Fostering Innovative Skills within the Classroom: A Qualitative Analysis from Interviews with 60 Innovators

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1 Introduction

With a shared conviction that the future can be consciously shaped for the better, world economies have innovated over the years and they keep innovating. However, we cannot take our innovation capacities for granted. There is an overall agreement that now, more than ever, we need to develop ways of improving the capacity of individuals and organizations to innovate. This includes educating our students to create future generation innovators. In this paper, we explore the identification of classroom strategies that can foster innovative skills among our students. In particular, we focus on understanding how successful innovators perceive the role of these pedagogical interventions to enhance the innovation capacity of the students.

We derive our findings by analyzing data collected as a part of the Educate to Innovate project that was initiated to understand what factors contribute to the success of innovators, and how these factors can be incorporated into our education system. Charles Vest, the former president of the National Academy of Engineering (NAE), appointed an advisory committee for the project who provided guidance to this research team at the University of Illinois at Urbana-Champaign (UIUC) who would interview a select group of successful American innovators and ask them to reflect on their education and careers, and to identify factors that contributed to them becoming successful innovators. The results documenting the definitions of innovation, its differentiation from entrepreneurship, and the skills, experiences, and environments that contribute to successful innovators are documented in a recent publication by the National Academies of Engineering.\(^1\)

Although both (this and the above-mentioned NAE) papers used the same qualitative data, in this paper, we analyze the data and extract findings specific to classroom-level strategies that innovators mentioned repeatedly as contributors to their success or success of future innovators.

2 Related work

Below is a brief and non-exhaustive summary of research that attempts to understand innovation followed by a summary of the current educational efforts to train students in innovation.

2.1 Researching innovation

Understanding the impact of factors influencing innovation is an effective mechanism for understanding pedagogical interventions to educate students to innovate. The Educate to Innovate Project is based on this premise. According to a report from the National Science Foundation, academic research on innovation has largely been conducted within three disciplines: social psychology, cognitive psychology, and engineering education.\(^2\)

- Social psychologists have focused on understanding the impact of personal and contextual factors influencing innovation. For example, it has been shown even two decades ago that higher autonomy fosters innovation\(^3\), and that an innovator’s motivational focus influences her strategies and collaboration efforts\(^4\).
• Cognitive psychologists have focused on understanding how the human brain processes knowledge and different resources in order to innovate. Researchers have shown, for example, that novel solutions are rarely retrieved from memory, but rather by an analogy with a solution to a (distantly) related problem. Furthermore, designers can have much better success in analogical retrieval if they are able to capture the problem in the right representation format.

• Engineering educators have focused on understanding the innovation processes by studying teams and individuals participating in design activities. For example, it has been studied that sharing ideas of design concepts, i.e., getting inputs from team members, leads to unique concepts that are not generated individual.

Few researchers have surveyed a large number of inventors and innovative companies to understand innovation. For example, Walsh and Nagaoka have considered the question “Who invents?” by surveying about 1900 Japanese and American innovators identified from their patents. Arora, Cohen, and Walsh have recently conducted a survey of American companies to identify the sources of innovation (e.g., supplier, customer, internal lab, startups, etc.); they also study whether patents have played a role in the innovation.

2.2 Teaching innovation

University programs that teach innovation can be categorized as follows:

1. Courses in innovation: Some universities offer semester-long courses in innovation, i.e., innovation appears in the course title. Typically, these courses focus on informing and exposing students to activities such as exploring analogies and abstracting design patterns. For example, the University of Illinois at Urbana-Champaign offers a graduate-level special topics elective on Innovation in its regular Engineering program. The Program in Open Innovation at University of California, Berkeley offers undergraduate and graduate-level electives that range from teaching theories of innovation to providing project-driven experiences.

2. Certificate programs in innovation: Several universities offer a sequence of two to four courses leading to a certificate (not a degree) in innovation. Case Western Reserve University, for example, offers a certificate program in innovation and strategy, and Georgia Institute of Technology offers a graduate certificate program called “Technological Innovation: Generating Economic Results” (TI:GER).

