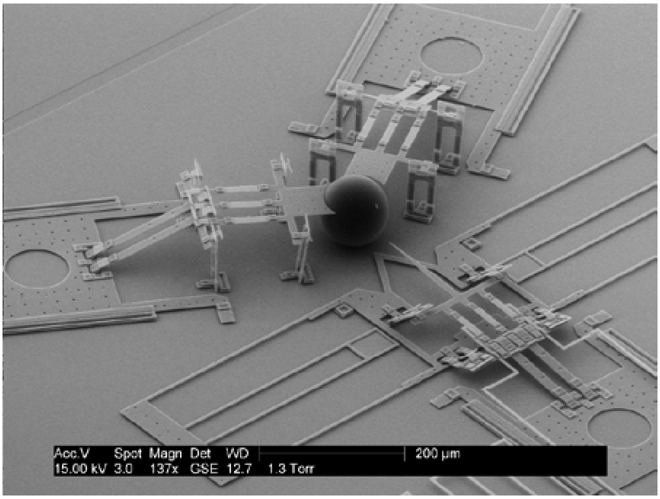

Figure 6. Scanning electron micrograph of a nanoinjector prototype made from the same processes used to make computer chips. The sphere is approximately the same size as a single mouse egg cell. The micrograph was taken by Quentin Aten.

a surgery training setup. It starts small to go through the incision and expands once inside the body. In this case, it is used to grip something, but it could also be configured to clamp or cut. Figure 5 (bottom) is a computer illustration of the device in a surgery. These concepts led to others, and the final result was minimally invasive surgery tools that are smaller and more compact than current devices.

Let's consider another example. Our lab once worked on a project for which the goal was to design a machine so small and precise that it could inject DNA into a single mouse egg cell without damaging the cell. That was a challenge—how do you make something that small and that precise? People were making computer chips by patterning flat layers of silicon. What if we used those same methods, but instead of making a computer chip, have it pop up and morph into the kind of machine that we needed? Something flat that then pops up—doesn't that sound like origami, or even more like a pop-up book? If you look beneath the artistic features of a pop-up book, you can see the fundamentals of how they work. Achieving pop-up motion in silicon, which is brittle like glass, and achieving microscopic precision is not trivial. The image in figure 6 was taken using a scanning electron microscope of an early prototype designed by PhD student Quentin Aten. The sphere is the size of a single mouse egg cell. We successfully demonstrated injecting DNA into mouse egg cells, and I'll talk more about that later.

When I first mentioned inspiration, you likely expected a discussion on seeking divine guidance. Let me fulfill that expectation now. Of all the things we'll discuss, none of them are as important or as impactful as receiving divine guidance in your work. "Ask, and it shall be given you; seek, and ye shall find; knock, and it shall be opened unto you" (Matt. 7:7). We talked about Nephi's contributions, but he made it abundantly clear that it was divine inspiration that made his work possible (1 Ne. 17). We have the ability to ask for help from a divine source with infinite knowledge and wisdom. I can testify to you from my own experiences that he is willing to provide that personal revelation.

Collaboration

The second principle we'll discuss is collaboration. By collaboration, I mean working with people who have knowledge, skills, and abilities that are complementary to our own. Collaboration enables us to accomplish goals much greater than what we could do on our own.

When watching movies, I am happy to suspend reality so that I can enjoy a good story. But, when I see a hero or a mad scientist who single-handedly creates some sophisticated new technology, it totally takes me out of the illusion. I just can't suspend reality that far because it is so counter to my own experience. There is a good reason why mad scientists are fictional. It isn't that there aren't scientists capable of horrible things; rather, it's because it takes a lot of people to accomplish complex things. Consider a couple examples from history. The Manhattan Project, which was the development of the atomic bomb during World War II, was estimated to have employed over one hundred twenty thousand people.[1] The Apollo Program, which had the exciting, bold, and audacious goal of putting people on the moon and bringing them safely home, required about four hundred thousand people and twenty thousand companies and universities to make it happen.[2]

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1. Independence Hall Association, "51f. The Manhattan Project," *U.S. History: Pre-Columbian to the New Millennium,* http://www.ushistory.org/us/51f.asp.

