CHANGING TIMES, CHANGING MINES
Reflections on the Evolution of Mines and Its Faculty by a Female Professor Studying Human Skin

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Faculty Senate Distinguished Lecture
Delivered March 23, 2011

As indicated by my title, I want to talk today about how Mines and its faculty has changed over time from my perspective as a woman professor in chemical engineering with a research interest in bioengineering in life science.

In thinking back to 1981 when I joined Mines as Assistant Professor, I was surprised by the number of similarities between then and now. Like today, the price for oil was high and the same was true for minerals. Also, there were concerns about dwindling resource supplies. In 1981, high oil prices had pushed the development of oil shale in Colorado; in 2011, the development of Colorado oil shale is being discussed again. Even Jerry Brown, whose signature is on my PhD diploma from the University of California, is governor of California again.

At Mines, in 1981 the student body had just doubled, the number of faculty was growing in response, and we graduated about 100 women that year with a bachelor of science (BS) degree.[1] The same is true for 2011, except that about 150 women graduated with BS degrees and almost another 100 received graduate degrees.[2]

Of course, there are many differences between 1981 and 2011. In 1981 Mines proudly declared itself as the "World's Foremost School of Minerals Engineering," and about 80% of the degrees granted were in the earth sciences and earth resources disciplines.[3] Even the economics program had the word *mineral* in its name: the Mineral Economics department. Today, we make more general claims like "Colorado School of Mines Engineering the Way" and "Colorado School of Mines Earth Energy and Environment". In 2011, there are 32 women professors at Mines, an increase of a little more than 5 fold since 1981.

However, I don't want to focus today on the differences between then and now. Rather I want to focus on the evolutionary process of responding to change; specifically, the successful response to change. Moreover, I want to propose that three actions are commonly present in a successful response to change.

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[1] This and other historical information about women students and student enrollment can be found in K. Altman *et al*., *A Century of Women at Mines*, published by the Florence Caldwell Centennial Celebration Committee and the Women in Science, Engineering, and Mathematics Program, Colorado School of Mines, Golden, CO (1999).

[2] Degrees Granted by Department (BS, MS, PhD) - 1993 to Present at http://inside.mines.edu/Internal_Reports (March 2011).

[3] Commencement '98, George Ansell's Keynote Address, "Managing a vision, not just operating a school", *Mines Today*, Colorado School of Mines, 98 (2), 30-35.

The first of these actions is *Make a Plan*. This is the process of evaluating the changes and then deciding what you need to do or want to do to adapt to those changes.

The second action is *Seek Diversity*. For an organism adapting to changes in the environment, it is genetic diversity that is important. If the gene pool is too small, the species won't be able to survive environmental changes. As a result, successful species exhibit behaviors that promote genetic diversity.

I believe that diversity is also required for institutions and individuals to successfully adapt to a changing world. In this case, it is diversity in knowledge, talents, skills, interests, and points of view that matter. Academic institutions seek diversity by hiring a diverse faculty. For individuals, diversity is achieved by surrounding ourselves with people who are different from us.

The third action is *Enjoy Serendipity*. Serendipity you will remember is achieving a desirable result by accident. Often these are accidents of timing: a chance meeting or a chance conversation that evolved to become a long-term productive collaboration. This action is different from the other two because it occurs after the successful response to change has occurred.

With these three actions in mind, I want to explore the theme of responding to change with three stories of how Mines and its faculty have evolved in response to *Changing Times* beginning in 1970. Mines had just hired Guy McBride as president and he soon began implementing a plan to double student enrollments. The women's movement and concern about the environment were big issues of the day and in 1972 Congress passed the Equal Rights Amendment and the first earth day celebration occurred. In that same year, the number of women students enrolled at Mines reached 100 for the first time; the total enrollment was 2,000. In 1974, the first woman professor was hired. As the end of decade approached, the Environmental Sciences and Engineering Ecology Department was started and a year later the Board of Trustees adopted the requirement that every Mines student had to take at least one course in environmental science. Overall, during the decade of the seventies, 153 women had graduated from Mines. This was a remarkable achievement considering that only 14 women had graduated in the entire 100-plus year history of Mines before 1970. The momentum for women students at Mines continued and 99 more women graduated in 1980.[4] In that same year, Mines reached its goal of about 3,000 students.

We can summarize this period from 1970 to 1980 as a time of tremendous growth for Mines fueled in large part by huge increases in oil prices, which brought new students to Mines and provided employment opportunities for those who graduated. These increases stopped abruptly in 1982, when oil prices peaked and started falling faster than they had risen over the previous decade. Before this, in 1979 while oil prices were still increasing rapidly, Exxon started working on the Colony oil shale project near Rifle, Colorado. It was estimated that this project would cost at least $5 billion to complete.