3. Innovation “minor” in degree programs: Some degree programs at the graduate level enable students to receive a minor in innovation. Typically, such minors require a three-course sequence that may also include industry internships. For example, the engineering school at Dartmouth offers an innovation program that provides doctoral students with entrepreneurial training to turn discoveries into marketable applied technologies.

4. Degree programs in innovation: Few U.S. universities provide a formal degree in innovation. The University of Colorado at Colorado Springs offers a Bachelor of Innovation. It has an “innovation core” with a focus on multi-disciplinary long-term team activities. Outside the U.S., the University of Strasbourg in France offers a Master’s degree in innovation with a primary focus on teaching the theory of resolving problems of invention.
2.3 Research on improving student learning

Several research efforts have focused on individual ideas to improve education. For example, Smith et. al discuss best practices for implementation of co-operative learning and problem-based learning as a part of the effort to improve Science, Technology, Engineering, and Mathematics (STEM) education. Deslauriers et. al present the value in learning and engagement of methods that would require the students to practice physicist-like reasoning and problem solving during class time while provided with frequent feedback. These and several other such research publications discuss different approaches supported by rigorous data.

2.4 Summary of related work

While we firmly believe in the merits of the above-mentioned efforts, in this paper, we identify a group of themes relevant to class-room strategies to foster innovative mindset by tapping into a group of 60 successful American innovators and asking them to reflect on their education and careers and their perceptions on what would work and what would not. We believe that this approach yields significantly richer information that would be used for this research.

3 Methods

The data analyzed here is based on interviews conducted with 60 innovators over the course of seven months between April 2013 and October 2013. These data emerge from the broader study of innovation and education mentioned above. The research methods for the broader study included a workshop held on October 22-23, 2013, at the NAE Washington, D.C. The workshop brought together over 75 innovators and leaders from several fields to share insights on innovation and its education in focus-group style sessions. Although data collected from the workshop sessions enhanced interview reliability, which will be discussed in this section, this paper is based primarily on data collected during the interview-based portion on the project.

All procedures were approved by the Institutional Review Board for human subjects’ research at the University of Illinois at Urbana-Champaign.

3.1 Participants

3.1.1 Participant eligibility and recruitment

In selecting a sample, the advisory committee and the research team took into consideration participants’ public acceptance as innovators partly determined by the awards or recognition that the participants received, or their CTO/CEO positions in widely-recognized innovative companies. Participants were recruited through e-mail invitations sent to about 150 innovators.

3.1.2 Participant profile

60 U.S. innovators were interviewed. The innovators have distinguished themselves in diverse fields; they include professors, researchers, engineers, innovation authors, artists, entrepreneurs, venture capitalists, technical and business leaders of large businesses. The cohort of participants
have received a range of prestigious awards and elected memberships for their contributions. These include (a non-exhaustive list): Nobel Prize, NAE membership, AAAS fellowship, MacArthur Fellowship, Fast Company's Most Creative People in Business, IRI medal, National Medal of Technology and Innovation, Technology Review’s 35 under 35, TED prize, and various awards for innovation in education. For the complete list of the interviewees, the reader is referred to the NAE publication1.

Forty-nine (81.7 percent) of the interviewed innovators were male and 11 (18.3 percent) were female. The participants were concentrated in different areas of experience and work. Figure 2 shows the percentages of participants with experience in various sectors—academia, small business, large business, arts, federal organization—at some point in their career. Most of the interviewees (61.7 percent) had some experience working in a small business.

![Figure 1: Areas of experience across entire career (percent) of the interviewees. Most of the interviewees have experiences in multiple areas.](image)

3.2 Interviews

3.2.1 Interview procedure

The 60 innovators who agreed to be interviewed interacted with the interviewers by phone, through video, or in person. The interviewing team consisted of two researchers: one participated in all the interviews while the other participated only in the first half of the set of interviews.