2. See "NASA Langley Research Center's Contributions to the Apollo Program," NASA, http://www.nasa.gov/centers/langley/news/factsheets/Apollo.html. As another example, consider a company like Apple and what it takes for them to bring you that next cool gadget. Apple estimates that they create nearly two million jobs in the Unites States—that's about seventy-six thousand direct

One of the key elements for successful collaboration is to have respect for people who are different than you. When people with different life experiences, educational backgrounds, and abilities work together, it is important for everyone to appreciate what others bring to the table. This can be particularly challenging in universities, where there can be structural and social barriers between the disciplines.

This principle of collaboration is obvious in the example of the development of the spinal implant. A lab working on the compliant mechanism wasn't enough. It took a spinal biomechanics expert, a venture capitalist, surgeons, and many others to move it forward.

We discussed Nephi as a great innovator, but even he needed his brothers' help to build the ship (1 Ne. 17:18, 49). Getting their cooperation was an impressive feat considering that they had just tried to kill him (1 Ne. 16:37; 17:48).

You may be thinking, "Oh, this collaboration idea isn't anything new; this sounds like what I've been taught about teams in my classes." After all, the idea of valuing different kinds of contributions was taught by Paul nearly two thousand years ago using an analogy of different body parts and how they need each other. He said, "And the eye cannot say unto the hand, I have no need of thee: nor again the head to the feet, I have no need of you" (1 Cor. 12:21). Although collaboration and respecting people of other backgrounds is certainly not a new idea, its role in innovation is often overlooked or underestimated. A lack of collaboration is a common problem that keeps backyard inventors from reaching their full potential, either from a lack of trust or respect for others' contributions or from lack of opportunity for collaboration.

As the sophistication of technology increases, so does the importance of collaboration. The number of inventors on U.S. patents has increased each of the last four decades, from 1.6 inventors per patent in the 1970s to 2.5 inventors per patent in the 2000s.[3] My own patent applications have an average of over 4 inventors per patent, and I am a sole author on only about 1 percent of my technical publications.

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employees, plus the suppliers, manufacturers, app developers, and others (see "Creating Jobs through Innovation," Apple Inc., http://www.apple.com/about/job-creation/). When you add the overseas jobs to those two million U.S. jobs, that's a lot of people.

3. The percentage of patents with lone inventors also continues to fall. See Dennis Crouch, "The Changing Nature Inventing: Collaborative Inventing," *Patently-O,* http://patentlyo.com/patent/2009/07/the-changing-nature-inventing-collaborative-inventing.html.

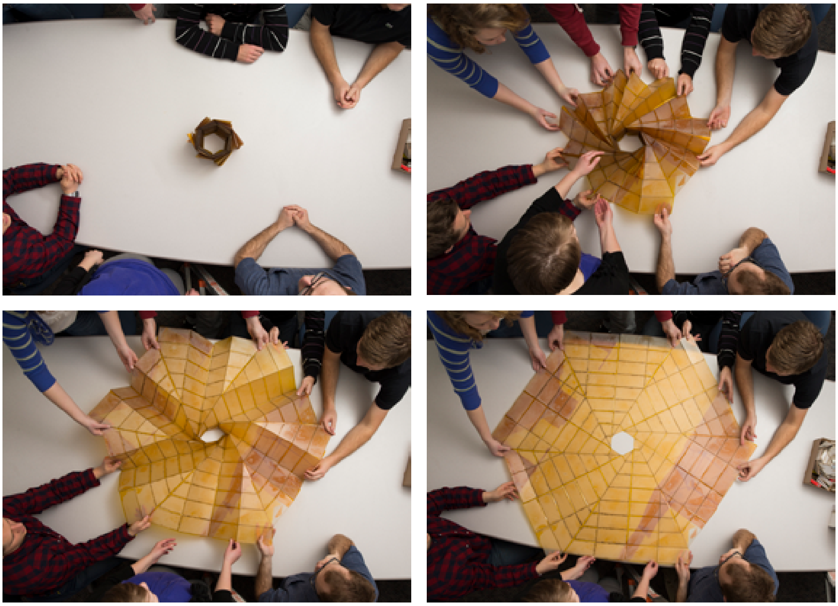

Figure 7. A 1⁄20 scale prototype of a deployable solar panel array. Photographs by Jaren Wilkey, courtesy Brigham Young University.

