Academic – Industry Partnership to Develop Tomorrow's Engineering Innovators

Carol S. Gattis, Ph.D.
Associate Dean Emeritus, Honors College
Adjunct Associate Professor, Industrial Engineering
University of Arkansas
Fayetteville, AR 72701, USA
csg@uark.edu

Karl D. Schubert, Ph.D., FIET
Research Professor, College of Engineering
Director of Research for Innovation and Data Science Initiatives for the College of Engineering and the Sam M. Walton College of Business
University of Arkansas
Fayetteville, AR 72701
schubert@uark.edu

Michele Cleary
Evaluation and Reporting Consultant
Cleary Scientific Intelligence, LLC
Minneapolis, MN 55410
michele@clearymedintel.com

Abstract

Innovation in the United States (US) has begun to lag behind other developed nations, jeopardizing the nation's economic health and political influence. While federal agencies and policymakers focus efforts on spurring innovation through business-centered initiatives, universities play a prominent role in spurring innovation long-term by developing the next generation of innovative engineers.

The University of Arkansas' College of Engineering (COE) is addressing this challenge by infusing innovation principles and processes into its curriculum by creating new courses and adapting existing ones. These courses will equip COE students with the skills and experiences to become engineering innovators. Entrepreneurs and industry sponsors are partnering with COE to provide real-world innovation experiences, which will ultimately help fulfill employer demand for engineering graduates with highly marketable innovation skills.

This paper provides an overview of the relevant literature used to design and develop COE's Innovation Initiative: 1) the First-year Innovation Experience, a two-semester freshman engineering innovation sequence focused on innovation; 2) Industrial Engineering Senior Design/Capstone Experience, an adaptation of a two-semester IE course sequence through which student teams implement complex innovation projects. Finally, this paper reviews the critical role industry plays in course development and how it can continue to refine engineering innovation instruction.

Keywords
Innovation, curriculum, industry, engineering, interdisciplinary

1. Introduction

The United States (US) is falling behind other countries in innovation which is a critical problem for the nation's health, economy and political influence (Estrin 2018). The situation is serious enough that the US National Science Foundation has set stimulating innovation as one of its three strategic goals (NSF 2014). The College of Engineering (COE) at the University of Arkansas (UA) is developing new curriculum and connections with industry to help their undergraduate students develop the skills needed to become engineering innovators. This paper describes the COE's two-pronged Innovative Initiative for engineering students – the first focusing on first-year students and the second focused on students in their final year of industrial engineering.

2. Background

There are many indications that the US is losing ground as a global leader in scientific and technological innovation. The 2018 Bloomberg Innovation Index dropped the US from its Top 10 ranking for the first time since the list's inception six years ago. This change was attributed in part to a shortage of college STEM graduates in the US (Jamrisko and Lu 2018). In addition, the US ranked last of 40 countries in the Information Technology and Innovation Foundation's report for improvement in innovation and competitiveness, while also ranking at the bottom in year-to-year improvement in innovation and competitiveness (Atkinson and Mayo 2010). Clearly, the US needs to train more STEM students to become STEM innovators to improve global competitiveness (Harrington and Voehl 2016).

What is innovation?

Innovation implies a marketable solution to something that society needs or wants. Literature in this area suggests that effective innovation is the product of both individual-level and organizational-level attributes. Infusing innovation concepts into engineering curriculum is not straightforward. While providing engineering students with the practical expertise (e.g., engineering content knowledge, product development, fundraising processes) may be a relatively clear process, teaching these students how to think creatively like an innovator is far more complicated (Keck and Cottingham 2016).

How can innovation be developed in students?

The literature on teaching innovation to engineering students highlights the contributions of Kazerounian and Estrin.

In identifying processes to develop young innovators, Kazerounian identified ten maxims to build creative thought in engineering students (Kazerounian and Foley 2007): 1) keep an open mind; 2) ambiguity is good; 3) iterative process that includes idea incubation; 4) reward for creativity; 5) lead by example (other innovators in the field); 6) learn to fail (avoid harsh discipline for mistakes); 7) encourage risk; 8) search for multiple answers (brainstorming); 9) internal motivation (engagement); 10) ownership of learning. While these maxims are a great target, how these maxims are best applied continues to evolve within the scientific community (Kober 2015).

Estrin further clarified innovation by identifying five core values that individuals and organizations must adopt to cultivate a thriving innovation ecosystem (Estrin 2008): 1) curiosity and a natural ability to question the status quo; 2) risk-taking and willingness to learn from failure; 3) openness across divisions, teams, etc.; 4) patience in giving ideas a chance to grow; and 5) trust, supporting the four other values. Innovative cultures have been characterized by "high levels of dynamism, support for new ideas, trust, availability of time to discuss fresh suggestions, and risk-taking", where people behave "more creatively when the environment contributes to increasing their intrinsic motivation, interest, enjoyment, satisfaction, and challenge of the work itself (Amabile et al. 1996)."