Interview times varied from 30 to 90 minutes. Use of a semi-structured interview allowed participants to tell their stories at their own pace, in their own ways, and within their own time frames. Interviews were slightly adapted for each participant based on researchers’ knowledge about their background in an effort to obtain more participant-specific data, and to explore emerging themes from concurrent analysis. Interviews were audio-recorded, transcribed, and confirmed with interviewees for accuracy.

Before each interview, the interviewees were given a copy of the interview discussion guide, which was prefaced by a brief overview of the aims of the project and our interpretation of the term “innovation.” By sharing this information with participants, we expected to elicit views on the meaning of innovation and give participants the opportunity to reflect on their experiences prior to the interview. One interviewee chose to not read the interview questions in advance. The interview questions were designed to elicit participants’ experiences and perspectives regarding innovation and its education. Examples of interview questions include: 1) What are your thoughts about promoting or nurturing personal innovation? 2) Describe any experiences and environments.
that you feel may have influenced your innovative abilities. 3) While in college, what aspects of your non-classroom environment do you feel played a role in your innovative abilities? 4) What do you believe hinders innovative thinking in the education system? 5) If you were given the freedom to develop a course or a program that should focus on educating to innovate, what are the most important items you would consider?

3.2.2 Interview reliability

Interview participants provided subjective, first-person feedback regarding the accuracy of our interpretations during the interview. For instance, probes were used to elicit richer information and more consistent data from participants. Additionally, whenever two researchers were present for the interviews; both discussed and agreed on what was heard at the conclusion of the interview. The transcripts were confirmed with the interviewees for accuracy. Furthermore, every published quote has been verified by the interviewees who were also provided with a brief understanding of the context in which that quote would be used. Finally cross-referencing of interviews, and notes from the workshop focus group sessions strengthened the reliability of our findings, especially because 50% of the workshop participants were interviewees as well.

3.3 Analysis

We conducted a thematic analysis that involved multiple readings of the qualitative data to capture evolving patterns. Finalized transcripts were managed and analyzed in ATLAS.ti™, a qualitative data analysis program. During the first reading, coders read each interview transcript, identifying the general themes representative of the interview content. During the second reading, researchers coded the interviews using a predominantly inductive approach, out of which preliminary themes emerged. Finally, after reexamining and drawing connections among the broader themes, codes were thematically organized into their respective categories. After the main themes were identified, researchers returned to the data with an objective of refining connections. It is important to note that the content of the interviews represents not only the topics we discussed, but also how innovator chose to represent himself or herself across the set of interviews.

Team-based coding was used to promote consistency and facilitate project management. Two coders were assigned to each interview. The coders independently conducted sentence-by-sentence coding of the interview transcripts using the interview guide as an initial framework. When encountering a text segment that expressed a unique idea or meaning, coders manually marked that segment and assigned it a semantic code. Coders then compared their ideas and codes to determine if they arrived at similar data interpretations. During this open coding, researchers reached consensus about each code's meaning and definition, and also about a composite code list. Furthermore, the primary coding team iterated multiple times with the researcher who was present in all the 60 interviews. This approach of team-based coding increased the likelihood of capturing multiple semantic meanings within the data.
4 Findings: Classroom-level Strategies for Fostering Innovation

The following themes are specific to broad classroom-level strategies mentioned repeatedly as valuable to fostering an innovative mindset in students. These include: 1) Exposure to compelling challenges and real-world problems, 2) Enabling Experiential/Hands-on learning, 3) Changing students expectations about failure, 4) Exposure to collaboration 5) Teaching students to identify good ideas and articulate them, and 6) Teaching cases of innovation.

These themes convey salient and recurring points made by participants during the interviews. Interpreting these categories as a whole—understanding that the social context of events, thoughts, and actions are all important for interpretation—will yield the greatest understanding of the factors.

Note that in this paper, we have reused some of the quotes and corresponding contextual text from the NAE publication by the same authors,¹ but with the purpose of understanding classroom-strategies that can foster an innovative mindset in US.