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[4] K. Altman *et al.*, *A Century of Women at Mines*, https://inside.mines.edu/UserFiles/File/WISEM/A%20Century%20of%20Women%20at%20Mines.pdf (retrieved March 2019).

Two years later, I started as an Assistant Professor at Mines and my husband went to work for Exxon's partner, Tosco, on the Colony project. Unfortunately, our move to Colorado preceded the fall in oil prices by only a few months. With oil prices on the decline, Exxon concluded that the Colony project had little hope of being profitable, and on May 2, less than 9 months after I moved to Colorado, Exxon cancelled Colony after spending more than a $1 billion. Black Sunday, as May 2, 1982 was later called, was one of the early signs that the oil boom had gone bust and it was going bust in big way.

This was a significant event for me personally because my husband lost his job on the Colony project. And, he wasn't the only one to lose a job. Many recent graduates from Mines lost jobs and new graduates had a hard time finding jobs. In response to the bleak employment opportunities, student enrollments at Mines began to drop.

Oil prices continued to fall until 1986, to reach lows that were sustained for more than a decade. During the same time period mineral prices also collapsed. In 1984 amidst these near catastrophic declines in Mines' traditional industries, Mines hired George Ansell as its new president. He later described this time as "a period of abrupt, discontinuous change." [5] He went on to say "… the world of energy and minerals", which had been the emphasis of Mines for over 100 years, "was no longer narrowly focused nor slowly changing." He concluded that "you either had to change the world or change the School." Since changing the world was unrealistic, clearly, "the School had to change." As a sign of those times, this bumper sticker was seen: "Please God, just give me one more oil boom. I promise not to blow it next time."

With this brief historical review, we have now arrived at our first story: Chapter 1 –You've Come a Long Way Baby. This is the story of women joining the Mines faculty.

By 1981 when I became an Assistant Professor, there had been women professors at Mines for only 7 years. Although I was a member of the faculty for most of the history of women professors at Mines, I didn't remember all the details. I wondered how far had Mines come since those early days? How many women faculty had Mines hired? What happened to them? And, could we learn any lessons from this history that could apply today?

I thought I could find answers to these questions by making a few phone calls to find the *right person* who had this information on their computer or in their filing cabinet. I never did find that right person and I had to collect the data myself. My primary data source was the "Directory of the School" and the departmental lists of faculty in the Student Bulletins that are published each year. These data were supplemented by information I could gather from human resources, student yearbooks, and, in the case of women faculty, direct contact when possible. In a few cases, I located resumes posted on the web. The goal was to establish for all women faculty the important dates: when they started, when they were promoted, and when they left if they were no longer at Mines. For men, the goal was to determine the total number as a function of year.

There are problems with the information in the Student Bulletins. The Bulletins are published once a year before the academic year starts. This means that a professor who

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[5] Commencement '98, George Ansell's Keynote Address.

started at the beginning of the academic year was often not listed until the next year. Even more problematic is that departments have not always kept their data up to date. In addition, there was a 4-year period (1988-1991) when the Student Bulletin was published only every other year. I did my best to ascertain the correct dates for the women faculty, but errors of a year are possible for some individuals. In counting the total number of faculty, I have used the number in the year of the Student Bulletin without any adjustment for the one-year lag.

I restricted my analysis to the tenure-track titles: Assistant Professor, Associate Professor and Professor. I did not include individuals who had titles of lecturer or instructor, or who had professor titles that include qualifiers other than assistant and associate alone (i.e., Adjunct Professors, Visiting Professors, Research Professors and Emeritus Professors were not included). This was a practical decision because the information for these groups was inconsistent and often completely lacking. Finally, faculty assigned to the Military Sciences and Athletics Departments were excluded.

To understand the faculty data I will show, it is helpful to know how the academic structure works. Let me describe it briefly since it may be unfamiliar to some members of the audience. The life cycle of most professors starts with being hired as an Assistant Professor, from which they are subsequently promoted to become an Associate Professors and finally a Professor, which is also called a *full* Professors. Although I use this terminology myself, I have always thought it is a silly description since it implies that Associate and Assistant professors are only *partial* Professors.

Faculty at any of these ranks can leave the school. For Assistant Professors, there is a 7-year time limit, which means they must be promoted or leave by the end of 7 years. There is no such time limit for the ranks of Associate Professor or Professor. Faculty can be hired into the Associate or full Professor ranks, although this occurs less frequently. At Mines 86% of all women tenure-track faculty started as Assistant Professors.

In considering the life cycle of a professor, we see there are two ways to increase the number of female faculty. You either hire more or retain more. Ideally, you do both. We will keep these two strategies in mind as we look at the number of tenure-track faculty at Mines, starting first with the total.