Another example of collaboration is our experience working with origami artists and other experts. Our lab once worked on a project where we wanted to create a deployable solar panel for space applications. An origami pattern called the "flasher pattern" served as our inspiration. But there's this little problem—you can't crease solar panels. Also, origami patterns assume that everything is paper thin, but these panels would be about a centimeter thick. Accounting for these issues required a combination of mathematics, creativity, and advanced prototyping. PhD student Shannon Zirbel took the lead, and we worked with NASA's Jet Propulsion Laboratory, origami artist Robert Lang, and many students. Figure 7 shows one of our early prototypes, built at 1⁄20 scale. It deploys to be nine times larger than its original diameter. This means it can be very compact to launch into space, and then, as it gets into space, it can deploy into a large solar panel. The hole in the middle is convenient because that's where you put the spacecraft. Figure 8 illustrates the solar panel deploying to be twenty meters in diameter—that is big enough to cover about five lanes of traffic and would produce double the amount of power produced by all the solar panels on the International Space Station combined.

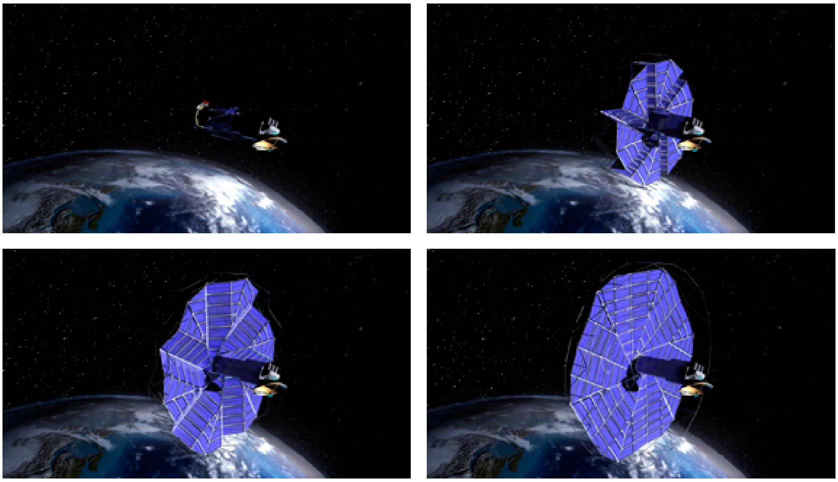

Figure 8. An illustration of the origami-inspired solar panel array in a spacecraft application. Computer illustrations from animations created by Dennis West.

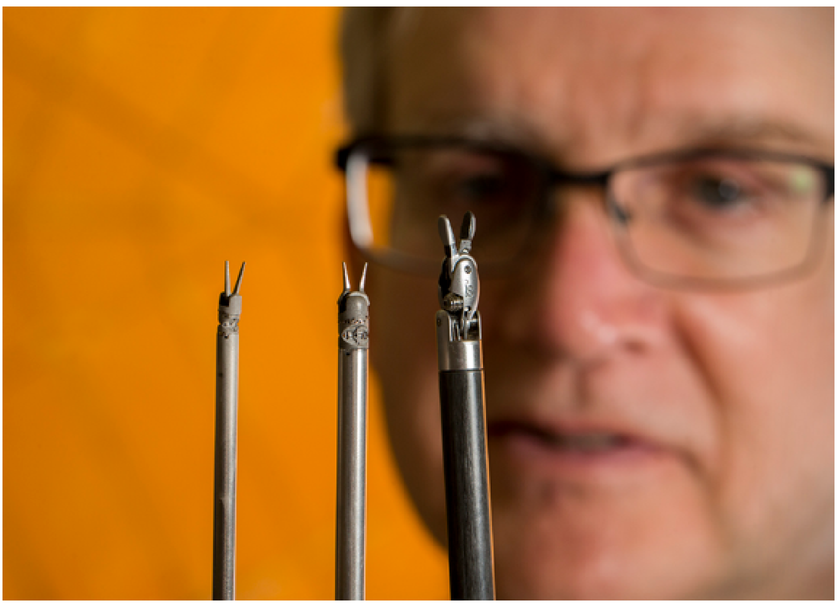

Figure 9. New small surgical instruments *(left and middle)* next to a commercially available instrument *(right),* shown with collaborator Spencer Magleby. Photograph by Mark Philbrick, courtesy Brigham Young University.