4.1 Exposure to compelling challenges and real-world problems

It is important to look beyond the generally accepted purpose that students should be exposed to real-world problems and environments to prepare them well to participate in or transition to the industrial workforce. However, it is important to look beyond this purpose. Innovation requires passion, and passion is not usually about money; it is when innovators are working on real-world problems that they think matter. Thus, there is a strong “personal” growth element associated to exposing students to such challenges and problems. During the interviews, John Rogers, professor at the University of Illinois at Urbana-Champaign, reflected on his doctoral education, and felt “being able to do at least some fraction of your research that has an outcome that people care about, beyond your field of specialty, was an exciting thing.”

Accordingly, two important components of this strategy emerged during the discussions:

1. Finding ways of connecting the personal to the professional
2. Finding ways of making students solve open problems

Connecting the personal to the professional

We need to work on recognizing what might stir a person’s passion, because “it is … a good proxy for when they’re going to be at their innovative best” according to Dwayne Spradlin. This line of thinking can help educators understand more about how they could evoke the passion of the students.

Students should feel connected to problem-solving in general. We need to ask students to identify what they deeply care about, because, according to Beth Noveck, “we’re learning with students that, building off their interests and the things they care about, to then learn skills using that subject matter has a much more powerful effect than trying to force them to be interested in something else.”¹
In addition, there is an attitudinal shift especially in American students who are now thinking more about the philosophical aspects of their professional lives. From the perspective of religious scholar Varun Soni, the exploration of social problems is now inherently a personal endeavor for students. Therefore, inspiring students requires challenging them to think about the ultimate questions in their life—those based around meaning, purpose, and ultimately their own identity:

[Our students] are the first generation in American history to list “meaning and purpose” as one of the top things they want out of their careers. Their parents wanted security and stability; they want meaning and purpose. They want to connect the personal to the professional. They don’t just want to be doctors; they also want to do global health work. They don’t just want to be lawyers; they also want to do pro bono work. They want to do something for the social good because that’s where they find meaning and purpose in their own life [...] I think we can challenge our students to think about the big questions in their life, and juxtapose these big questions in their personal life with the grand challenges in the world. We need to expose them in their education to problems such that they can connect their personal to their personal.

Making students solve open problems

A common critique among innovators was that most of our education system sets students up for a predictable world wherein there are “right answers,” and in which the world functions rationally. However, most experiences in the “real-world” involve open-ended problems. According to Stuart Parkin IBM Fellow,

Schools pose a problem to which you know there is an answer, and the very fact that you know there is an answer changes the way you think about the problem. If you have a problem to which there is no known answer, you actually need to address that problem in a very different way.¹

An example of how solving problems classroom was provided by Nina Tandon, CEO and co-founder of EpiBone, who focuses on teaching students problem-solving beyond the traditional classroom experience. In one of her courses, she instructed students to create educational videos:

And so they were wondering, “How do we make educational videos?” I said, ‘you know what, I don’t know, and neither do you,’” “And not only that, but I’m going to bring in a couple critics from TED, and they’re going to judge you.” These students were in a total panic [...] but I thought this was a really great opportunity for them to just realize “this is the world. This is how the world works. No one knows how to do things, and we do it anyway, and you’re going to start now.”

Several innovators advocated for letting students discover problems for which they want to work. In contrast to the standard model of a capstone design program in engineering, wherein students are given a problem to solve, Tom Miller, the McPherson Family Distinguished Professor of Engineering Entrepreneurship and senior vice provost for Academic Outreach and Entrepreneurship at North Carolina State University, describes an alternative model he has used
What we’re giving the students is a blank sheet of paper. They have to go out and find a problem, figure out a problem, and we’ll help them with that ideation process, but what ends up happening is that they—and I’ve heard this from students, who have done dual majors and done both the traditional Capstone Design Project and an engineering entrepreneurs program Capstone Design Project—they learn so much more and they’re so much more engaged in the project because they have personal interest and ownership of it, and that seems to make a real difference.