This brings us to the data. Let's look first at the total number of faculty by academic year from 1974, when the first woman professor was hired, until now (Figure 1). The number of faculty increased by more than 50% from 1975 to 1984, which coincided with increased enrollment of students. This was followed by a decline in faculty due to the enrollment declines after prices for oil and minerals fell. More recently, faculty numbers have increased in response to the plan to double the student body size again. Interestingly, the 1984 maximum of 185 professors was not exceeded until 2008, when the number reached 191. In 2010, the total number of professors was 198. During this time the number of women professors grew from 1 in 1974 to 32 in 2010.

Let's look now at the number of women professors at Mines over time by rank (Assistant Professor, Associate Professor, and Professor) and department. In these graphs I used the current department name for departments that have had name changes and the names of the

13 departments are listed in alphabetical order: Chemical Engineering, Chemistry and Geochemistry, Economics and Business, Engineering, Environmental Sciences and Engineering, Geology, Geophysics, Liberal Arts and International Studies, Mathematical and Computer Sciences, Mining, Petroleum Engineering, and Physics.[6]

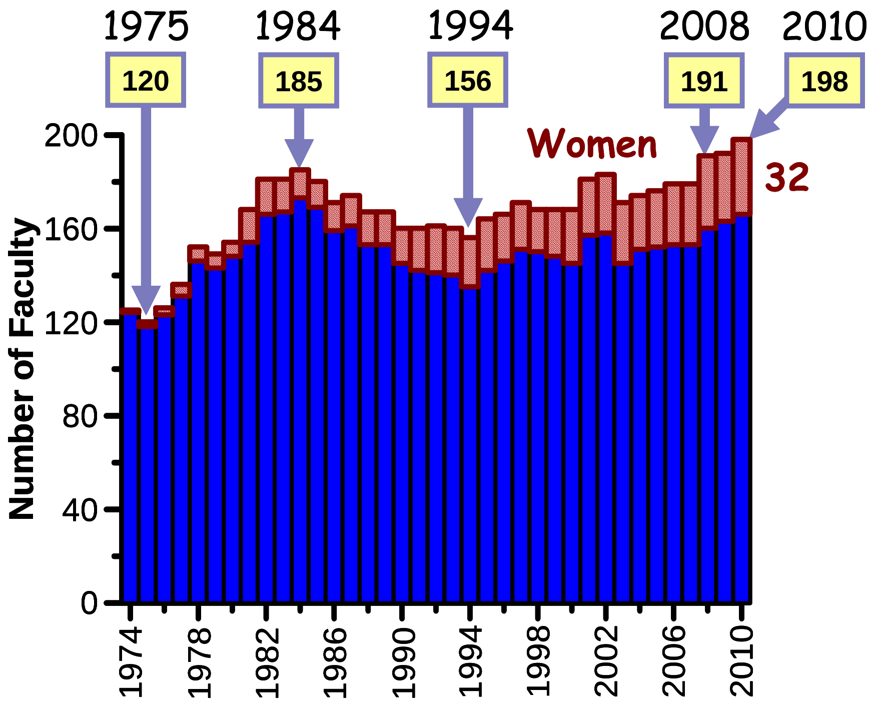

Figure 1. Total number of tenure-track faculty (i.e., Assistant Professors, Associate Professors, and Professors) at Mines by academic year since 1974. Women faculty numbers are designated in red.

In 1974, Julia Alexander was hired as an Assistant Professor in Humanities and Social Sciences. The next year, Joan Hundhausen became an Assistant Professor in Mathematics. Joan Brooks was appointed as an Assistant Professor in the Basic Engineering Department in 1976, and Emmy Booy joined Geology in 1977, also as an Assistant Professor. In 1977 Mines also hired its first woman Professor, Beatrice (Betty) Willard. She was also the first woman to be a department head at Mines and the first department head of the new Environmental Sciences and Engineering Ecology Department. Ruth Maurer became an Assistant Professor in

[6] These graphs and other graphs as well the tabulated lists of faculty data collected for this lecture are available as Additional Information on the webpage describing this 2010 lecture available on the Mines Faculty Senate webpage for the Faculty Senate Distinguished Lecture series, https://www.mines.edu/faculty-senate/lecture/2010-bunge/

the Mineral Economics Department in 1978, and in 1979 Joann Hackos replaced Julia Alexander, who left. No women joined the professor ranks in 1980.

In 1981, a year when the number of Mines faculty was increasing and the Women's movement was active, the number of women faculty increased by eight, all of them joining as Assistant Professors (Annette Bunge, Betty Jo Cannon, Debra Carnell, Kathleen Ochs, Sally Oslund, Ramona Graves and Karen Wiley). Only 8 years after the first woman professor was hired, there were now 14 women faculty in 8 departments, and for the first time, there were departments with more than 1 women professor: Basic Engineering had 3 and Humanities and Social Sciences had 4. Also, in 1981, Joan Hundhausen became the first women to be promoted to Associate Professor. The number of women professors at Mines was still small, but no one could question that times had changed.

