# Educational Institution Strategies to Increase U.S. Innovation

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## Abstract

In a paper titled, "Global Trends in Patenting," also presented at this conference, the authors cited data indicating the United States' leadership position in the issuance of patents is being threatened. They also cited references stating that patents are an indication of a country's innovativeness and that innovation leads to technological development. This paper addresses educational institution strategies to increase U.S. innovation. Specifically, it explores creativity and innovation as essential characteristics of engineers and scientists. It also investigates approaches to instill these characteristics in college and university students. Finally, it addresses the shortage of science and engineering graduates. A national agenda to promote, implement, evaluate, and improve efforts to recruit and prepare students to be inventive scientists and engineers will increase U.S. innovativeness and patent output.

## Introduction to Creativity, Innovation, and Critical Thinking

Creativity brings into existence an idea that is new, and innovation is the practical application of creative ideals [1]. All people have some level of creative ability, particularity at a young age, and that creative level can be greatly enhanced throughout life with continual education, knowledge development, and practice [2]. Engineering and scientific creativity, as well as innovation, require specific knowledge in mathematics; design and engineering theories and principles; problem-solving principles; and logical (critical) thinking. This type of knowledge can be taught within the educational system. To fully develop one's creative and innovative abilities requires educators to develop curricula that promote the creative, innovative, and critical thinking skill sets.

If the United States is to lead the world in the research and development of high-technology products, services, and industries, the workforce must possess the ability to solve problems and to make creative decisions. Evans [2] stated, "Problem solving and decision making in today's global social and business environments have become complex tasks. The


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uncertainty of the future, the nature of the completion, and the nature of social interaction increase the difficulty of managerial decision making. Because knowledge and technology are changing rapidly, new problems with little or no precedents continually arise. Thus, one cannot rely on existing methods and approaches to solve such problems. Truly creative approaches are becoming a necessity." Educational programs in engineering and technology are challenged with the task of preparing their students for tasks and jobs that may not currently exist; therefore, they must develop curricula that will educate students to be successful without knowing the specific job requirements. If the student's creative, innovative, and critical thinking abilities are enhanced to a high level, chances are the student can become a successful problem-solver and inventor in his/her technical career. "Students of innovation at the beginning of the 21st century are likely to conceive of this critical activity rather differently than did scholars some 30 years ago. At that time, innovation was seen as essentially synonymous with the linear progression that was thought to characterize research and development. Today, we are apt to recognize that successful innovators—whether individuals, teams, or companies—are engaged in a sequence that is highly variable and interactive rather than linear" [3].

Engineers, inventors, technologists, and scientists of the future need a greater ability to think critically. Therefore, educators need to understand how to teach this skill effectively. To think critically, students require the following:

- A high degree of knowledge in the discipline or area
- An attitude of questioning and suspended judgment
- Some application of the methods of logical analysis or scientific inquiry
- The taking of action in light of the analysis, reasoning, and outcomes [4]

Additionally, the principle of shared learning or cooperative learning must be put forward. In this process, the students are taught to work in teams or units and to assist and encourage each other in the mastery of required knowledge and skills. Effective interpersonal and social skills are necessary for collective groups to develop harmony and to achieve high levels of success. Ruggiero [5] stated, "Much of our education was built on the idea that thinking can't be taught or that some subjects teach it automatically. Modern research has revealed the error of both ideas. Thinking can be taught—not to just gifted students but to all students. No course teaches thinking automatically, but any course can teach it when the teachers make thinking skills a direct objective." Students must also be knowledgeable of world cultures and the impact culture plays on the creative and innovative processes from nation to nation.

Successful global companies of the 21st century and beyond will continue to use creativity, innovation, and critical thinking as major tools in their competitive advantage toolbox. Therefore, it is imperative that the educational process of today and the future places more emphasis on the development and enhancement of these skills in students. The United States is losing market share in the high-technology industries and will continue to do so if it does not place more emphasis on inventor-type skills in engineering, technology, and scientific disciplines.

## Challenge to Higher Education in the United States

The previous sections established the terminology for and need to teach creativity, innovation, and critical thinking skills in higher education in the United States. This section presents approaches for incorporating the teaching of these skills into college and university curricula. The approaches may require the need for higher education institutions to partner more effectively with K–12 educational institutions and industry. It may also require higher education institutions, as well as state and federal governments, to place a renewed emphasis on education of students through quality teaching, instructors, and partnerships reflected through increased resources for this purpose.