The strategy of exposing students to compelling challenges and real-world problems is inextricably connected to experiential learning, as explored in the next section.

### 4.2 Experiential/Hands-on learning

Experiential/hands-on learning not only helps students learn how to refine and understand problems, but it also helps students understand how ideas are implemented. Many of those interviewed agreed that the craft of innovation is forged through experience. Sundu Brahmasandra, the president of NeuMoDx Molecular, explains that while some aspects of being innovative can be taught, “in the grand schemes of things, it has to be trial by fire.”

Along with various capstone projects, and incorporating experiments in classes, hands-on lab experiences and internships were repeatedly mentioned as being valuable. Hands-on lab experience are unique because they can be made available to students within the university. John Rogers from the University of Illinois at Urbana-Champaign uses it to provide his students with the relevant experience. He explains:

> I always tell my students you’ve got to be in the lab. You absolutely have to be in the lab. You can plan, you can do computer design and such, but until you get your hands dirty and really get a feel for what’s going on, you’re not going to have a good sense of what’s going to work and what’s not.

Several participants noted an increasing connectivity between industry and academia, the result of which was viewed by many innovators as good for the competitiveness of the nation and one that helps both students and industry. According to David Morse, CTO of Corning:

> Industry experience adds value for everybody. I think it’s a wonderful experience to get into an industrial lab and have an internship experience or in some way get broadened. Even if the person’s whole ambition is to be academic forever, it doesn’t hurt, and it’s not a very big time investment in terms of their overall time in college. I see tremendous learning from interns that we get here [at Corning] every summer.¹

While acknowledging the value of industry experiences to his own success, Rakesh Agrawal, from Purdue University, cautions against their over-valuation in experiential learning, because “involving industry in education is good, but really not as important as people often think, because you have to teach students self-learning and if they have it, then they will learn very quickly; it doesn’t matter what situation they go into.”¹ Accordingly, there is a need for
coordination between universities and industry on the nature of work students are exposed to. Ashifi Gogo, co-founder of Sproxil, articulates,

Industry’s involvement in a measured way could be useful. The concern I have is industry may come with a very refined problem that they’re seeking a solution to, and mapping that to a specific base of students who may or may not even want to work on that problem could be challenging.¹

4.3 Changing students’ expectations about failure

Acknowledging the value of the ability to manage risk and discouraging the fear of failure were accepted as significant challenges in academic, social, and professional environments. In the words of Bernard Meyerson, VP of innovation at IBM, “the biggest challenge [in educating to innovate] is getting people to buy into taking risk.”¹

A number of the interviewed innovators commented on the utility—and even the necessity—of failure, insisting that, in the words of Sundu Brahmasandra, “any environment that can teach that failure is not really a failure, failure is just an obstacle in some sense, is going to be very crucial,” adding that “we need to advocate that a failure should not usually be pinned on a person but on a process, or is a part of the process.”¹

It is important that students should not be punished for their creations (or their failure) nor blamed for it in schools and outside of it. Perhaps, providing examples of failure from the lives of successful innovators can be useful. For example, Bob Metcalfe, co-inventor of Ethernet and professor of innovation at University of Texas at Austin provided a personal example from outside of his school life:

The wooden raft I built for our summer house broke apart, and my father declared it a failure. He overruled my desire to repair it because he saw that it was a lost cause. [But] there was no punishment; just that it didn’t work out. It’s just something that didn’t work out, and so he cut it loose. It was his decision to abandon the project, and I went along, but I have long remembered that I wasn’t blamed for it.¹

However, it is important to ensure that there is not a blind acceptance of failure, which could lead to experimenting for the sake of experimenting. Regina Dugan, senior vice president of engineering at Google’s Advanced Technology and Projects group, feels that it is important to make students understand the distinction between encouraging failure and discouraging the fear of failure:

There’s a big difference between encouraging failure and discouraging fear of failure. The really big wins, from an innovation perspective, are often risky and uncertain. You can’t tell if you’re going to succeed or fail when you start. You have to build and be unafraid of failing on the other side. You don’t have to like failure, but in order to get the big win, you cannot fear it.¹
Overall, there were few concrete suggestions on how to achieve or implement this strategy in classroom education; the ideas were strongly biased toward behavioral adjustments and encouragement. In order to discourage the fear of failure among students, the educators themselves need to develop patience and tolerance to the failure of students.