Julia Ann Alexander
Humanities & Social Sciences

1974

Joan Hundhausen
Mathematics

1975

Joan Brooks
Basic Engineering

1976

Emmy Booy
Geology

1977

Beatrice Willard
Environmental Sciences
& Engineering Ecology

1977

Joann Hackos
Humanities & Social Sciences

1978

Figure 2. Women professors hired at Mines from 1974 to 1980. All were hired as Assistant Professors except Beatrice (Betty) Willard, who was the first woman to be hired as Professor, the first women to be a department head, and the first department head of the new Environmental Sciences and Engineering Ecology Department (pictures from the *Prospector* student yearbooks from about the time they joined Mines).

In 1982 student enrollments began to drop and over the next few years faculty numbers decreased. The number of women professors remained relatively constant during this time, although through promotions the number of Assistant Professors decreased with a corresponding increase in the number of Associate Professors. For example, in 1987 there were 10 Associate Professors and only 3 Assistant Professors. By 1991, there were 18 women in 9 departments and 4 departments had at least 2.

Significantly, there were 3 new women Professors in 1991. Two were hired directly into the Professor rank. One of these was Joan Gosink, who took over as Division Director of the Engineering Division (formerly called the Basic Engineering Department), becoming the second woman at Mines to head a Department or Division. I was the third new Professor, becoming the first woman who started as an Assistant Professor to reach the rank of Professors by promotion. By 1997, there were 20 women in 10 of the 13 Mines departments. Fast forwarding to 2010, Mines now has 32 women professors in 10 departments, which includes the hiring this year of the first woman in the Metallurgical and Materials Engineering Department. There are 13 Assistant Professors, 12 Associate Professors, and 7 Professors. Interestingly, 6 of the 7 Professors hold leadership positions on the Mines campus: 1 is Associate Provost, 3 head departments or divisions, and 2 are directors of campus-wide institutes. The one remaining Professor has retired just this semester.

Overall, since 1974, there have been 68 women professors with at least one in every department except for the Mining department. As you would expect, there have been more women in departments representing disciplines that produce more female PhDs, or where the number of faculty positions available to fill have been larger. The converse holds too. There have been fewer women in departments with disciplines that produce fewer female PhDs and where the number of positions available to fill are fewer – either because the number of faculty in the department is smaller, or because there has been little turnover. The Mining Department falls into this situation: there are few qualified women available with expertise in Mining and the department has had few positions open.

Looking now at the number of women faculty by rank since 1974, we see that the number has grown in all ranks (Figure 3). We know that the number of total faculty has also grown since 1974, so it is useful to look at these numbers reported as a percentage of all professors. When we do this, we see the large jump between 1980 and 1981 when 8 women were hired and then a slower increase to 13% in 1994, followed by smaller increases with a few dips to reach 15% in 2003 and 16% this year (2010). When we look at the data this way, we see that the increase in women professors from 21 to 32 over the past 16 years is an increase of only 3%.

If we restrict the analysis to the science, engineering and math departments alone, we find that the number of women faculty increased from 10% in 1994 to just 12% in 2010. It is interesting to compare these numbers to those reported earlier this week by the Massachusetts Institute of Technology (MIT)[7] for the essentially the same period of time: 1995 to 2010. At MIT, the percentage of women faculty in the science and engineering departments more than doubled changing from 8 to 19% in the science departments and from 7 to 16% in the engineering departments. Mines was ahead of MIT in 1994, but since then has failed to keep up. What happened? Why have the increases been small?

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[7] A Report on the Status of Women Faculty in the Schools of Science and Engineering at MIT, 2011, http://web.mit.edu/newsoffice/images/documents/women-report-2011.pdf (March 2011)