Amabile [6] presented three components of creativity: expertise, motivation, and creative-thinking skills. Expertise is a person's knowledge and ability in his or her work [6]. Teaching expertise is a traditional strength of higher education institutions. Motivating students is not, in general, a focus of higher education institutions. Students are motivated by different things. One way to determine students' motivations is to administer personality tests. Individualized and/or team assignments can help specifically address each student's motivation. However, team assignments may be more beneficial for instructor time requirements and student learning. As mentioned previously, the principle of shared learning or cooperative learning must be put forward to address creativity, innovation, and critical thinking skills development. In this process, the students are taught to work in teams or units and to assist and encourage each other in the mastery of required knowledge and skills. Effective interpersonal and social skills are necessary for collective groups to develop harmony and to achieve high levels of success. The third component of creativity, creative-thinking skills, determines how flexibly and imaginatively students approach problems [6]. This also is not, in general, a teaching focus of higher education institutions. This is probably best taught toward the end of a course when students have most, if not all, of the tools they need to discover solutions to problems. This is where industry can play a role. Industry representatives can present problems for the students to solve using tools learned in the course. This can be accomplished individually, but working in teams may be more beneficial.

As previously mentioned, innovation is the practical application of creative ideals [1]. Peters [7] developed a circle of innovation that includes the following elements:

- Distance is dead.
- Destruction is cool.
- You cannot live without an eraser.
- We are all Michelangelos.
- Welcome to the white-collar revolution.
- All value comes from the professional services.
- The intermediary is doomed.
- The system is the solution.
- Create waves of lust.
- Tommy Hilfiger knows.
- Become a connoisseur of talent.
- It is a woman's world.
- Little things are the only things.

- Love all, serve all.
- We are here to live life out loud.

The creative descriptions for these elements are typical of Peters' [7] writing style. However, he explained in detail his meaning behind them [7]. According to Peters [7], if people and organizations study and practice these elements, the ability to proceed from creativity to innovativeness will increase. It is possible to incorporate at least some of these elements into higher education curricula. Peters' [7] interesting approach in presenting them contains information that can be used to do this. Some interesting quotes from Peters [7] regarding innovation and design follow:

- "The only sustainable competitive advantage comes from out-innovating the competition" (p. 29).
- "Wealth in the new regime flows directly from innovation, not optimization; that is, wealth is not gained by perfecting the known, but by imperfectly seizing the unknown" (p. 29).
- "Fifteen years ago, companies competed on price. Today it's quality. Tomorrow it's design" (p. 429).

Another approach to help students discover innovation is through empathic design. Its foundation is observation—watching consumers use products and services in their own environment. Its five-step process is observation, capturing data, reflection and analysis, brainstorming for solutions, and developing prototypes of possible solutions [8]. These can certainly be taught in higher education curricula, especially if industry is involved.

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The requirement of a high degree of knowledge in the discipline or area is the same as the expertise component of creativity from Amabile [6]. Again, higher education institutions do well with this requirement. To develop an attitude of questioning and suspended judgment, instructors can apply the team concept of brainstorming to the classroom. Brainstorming is an open, energetic, and positive exchange and discussion of ideas. Once the brainstorming session is complete, student knowledge and expertise can be employed to pare down the ideas to those believed to have the highest chance of success and meet resource requirements. This will also involve elements of the third requirement to think critically, which is some application of the methods of logical analysis or scientific inquiry. These are more general, subject-independent skills that will require institute-wide initiatives to ensure they are employed in as many courses as possible. The fourth and final requirement to think critically is also one that higher education institutions currently address. The traditional teaching process is to present content, work examples, and assign problems for the students to work. Students working problems constitutes this final part. Problems requiring knowledge from larger portions of a course and having industry participation can only help with the development of the fourth requirement to think critically. Industry will be able to provide less structured and more open-ended problems for the students.

**Shortage of U.S. Science and Engineering Graduates**

A national agenda to promote, implement, evaluate, and improve efforts to prepare students to be inventive scientists and engineers would have shortcomings if it did not address the growing shortage of U.S. science and engineering graduates. U.S. innovativeness and patent output will increase if efforts to recruit and prepare students to study science, technology, engineering, and mathematics (STEM) disciplines are included in the agenda.

As the 21st century begins, the demand for an abundant, diverse, and talented STEM workforce remains strong. Continued growth in national productivity requires a continuous supply of professionals who are highly competent in the STEM disciplines and who are adaptable to the needs of a rapidly changing profession. While overall employment in STEM disciplines is expected to increase during the 2000–2010 period, STEM degrees over the same time period are expected to remain stable. The number of 18–24 year olds will grow by three million by 2010; and African Americans, American Indians, and Hispanics will make up almost 60 percent of the population increase over that time period. The consensus among leaders in the STEM community is that the necessary increase in the STEM labor supply will come about only through the development of a more diverse workforce [9].