4.4 Exposure to collaboration

Innovators emphasized that innovation is necessarily a collaborative effort. In the words of Richard K. Miller, president of Olin College of Engineering, learning to work in teams is fundamental:

I believe innovation is a team sport. It’s not something that’s done in isolation. If you look at Bell Labs, if you look at 3M, if you look at Google, if you look at Pixar, all of the companies that are really innovative, it’s a team sport, and the team’s made up of intentionally diverse backgrounds. You don’t have a department with mechanical engineers in it. At Pixar [for example], you have an artist, a cinematographer, a computer scientist, and a mechanical engineer. That’s your team. And so learning how to work in a team is huge. If you can’t do this in a team, it doesn’t matter how smart you are.¹

Experience working in interdisciplinary teams is crucial to the extent that Kalyan Handique considers it as the most valuable aspect of his doctoral education was “getting the interdisciplinary environment [in which I was forced to collaborate],” and that without it he probably would “have not gained much and would have been less value to industry.”

In addition to having coursework and projects that force students to collaborate, following interventions were mentioned as those that can help student get habituated to collaborating:

- **Explicit encouragement and training.** Yoram Bresler, co-founder and CTO of InstaRecon Inc., observed, “I think academic culture in some cases stifles collaboration, and in my case it wasn’t that it stifled it but it did not encourage it. I needed to be retrained opposite to my own inclination, because some people are inclined to be collaborators just naturally, and they’ll do it. Others need to be encouraged and trained.”¹

- **Provision of tools for collaboration.** Spaces should be designed knowing that collaboration depends on the exchange of ideas. Karen Kerr, Sr Managing Director at GE Ventures, described one approach: “I used to work with Krisztina “Z” Holly at the University of Southern California, and one of the things that she did in outfitting the space at the Stevens Center was she had a lot of the walls painted… not the chalk board, but writeable walls, so you could just write all over them in huge swaths of space—I had a whole wall in my office that I could write on as a white board. So that’s very useful, because then people can draw and they can think together.”¹

- **Theme-based departments:** One approach suggested by more than one innovator was theme-based rather than skills-based academic departments to encourage interdisciplinary education. As John Hennessy, president of Stanford University, put it:
Nearly all the buildings we’ve built in science and engineering side of the campus in the last 10 years have been not—none of them belong to a single department. They all mix disciplines, they mix fields. They’re thematic, like there’s an environment and energy building, there’s a nanosystems building, nanotechnology building. So we’ve tried to distinctly mix things up, because it’s just that place is important. And the other key thing I think we’ve done that’s been successful is for new activities where we’re trying to inspire and encourage cross-disciplinary work, we’ve actually had a venture fund that will fund faculty research projects, very short, you know, few-page proposal, and the key rule is that it has to include faculty from at least two different departments who’ve never collaborated before.

- **Physical spaces enabling informal discussions:** The value of physical spaces for informal discussions in fostering innovation was repeatedly mentioned by the innovators, who felt that the best innovative ideas seem to occur through informal discussions, sometimes over coffee. The strategic placement of labs, designating meeting areas to express ideas, or using a certain architectural design that promotes the exchange of ideas are a few ways in which collaboration can be fostered among students. Tim Cook, the CEO of Apple Inc. has suggested that educators should consider the physical and spatial aspects of the classroom to support collaboration. Deriving from his experience at Apple, he states:

  There has to be areas for people, without planning, to meet, like for us it’s our lobbies, where they essentially are like huge coffee shops. There’s a café and it’s great to eat there, people don’t run out for lunch. Then there is the quad area where people sit outside. And so it’s in areas like that where it’s a natural, unplanned, serendipitous sort of informal collaboration. And then, if you went into some of our most creative areas, you would find that people sit at a table and have lunch together and sit across from each other on benches, and it’s like your family used to sit at the dining room table. That’s how they discuss and decide things. And so I do think that office space, environment, culture—all of these things play heavily in this.\

Whatever the structure or organization, Nina Tandon, co-founder and CEO of EpiBone, cited four elements to keep in mind in designing physical space: ¹

- proximity to ensure that multidisciplinary people are close to each other;
- interdependence because unless people are interdependent they won’t collaborate;
- untidiness—an open area for freeform discussions and experimentations; and
- privacy, because most innovative thinking happens during private downtime.

### 4.5 Teaching students to identify good problems and articulate ideas

Determining what problems to pursue and articulating that idea is key to turning that idea into an innovation. However, innovators acknowledged that identifying a good problem is not a straightforward process. In the words of Robert Langer, professor at MIT: “I’m not sure that there’s a single answer to that [how to identify good problems/ideas], and I don’t know that there’s a simple way to say that a certain idea is absolutely a good idea. It’s kind of like beauty—a good idea is just like ‘beauty is in the eye of the beholder.’”
Even as they acknowledged that identifying and defining problems is not an exact science, interviewees provided important guidelines for doing so and suggested that these can be explained to the students:

- Spend a considerable amount of time coming up with, thinking about, and defining the problem.
- Follow your instinct/intuition.
- Choose problems based on their impact on humanity and identify where there is a need.
- Identify actionable problems—those that are practical and have solutions that can be executed.
- Target areas where there is less activity.
- Gather input from those the innovation is meant to help.
- Investigate failure and ask yourself, “Is there a path that will lead to success?”
- Identify interesting problems, ones that you feel passionate about.
- Know when to quit or change direction.

The ability to communicate one’s ideas in a clear and inspiring way is increasingly important in the growing global information economy, and is crucial for innovators, who are often engaged in team activity. It is crucial to help students convey the significance of their work to different audiences. In Karen Kerr’s view, “[It’s important to teach students] to communicate an idea that’s highly technical to a group that isn’t technical.” The corollary is awareness of others’ perspectives, a point made in a number of the interviews and succinctly stated by Robert Metcalfe that, in contrast to inventing, innovation “involves more people, it involves selling your ideas—and selling also requires the ability to listen!”

4.6 Teaching cases of innovation

Several innovators agreed that presenting students with case studies of successful innovation and the history of science in general can serve as both informative and inspirational. By detailing the lives of scientists from case studies, the innovation process becomes humanized and students begin to see innovation as possible. Students can understand the innovation process even further if given the chance to interact with innovators face-to-face. This can be done by hosting innovators as guest lecturers or organizing internships for students. Bob Metcalfe colorfully illustrated the point:

You get two things from role models [from cases of innovation]. One is you discover they’re just like you, or worse! Then you really know—“God, if this idiot could invent something, I’m sure I can!” And then role models show you the steps, like you build something, you write a paper, you study the literature to be sure you’re not duplicating effort, you stand on the shoulders of giants, you look at things from different angles, you combine expertise in a multidisciplinary way, blah, blah, blah,… and if you just do that every day, then you start innovating.

A number of innovators recommended teaching “history” as a part of courses or even as a new course emphasizing the need to “connect” to the human in the innovator. According to Michael Frenkel from the National Institute of Standards and Technology,
You could design a course which you would call ‘The History of Innovation in Engineering,’ and during this course illustrate successes in developing new technology and making them broad-based innovations. And in doing that you could also illustrate the examples of real lives of the people who have been involved, because very often knowledge is being communicated without any connection to the very people who developed it, and that makes it very inhuman. I believe if people have examples of success, they will be in a better position to be successful themselves.