Another example of collaboration was our experience with nano-injection, where we injected DNA into mouse egg cells. You inject the gene into the mouse egg cell while the male and female DNA are mixing, then insert that egg cell into a surrogate mother. The cell will continue to divide until it becomes a baby mouse that will have the gene you injected. It's an efficient way to research genetic diseases and discover what different genes do. There's one complication: I could spell "D-N-A," but that was the limit of my knowledge about transgenic animals and genetic research. Here, Dr. Brian Jensen (also a mechanical engineering professor), our students, and I collaborated with Dr. Sandra Hope, a professor in the Department of Microbiology and Molecular Biology, and together we were able to do things that would not otherwise be possible.

Remember the surgical instruments I mentioned earlier? That work was in collaboration with a company called Intuitive Surgical, which makes the Da Vinci Robotic Surgery System. They are world leaders in robotic surgery, and working together made it possible to create minimally invasive surgery instruments that are smaller than what has been done before. Figure 9 shows our new small instrument next to a current commercially available instrument. The instruments are remotely controlled using the Da Vinci Surgical Robot.

This principle of collaboration, or respecting others with complementary skills, knowledge, and abilities, applies not only to technology development but to all parts of our lives, including our families. My wife, Peggy, graduated from BYU with a degree in accounting. She hasn't worked professionally for many years, but guess who does all of our family finances. And let's be honest, I wouldn't even think of embarrassing myself by leaving the house in a shirt-and-tie combination that's not preapproved by her. Of course collaboration even extends beyond families. If you'll allow me to talk crazy talk, I would say that the benefits of listening to and respecting others may even extend as far as public policy and politics.

One of the most rewarding parts of my career has been collaborating with students and colleagues. For example, Dr. Spencer Magleby and I have worked closely together for years in compliant mechanisms research. This collaboration has not only made it possible to do more than we could do on our own, but the interaction has greatly enriched my life. There's no question that working with a designer like Professor David Morgan helps our results look better, but the collaboration also expands my vision to new possibilities. It is rewarding to work with students and see them learn and grow, and working with students has probably been the most enjoyable part of my career. BYU administrators and the Office of Technology Transfer have provided essential help and have been supportive of our goals. Time and circumstances don't allow me to mention everyone by name today, but I do want to sincerely thank the students and colleagues with whom I have collaborated over the years—I can't adequately express my gratitude for the blessing it has been to work with them.

Exploitation

The third principle is exploitation. That's kind of a scary-sounding word because it has multiple definitions, but I am referring to making the most of opportunities that present themselves. Make sure that you are constantly moving toward a goal, because it's while you are moving that things happen. But it is also important to be agile and flexible so that you can exploit new opportunities when they arise. This also means, whenever you see challenges or road blocks, that you evaluate those as potential opportunities.

I have a friend, Vern Henshaw, who once was a high school basketball coach. He expressed the frustration he sometimes felt as the team learned plays. When in a game, they would call a play and the players would execute the play as they'd practiced, but the frustration would come when the play would create an opportunity to score, and rather than taking the open shot, the players would continue to execute the play. But that's not the purpose of the play! The purpose of the play isn't to execute the sequence of tasks; it is to create opportunities to score. So it is with invention, creativity, and innovation. You have to be moving and doing things, but you also want to look for opportunities that arise.

If we reflect on the spine example, we were busy developing technologies for consumer electronics, and when the time came we were able to transform an event that appeared to be a roadblock into an opportunity. If the next round of funding would have come from the company as I had hoped, it is unlikely that we would have found ourselves working on the spine application. Fortunately, the opportunity came, it was identified, and we were able to pursue it.