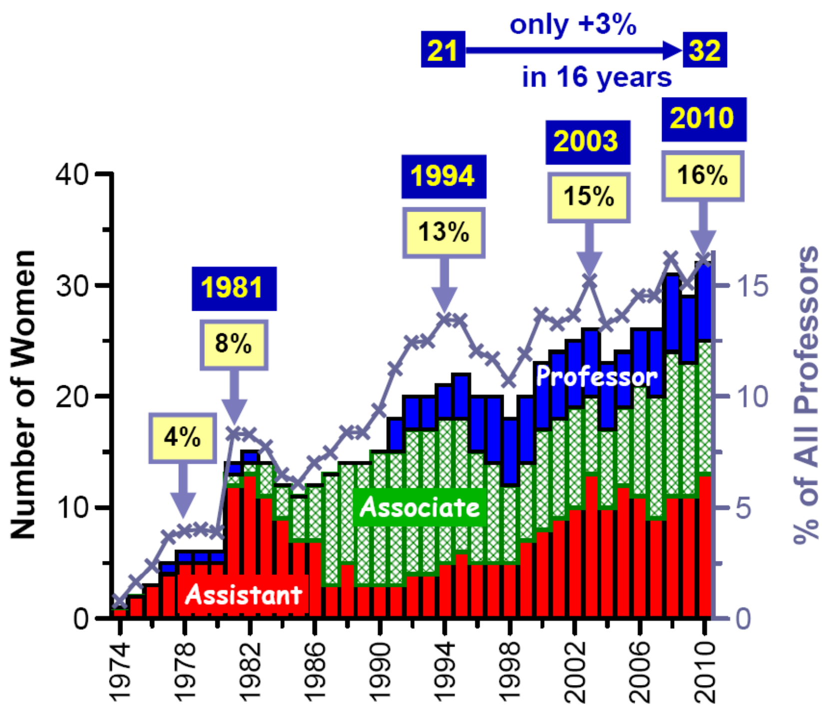

Figure 3. Number of women professors by rank (left axis) and percent women professors of all professors (right axis) by academic year since 1974 when the first woman professor started at Mines.

With this in mind, let's look back at the two ways to increase female faculty numbers: hire more and retain more. How have we done? First, have we hired more? I want to focus on the Assistant Professors since the majority of tenure-track faculty at Mines start as Assistant Professors. If we look back over the past 7 years, 15 women were hired as Assistant Professors. I don't know the exact number of men hired in this time, because I don't have information at the same level of detail for men. What I do know is that there are 40 men who are Assistant Professors at Mines this year (2010). Because there is a 7-year time limit for Assistant Professors, we know that all of these 40 men were hired within the past 7 years. So we can conclude that at least 40 men have been hired as Assistant Professors since 2004, and that the total number of Assistant Professors hired since 2004 is at least 55: 40 men and 15 women. This means that approximately 1 in 4 Assistant Professors hired since 2004 were women. And, this number could be smaller than 25% if more than 40 men have been hired since 2004.

Frankly, I was surprised to discover the fraction of women hired was so small. I knew that the number of women professors was increasing, but I had not realized how many more men were being hired. Since a hiring rate of 25% is larger than the 16% of women professors on campus, the percentage of women faculty should increase, although slowly, just as we have observed over the past 16 years.

What about retention? Has Mines retained more? Let's focus again on Assistant Professors. In 2004, 10 women were Assistant Professors. Over the next 7 years, only 4 of those were promoted to Associate Professor. The other 6 left Mines. Mines retained only 40% of the female Assistant Professors since 2004. This is a disappointing number.

Unfortunately, I do not have the data to make a similar assessment for male Assistant Professors, so I don't know if this 40% retention is different for men. What I can say, is that hiring and starting a new Assistant Professor is expensive. Poor retention of women or men is a cost the institution cannot afford.

If someone asked me to summarize the story of women professors at Mines, I would say there is a consensus that a more diverse faculty strengthens Mines. I believe that Mines is committed to increasing diversity through the hiring of women and other minorities. I would also say that the current approach for hiring women professors is not working. The simple truth is that the number of women professors at Mines has increased by only 3% in 16 years. The MIT data on women faculty indicate that it doesn't have to be this way. We can do better.

We recognize that the pool of women who are qualified and also interested in becoming a professor is small. This is a fact that we are unlikely to change. In addition to this, each faculty hired is an accident. It is accident of matching the timing of Mines' search with the timing of the candidate's availability. You don't have to have a degree in advanced mathematics to appreciate that accidents of hiring will occur less frequently when the pool of qualified candidates is small, as it is for women. When you consider this situation, it is not surprising that Mines has not made significant progress in the percentage of women faculty hired. To increase the percentage of women professors at Mines, we need to change how we go about hiring women.

I think it is time to seek diversity by making a plan to increase the number of favorable accidents that result in hiring women to the Mines faculty. We cannot change the timing of a candidate's availability, but we could introduce more flexibility into the timing of our searches. One strategy would be to change our approach so that we can hire opportunistically; that is, we could hire a highly qualified diversity candidate who contacts us even if we are not actively searching at that time. Another option is to adopt strategies that companies use during periods of competitive employment. They don't wait until the potential employee is about to graduate and available to start work to begin recruiting them. The successful companies identify and begin to recruit the best students one, two or even three years before they graduate.

Another strategy is to make Mines more attractive than its competition. This doesn't increase the number of accidental events, but it can tip the outcome in our favor. Sure, we need to be competitive in our salary and start-up offers, but this isn't the whole story. I am sure there are more than a few faculty in this room today who decided to come to Mines for reasons other than it was their best offer. I think we recognize that work-life issues are important, but so far these are handled on an adhoc basis. I think if you study the example of MIT, you will find that part of the reason they have been able to significantly increase the percentage of women faculty is that they worked hard to change the institutional climate on work-life issues. Doing the same thing at Mines might be enough to attract women we are now losing to other universities.