DeReamer and Safai [10] also stated that employment opportunities in the United States requiring STEM expertise are growing rapidly. From 2000–2010, growth is expected to increase about three times faster than the rate for all other occupations. However, the available domestic STEM labor supply has not and will not be able to satisfy this growth because of the long-term trend of fewer students entering STEM programs in college, thus threatening the ability of U.S. businesses to compete in the global marketplace. The situation is so dire that the National Science Board has stated that the federal government and its agencies must step forward to ensure the adequacy of the U.S. STEM workforce, and that all stakeholders must mobilize and initiate efforts that increase the number of U.S. citizens pursuing STEM studies and careers.

May and Chubin [11] mentioned that the STEM workforce, despite years of efforts to diversify it, remains overwhelmingly white, male, and able-bodied, and the available pool of talented women, minorities, and persons with disabilities remains significantly under-utilized. If individuals from these underrepresented groups were represented in the STEM workforce at the same percentage as their representation in the total workforce population, the shortage in the STEM labor supply would largely be filled. Also, currently underrepresented groups are projected to increase from about a quarter of the workforce to nearly half by 2050. This suggests that the United States must cultivate the STEM talents of all of its citizens, not just those from groups that have traditionally worked in STEM fields.

The fact that women and minorities are underrepresented in the STEM labor force has led to the formulation of the following questions:

- What are the psychological mediators of both gender and ethnic group differences in entry into and persistence in the STEM labor force?
- What are the family and school forces that underlie the gender and ethnic group differences in these psychological mediators?
- How do experiences in tertiary educational settings and in STEM work settings influence gender and ethnic group differences in entrance to and persistence in the STEM labor force? [12]

Many efforts have been established to answer these questions and to increase the percentage of underrepresented populations in the STEM workforce. These efforts have included special college and university freshman courses and programs, summer and after-school programs for high school students, and the integration of STEM applications into high school curricula. One proven technique is from George and Burden [13]. These authors described a Youngstown State University effort to improve the mathematics skills of freshmen entering their technology program. One part of this effort was the development of a freshman-level course titled Technical Skills Development. The approach in this course was to teach the necessary skills according to the precepts of contextual learning. Groundwork was laid on orienting students to engineering as a problem solving activity, algebraic equation and unit manipulation, composite shape usage, engineering graphic techniques, hypothesis formulation and testing, and the entire engineering lab writing process. The second part of this approach involved students taking an elementary algebra course simultaneously with the Technical Skills Development course. In the elementary algebra course, a mandatory lab component was instituted, a supplemental computer and drill assessment was introduced, off-hour Web site tutoring was offered, and mathematics based simulations were used. Analyses showed a statistically significant improvement in the pass rate of high risk students.

Lam, et al. [14] described a part of the University of Akron's approach to improve its STEM graduation rate where, during the academic year, students attended a series of career workshops at local manufacturing companies and research facilities. These activities were designed to inform students about the STEM professions. They also included one-on-one discussions between the engineers and the students.

Gilmer [15] described a Bowling Green State University effort where, starting their first academic year, students were awarded a four-year academic scholarship of $1,500 that increased annually by $500 increments if they remained in good standing. This meant a student remained in a STEM major and showed academic success by achieving certain GPA levels after the first three years of college. Gilmer [15] stated that participating students exhibited pride in earning annual incremental increases and tended to work harder and smarter to ensure that they received the increases.

Popular and successful efforts to introduce STEM topics to high schools include the Infinity Project [16] and Project Lead the Way [17]. The Infinity Project is a national award-winning high school and early college math- and science-based engineering and technology education initiative that helps educators deliver a maximum of engineering exposure with a minimum of training, expense, and time. It is a software-based curriculum that includes a state-of-the-art curriculum; an easy-to-use, yet powerful classroom technology kit; and best-in-class professional development and teacher support for science, mathematics, and technology teachers [16]. Project Lead the Way's equipment-enhanced curriculum makes mathematics and science relevant for students. By engaging in hands-on, real-world projects, students understand how the skills they are learning in the classroom can be applied in everyday life [17].

## Conclusions

Efforts to recruit and prepare students to study STEM disciplines must continue. Recently, organizations have started to address innovation. Marquette University's College of Engineering will offer a graduate certificate in engineering innovation starting in the fall 2008 semester. Lehigh University's engineering and applied science magazine, *Resolve*, recently focused on innovation as it relates to research in Lehigh's P.C. Rossin College of Engineering and Applied Science [18]. The American Society for Engineering Education's (ASEE) 2008 Annual Conference and Exposition had exhibitors whose presentations focused on their innovations.

Progress is being made to promote, implement, evaluate, and improve efforts to recruit and prepare students to be inventive scientists and engineers. A more organized and fully-resourced national agenda to do this will be more effective in increasing U.S. innovativeness and patent output.

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