Think of Nephi when his brothers again threatened his life after Lehi's death. Rather than skulking away and feeling picked on, he took the opportunity not only to move to another place, but also to create the foundation of a new nation (2 Ne. 5).

I have to express a caution here—in employing exploitation, you don't want to always be running after every new idea that comes along. That might be good for invention, but it's horrible for getting things done. To deal with this, I encourage you to keep a record of your thoughts and of possible opportunities so that you can review and evaluate them to decide if you want to pursue them now or to save the opportunity for another time.[4]

In engineering, we teach a method for developing new products called the engineering design process. It starts out with a customer need that we are trying to fulfill. Understanding the need and measuring how well you fulfilled that need is just good engineering; it's what engineers do. As good as that process is, I often enjoy doing something counter to it that is sometimes controversial. In this approach, rather than starting with a need, you start with a new technology and you search to identify a need that it can fulfill. This second, more controversial approach is called "technology push" design. You can imagine the criticisms of this approach—it's sometimes referred to as "a solution looking for a problem," or "when you have a hammer everything looks like a nail." There's definitely some truth to this criticism, but there are also some amazing opportunities. When you look at the history of technologies that have made a significant impact on society, many of them did not start with a need—they preceded or even created the need. For example, before smart phones I never thought, "Wouldn't it be cool to carry a powerful computer in my pocket that could make phone calls, provide hourly weather predictions, be my navigation system, carry all my scriptures, be my alarm clock and my calculator, and have access to limitless information?" Before microwave ovens, no one was sitting around thinking, "Oh, wouldn't it be convenient if I could nuke my leftovers and heat them up in thirty seconds?" No one thought that because it didn't occur to us that such a thing could even be possible. Many great inventions are entirely unanticipated before their creation.

In university research, there are many opportunities to use technology push processes to move research results from the lab into places

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4. An example to illustrate this involves what we call "burst projects" that our lab does in the summers. These projects focus on applications of the theory graduate students have developed in their research. This summer, we are doing four burst projects—but those were selected after evaluating a list of over sixty possible projects ideas.

Figure 10. A set of hammers from Larry Howell's garage, ranging from a roofing hatchet to a rubber mallet. Rather than a "hammer looking for a nail," good technology push design is more like matching the right hammer with the right type of job. Courtesy Larry L. Howell.

where they can make a positive difference. The story of the spinal implant illustrates this concept. We had developed a technology that gave us new capabilities, and we searched for where it could have a positive influence.

It would be unwise to try to apply new technology wherever you might be able to force it; the reward comes from finding those places where the characteristics of your technology are a good match to fulfill a need. Figure 10 is a picture of several hammers in my garage, ranging from a roofing hatchet to a rubber mallet. Each hammer is best suited for a certain type of job. Rather than a hammer looking for nails, good technology push design may be more like trying to match the right hammer to the right job.

You can liken the technology push process to your life. *You* are the hammer. Always be looking for the right nails—how are you going to make a contribution? You have unique abilities, skills, talents, and background. How are you going to use that to make a difference in the world? As you work toward this, you will find that you're going to be creative in the things you do and that you can make a positive difference in the world, and society will be better off for having you as part of it.

Conclusion

Today we've discussed the principles of inspiration, collaboration, and exploitation. Although they could be worded differently and could be illustrated with different examples, I have come to believe that these principles are important to the anatomy, or internal workings, of innovation and invention. It's my hope that you can liken them to your own life and that you might find new ways that you can make your unique positive difference in the world.

Larry L. Howell is Professor and Associate Dean of the Ira A. Fulton College of Engineering and Technology at Brigham Young University. He received his BS degree from BYU and MS and PhD degrees from Purdue University. Prior to joining BYU in 1994, he was a visiting professor at Purdue University, a finite element analysis consultant for Engineering Methods, Inc., and an engineer on the design of the YF-22 (the prototype for the U.S. Air Force F-22 Raptor). He is a Fellow of the American Society of Mechanical Engineers (ASME), the recipient of the ASME Machine Design Award, ASME Mechanisms & Robotics Award, Theodore von Kármán Fellowship, NSF Career Award, and the BYU Maeser Distinguished Faculty Lecture Award. He and his wife, Peggy, live in Orem and have four children and two grandchildren.