So to summarize the story of women faculty at Mines, I would say we haven't come as far as I thought before I collected and reviewed the data. Furthermore, I don't think Mines will make progress at increasing the percentage of women faculty until we change the way we recruit and hire faculty.

This brings us to the second story: Chapter 2 – Wrapped Up In My Research. This is my story and how changing times changed my research. As I already said, I joined Mines as an Assistant Professor in 1981. My PhD research had been in the area of enhanced oil recovery. After joining Mines, I expected to continue this work on techniques to increase the amount of oil produced. Enhanced recovery methods cost more than traditional approaches, but when oil prices are high it is worth the extra cost. But, as you know oil prices started to drop in 1981, and soon prices were too low to support the extra cost. In response, research funding for enhanced oil recovery disappeared. Strike 1. I had to find a new research area.

Because it had some similarities to the work I had done in enhanced oil recovery, I decided to study underground leaching for minerals. I successfully acquired funding from the National Science Foundation for one project on this subject before minerals prices dropped too low to justify further research in this area too. Strike 2. I was looking once more for a new research topic.

Next I worked on membrane techniques for cleaning contaminated water. This research was funded by the Environmental Protection Agency (EPA). However, Ronald Reagan became President in 1980 and within 5 years EPA's budget had dropped by nearly 50% making further research funding from EPA unlikely. Strike 3. Again I was searching for a fundable research area.

Fortunately, I wasn't playing baseball, so three strikes didn't make me out. However, I recognized that I needed to find a research area that would be supported by more than one funding source. I just wasn't sure what the research area would be. Fortunately, this was when I met the *human-rat skin flap model*.

When engineers describe a *model* they usually mean a mathematical model and a bunch of equations. When life scientists refer to a model, often it is an animal. The human-rat skin flap model was an animal model. Just as its name implies, it was a rat that had a flap of human skin on its back. This animal model was being used in the Division of Dermatology at the University of Utah to study absorption of chemicals through human skin. In their experiments they applied a solution containing a chemical of interest to the human skin side of the flap and then they measured the rate at which the chemical went through the skin. They expected that the absorption rate would increase over time to eventually reach a constant rate. However, they observed instead that the rate increased to a maximum and then began to decrease. One explanation for this observation was that the skin sensed there was chemical absorption and it changed to slow the absorption rate. Of course, other explanations were possible.

I thought the human-rat skin flap research was interesting and through my EPA research, I now had experience with membranes. We discussed a collaboration, and I arranged to take a sabbatical leave at the University of Utah in 1987. I was really excited to work on the human-rat skin flap project; but, if I am honest, I was even more excited to be spending the winter in Utah. The skiing was really good, but that's a different story.

To understand better the experimental results, it will help to understand how the human-rat skin flap is made.[8] You start with a nude rat (which refers to its lack of hair and not to its lack of clothes). You turn the rat over onto its back and make a U-shaped incision on its abdomen. The U-shaped piece of skin created by this cut, a flap, is then pulled back. Human skin is grafted onto the back of this flap and rat skin is grafted onto the region exposed when the skin flap was pulled back. After everything has healed you have a flap with human skin on one side and rat skin on the other – a human-rat skin flap. However, if you leave the flap on the rat's abdomen the rat is likely to chew it off. So, to protect it, the skin to the side of the flap is cut and the flap is pulled under the animal's skin to its back as shown in the photograph (Figure 4).

Figure 4. Human-rat skin flap model (photo provided by LK Pershing, University of Utah.

When an experiment was conducted, the animal was put to sleep and laid on its back with the flap pulled to the side of the animal with the human skin side up. A ring was glued to the human skin and then filled with a solution containing the chemical of interest. During the experiment, the blood flow through the flap was measured using a laser Doppler velicometer and the blood to and from the flap was sampled and the concentrations of chemical determined. Knowing these concentrations and the blood flow rate, the rate of chemical absorption was calculated.

The experimental results for an example chemical, benzoic acid, illustrate how the absorption rate increased to a maximum and then declined. As an engineer, I started by calculating how much chemical had absorbed compared with the amount in the solution that was applied to the flap. It seemed likely to me that chemical absorption in the skin was large enough to cause the concentration in the solution to decrease during the course of the experiment. As a result, we went back and checked the concentration of benzoic acid in the solution. Just as I had suspected, the concentration had decreased during the experiment.