At the same time, innovators cautioned against focusing on successes of innovations and not on the failures that lay the foundation of a successful innovation. Talking about failures can be instructive and even inspiring. As Bernard Meyerson, IBM’s VP for innovation, put it, “The hardest thing is to kill a program, and the ones we failed to kill are the ones that almost killed us, and so it is extremely valuable to tell people those failure stories. There’s a lot of lessons learned.”

Mark Randall, Adobe’s VP of Creativity, often lectures at universities and says:

[When I lecture at universities] I start out by saying “I'm not going to tell you how I succeeded, because frankly I don’t know. I can pretend that I know, but I’m just retrofitting success backward onto things; most books written about successful companies are just retrofitting based on what happened, but what I can do is tell you how to fail better, because that I know a lot about.” And then I just talk all about my failures, and a lot of people are like “Wow, we finished 90 minutes with Mark, and he never talked about, you know, these big innovations.” You don’t learn much from those! Those are the random things that happen because you tried so much, and you were able to try so much because you were good at failing.

5 Conclusion

Based on interviews of 60 successful US innovators, this paper presents the exploratory descriptive study that will become the basis for a more systematic analysis of classroom-level strategies for fostering innovation, each of which consist of several key concepts. For example, the research team is working on a more detailed publication on the theme of exposure to collaboration. The findings in this work are summarized as follows:

- **Exposure to Compelling Challenges and Real-world Problems**
  - Help students discover what they care about
  - Work on problems for which there are no known answers
  - Modify existing courses such that students can work on problems they care about

- **Experiential/Hands-on Learning**
  - Actively encourage students to hands-on work
  - Ensure that students get appropriate industry experiences – in class and through internships
• Improve coordination between industry and academia to define mutually beneficial approaches

• **Changing Students Expectations about Failure**
  o Discourage the fear of failure
  o Explain that failure is a part of the process
  o Pose failure as an opportunity to learn

• **Exposure to Collaboration**
  o Design physical environments that foster collaboration
  o Explicitly encourage train students to collaborate
  o Provide opportunities for students to interact in informal settings

• **Teaching Students to identify good problems and articulate ideas**
  o Explain that identifying a good problem is not an exact science
  o Provide important guidelines for identifying good problems
  o Emphasize the value of and teach the articulation of ideas

• **Teaching Cases of Innovation**
  o Teach history so that students connect to the human in the innovator
  o Ensure that failure cases are presented
  o Help students with identifying and studying role models

Our findings reflect many ideas that the engineering education community has had some level of familiarity with and interest in over the years. This study reinforces the importance of these factors and captures our understanding. Furthermore, our study has contributed to this understanding of class-room strategies for fostering innovation through a never-before done large-scale, interview-based analysis of inputs from highly successful innovators.

It should be noted that there is a constant interplay among the various themes discussed in this paper. Interpreting these categories as a whole—understanding that the social context of events, thoughts, and actions are all important for interpretation—will yield the greatest understanding of the overall strategies to be put in place. This means that we cannot have a one-size-fits-all approach to educating to innovate. Finally, it should be noted that these are major themes observed in the interviews and do not form an exhaustive list of class-room strategies. In general, we emphasize that it is only through the environments that we can create opportunities for experiences, and skills that contribute to successful innovation are gained from these experiences.

6 **Acknowledgments**

The authors gratefully acknowledge financial support provided by the Division of Research on Learning in Formal and Informal Settings (DRL), Directorate of Education and Human Resources, National Science Foundation through Grant #1241823. They also acknowledge financial support from the Edward William and Jane Marr Gutgsell Professorship at the University of Illinois at Urbana-Champaign.
The authors thank all the interviewed innovators and the participants of the October 2013 workshop for their time, effort, and insights.

Finally, the authors thank members of the NAE Advisory Committee, the project staff of the NAE, and the project staff at the Applied Technologies for Learning in the Arts and Sciences (ATLAS), University of Illinois at Urbana-Champaign for their valuable contributions to the project.

7 Bibliography