The next question was whether the decline in concentration was large enough to explain the observed decrease in the absorption rate. To answer this question, we did some *simple* mathematical modeling. I refer to this step as "cool things you can do with calculus" and I have included this slide of equations in my talk for members of the audience who think calculus only exists to torture students. Although these equations might look complicated to some of you, the ideas they represent are not. The first equation describes chemical absorption through the skin. The second equation describes how chemical transfers from the solution to the skin. The

[8] For more information about the human-rat skin flap model, see Krueger et al. *Fundam Appl Toxicol,* 5:S112-S121, 1985; Wojciechowski et al. *J Invest Dermatol* 88:439-446, 1987.

boundary conditions listed at the bottom of the slide specify the starting concentration of the chemical in the solution, the relationship between the concentrations in the skin and solution, and that the chemical concentrations in the skin and blood start at zero.

Some of the parameters in these model equations are not known. So, we estimated the values of these parameters by forcing the calculations from the model equations to match as closely as we could the observed change in the solution concentration over time as well as the time at which the absorption rate reached its maximum value. Using these parameters, we could then calculate the absorption rate predicted by the model equations as function of time. Like the experimental data, the model equations predicted that the absorption rate would increase and then decline. The model equations correctly predicted the experimental observations, although the model and measurements did not exactly match. However, as the blood flow rate was not known precisely, we judged that the differences between the model and experiments probably were not significant.

The goal was to maintain a constant concentration in the solution applied to the rat flap. To achieve this goal, the volume of solution needed to be larger than in the original experiment. Consequently, the chemical delivery system was redesigned to circulate the solution from a large vessel to a smaller stirred cell that was glued to the human-rat skin flap. Also, a water jacket was added to the redesigned cell so that water could be circulated to maintain a constant temperature over the course of the experiment.

Using this redesigned chemical delivery system, the absorption rate of a selected chemical (benzoic acid in this case) increased in time to reach a constant – just like we expected it should. It was clear then that the decreasing absorption rate observed in the earlier experiment occurred because the concentration of chemical in the solution decreased and not because the barrier function of the skin increased. With the new redesigned cell, we then conducted a number of additional experiments that were described in a few publications, which I won't talk about this today.

This successful collaboration with the scientists in the Department of Dermatology at the University of Utah made me think about the skills a chemical engineer might offer to the study of chemical absorption through skin. I concluded that a chemical engineer's general background in math, chemistry and physics, along with some specific expertise in thermodynamics and mass transfer, could be usefully combined with the expertise from other fields, like dermatology, pharmacology, pharmaceutics, toxicology, biophysics, occupational hygiene, environmental scientists and more, to answer many questions related to chemical absorption into skin. Some examples of these questions are:

- Can a drug be effectively and safely delivered from a patch?
- Is the generic topical cream as good as the cream from the original manufacturer?
- Is it safe to shower in your water when it is too contaminated to drink?
- Is skin contact with consumer products you use safe (like cleaners, soaps, paints, insect repellents, sunscreens, cosmetics and hair dyes)?

- After you have applied pesticides to your lawn, when is it safe for your kids to play on it?
- Is skin contact with chemicals at your job safe?
- Is it safe to walk barefoot on a beach contaminated with spilled crude oil (even if the amount is too small to see)?

Significantly, answers to these questions were of interest to many different funding agencies. I had found, really by accident, a research topic that would be funded by more than one agency.

To summarize this story, I discovered the primary topic of my research for the past 25 years, chemical absorption into skin, pretty much by accident. An additional benefit of this lucky accident is that I find most people are interested in my research on skin. I think this is because every one is, like all of you and me, wrapped up in my research project.

This brings us to our third story: Chapter 3 – Much More Than Its Name. This is the story of bioengineering and life sciences at Mines.

You will remember that in response to falling prices of oil and minerals and declining student enrollments, Mines' President George Ansell concluded that "the School must change", which is what Mines did. The primary goal was financial stability, and George Ansell set about reaching this goal by implementing with a 3-step plan. The first step was to increase student enrollments by diversifying degree options to make Mines attractive to a larger group of students. The second step was to reduce the impact of economic cycles in the energy and minerals industries by broadening the base of the supporting industries and the employment opportunities for Mines graduates. The third step was to increase research revenues, which would support faculty expansion without always requiring an increase in student enrollment.

These changes, especially with respect to expanded degree options, were reflected in the 1986 materials used to recruit students, which announced Mines was "Much More Than Its Name". The words were meant to convey that Mines was no longer just a school for minerals engineering. However, the picture of a woman wearing a hard hat and carrying a geologist pick made the message less clear, a sign that Mines was still getting use to its new reality. Eventually, the problem of mixed messages was resolved; by 1989 the image on the recruiting materials was definitely not minerals engineering, although the marketing experts were still struggling to find a tag line that described the new broader Mines adequately. That year, the tag line was "Much More Than You Imagine".

More diverse degree programs meant a more diverse faculty with expertise in new areas. One of the spin-off benefits was that this diversified expertise cross-fertilized with and energized Mines' traditional mineral engineering fields. Eventually, there were enough faculty with expertise in some areas for new groups to form. When these groups grew large enough, we can call it reaching critical mass, a positive feed back developed so that the group grew even larger and eventually programs developed. One of these was the group in bioengineering and life sciences. At Mines, we call this group BELS.

The growth of programs like bioengineering and life sciences (BELS) start with a group of faculty who conduct research and teach courses in their specialty – in this case related to BELS. Student interest then grew and the faculty responded with more courses and research in BELS, which increased the number of interested students. In response, the faculty working in BELS increased causing the number of students to increase even more, which led to still more faculty. Eventually, there were enough courses, students and faculty to organize a curriculum and programs in BELS.

You can see the development in BELS by looking at the increasing number of faculty working in the areas of bioscience and biotech over time. Since 1986, when it was decided to diversify degree options at Mines, the number of tenure-track faculty working in the area of bioscience and/or biotechnology grew from only one professor to approximately 10% of the faculty by 2009.[9] Over this time, the biomedical subset of this faculty has averaged a little less than half of this number.

In 2001 BELS was described in the Student Bulletin for the first time, although a curriculum was not yet established. In these early days of BELS, courses were developed within the existing departments. For example, the mathematical biology course was listed as a course in the mathematics department and the biology courses were listed as courses in the environmental sciences and engineering division. However, there were a few courses that didn't have a logical fit anywhere and this created some humorous situations. For example, who would have guessed that the math department course listed as number Math 498D in 2001 and 2002 was anatomy and physiology?[10] This odd arrangement occurred because the professor teaching anatomy and physiology was a member of the math department who taught mathematics courses when he wasn't teaching anatomy and physiology. He was also a medical doctor.

These problems of misplaced courses were resolved in 2003 when the BELS curriculum was made official and they could be assigned BELS course numbers. The momentum for "bio" continued. In 2007, the BS in Chemical and Biochemical Engineering became the first degree at Mines with "bio" in its name. That same year students were offered the option of completing a BS Chemistry degree with a biochemistry emphasis. Finally, in 2008 Mines started teaching biology laboratories. Before this, students who took biology had to take the required laboratories somewhere else, most often at nearby Red Rocks Community College.

The growth of the BELS faculty and program has also produced a related growth in BELS research. By 2009 approximately 15% of the research funding at the Mines campus could be identified as related to bioengineering and life sciences.[11]

To see how important bioengineering and life sciences has become to Mines, you need look no further than the Mines webpage, which asks prospective students if they "want to solve

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[9] Information provided by David Marr, Professor and Department Head, Chemical Engineering, which he developed for a NIH proposal submitted in 2009 (January 2011).

[10] Colorado School of Mines, *Schedule of Classes*, Spring 2001 and Spring 2002.

[11] David Marr (January 2011).

everyday problems that improve lives around a global community" such as those in six examples. Of these six examples, two are in the area of BELS.

To summarize this third story, in response to a decline in the price of oil and minerals, Mines transformed itself from a school of primarily minerals engineers to include bioengineers. In fact, Mines now considers bioengineering and life sciences as fundamental to its role and mission.[12]

Changing Times, Changing Mines. Three stories, each illustrating in different ways the actions of making a plan, seeking diversity and enjoying serendipity in response to changing times.

I want to take the opportunity provided by this lecture to publically acknowledge a few individuals who have played a significant part in my career success. First of all, throughout my career at Mines I have enjoyed great support from my department heads – Art Kidnay, Bob Baldwin and Jim Ely.

Those of you who know me, know the important role of my running partners, among them Dendy Sloan (from the Chemical Engineering Department), and Jim Brown and Reuben Collins (both from the Physics Department). They have been advisors, mentors, and counselors. Most of all they have provided a good ear and acted as sounding boards over many years and many, many miles. My current regular running partner, Reuben Collins deserves additional recognition for having to endure many discussions on the development of this lecture over the past many months and also for consenting to be the man of honor at my wedding a few years ago.

Special thanks to my husband (who is not the same husband who worked on the Colony oil shale project) for his love and support and especially his patience through the deadlines of many projects over the years. At least this deadline is nearly over.

I have had an active research program throughout my career, although I have described only a little of this research in this lecture. None of my research successes would have been possible without funding, and my many collaborators, students, and postdoctoral fellows.

Thanks to the several individuals who assisted in the preparation of this lecture by providing information or by helping me to find information. These include Jennie Kenney, Nasreen Sayed, Tricia Douthit-Paulson, Heather Boyd, and David Marr. Special thanks goes to Ethan Pearson, a student in chemical engineering, who counted faculty in 37 years of Student Bulletins.

Finally, to you. Thank you for coming.

[12] See description of the Bioengineering and Life Sciences (BELS) program in the Colorado School of Mines Undergraduate Bulletins. For example, page 149 of the 2010-2011 Undergraduate Bulletin, http://inside.mines.edu/Catalog (March 2011).