The education literature also adds some insight into developing innovative thought in students. While open-ended problems, teams, and interdisciplinary input have all been shown to improve student creativity (Howes et al. 2013), past studies have also shown that student creativity is greatly enhanced with a more risk-accepting educational environment (e.g., when design failures are not penalized heavily) (Freidman and Forster 2005), (Freidman and Forster 2001), (Crowe and Higgins 1997), (Stemberg and Williams 1996), (Von Oech 1990), (Wilde 1993), (Thousand et al 1994), (Dennard 2000), (Eisenberger and Rhoades 2001).

A failure-tolerant environment may also have the added benefit of enhancing student engagement and ownership, which could help increase the number of desperately needed engineering graduates. Other creative problem-solving methodologies used in engineering education include individual creativity blockers (Cropley and Cropley 2000), and team approaches (Fila et al. 2014).

How have other institutions facilitated innovation skills in students?

Multiple universities have initiated innovation instruction for their engineering students; for example:

Louisiana State University developed a program whereby engineering students utilized both critical and creative thinking skills simultaneously while designing a product or solving an open-ended problem (Cornwell et al. 1993). Other initiatives include incorporating open-ended problems via the Walla process and problem-based learning (Chang et al. 2000), (Stouffer et al. 2004). Finally, team dynamics have been incorporated into creative thinking by utilizing collaborative problem-solving (CPS) - a critical skill in innovation as it forces students to consider multiple perspectives and balance varied interpretations and solutions (Garvin and Roberto 2001), (Zou 2015). Given the importance of interdisciplinary input for successful innovation, such team approaches can be highly beneficial.

The *Olin College* Paradigm for Educating Engineering Innovators used a similar multidisciplinary approach towards engineering education. In addition to using problem-based learning, the Olin program emphasized social needs and human factors in engineering design, as well as business and management practices. This program has become highly popular at Olin, where roughly 25% of its graduates participate in entrepreneurial enterprises (Olin College of Engineering 2010).

One serendipitous benefit of interdisciplinary innovation programs is that they may act to diversify engineering further; prior studies have shown that women are attracted to interdisciplinary STEM work (Rhoten and Pfirman 2007), (Elfman 2007). Other researchers have hypothesized that interdisciplinary work may also hold significant appeal to underrepresented minority students, as well (National Academies of Sciences, Engineering and Medicine 2016).

3. A New Home for Innovation: The University of Arkansas

Few US states have a greater need for STEM innovators than the largely rural state of Arkansas (Aghion et al. 2016). Bloomberg's 2016 US Innovation Index ranked Arkansas 48th in the nation (Jamrisko and Lu 2018), while the Consumer Technology Association placed Arkansas in its lowest innovation category due to "small tech workforces, low numbers of STEM graduates, and slow or declining entrepreneurial activity (Consumer Technology Association 2017)." Despite steady growth in STEM enrollment at the University of Arkansas (UA) (Office of Institutional Research 2018), Arkansas' STEM-related growth lags due to the lack of an innovation culture or ecosystem, as evidenced by the state's slow integration of knowledge-based companies, its minimal patent activity, and its limited ability to attract STEM investment (Jamrisko and Lu 2018), (Consumer Technology Association 2017).

All innovation initiatives discussed in this paper below were developed within the College of Engineering at the University of Arkansas.

The University of Arkansas (UA) is Arkansas's flagship university, granting bachelor's, master's, and doctoral degrees in approximately 200 different academic programs. Established in 1871 as a land-grant university, the UA is a comprehensive Research-1 university carrying the highest possible classification by the Carnegie Foundation (RU/VH for the Advancement of Teaching), one of just 108 schools to carry this distinction. UA enrolls roughly 29,000 undergraduates and graduate students.

UA's *College of Engineering* (COE) enrolls approximately 3,500 undergraduates and 900 graduate students, awarding undergraduate degrees are awarded in 8 ABET-accredited engineering fields (biomedical, biological, computer, chemical, civil, electrical, industrial, and mechanical) and computer science.

Approximately 29% of engineering undergraduate students participate in the UA Honors College which provides an enhanced educational experience that challenges high-achieving students with a more in-depth academic experience, including honors courses, undergraduate research experiences with world-renown faculty and grant funding for study abroad or research.

4. The COE Innovation Initiatives

The UA COE is addressing the need for innovative engineering graduates through its two-pronged COE Innovation Initiative. The first prong focuses on first-year COE students, offering them new first-year engineering courses embedded with literature-informed innovation content, as well as innovation exercises. The second prong of the COE Innovation Initiative focuses on senior year students, uniting them with industry partners to confront real-world engineering challenges.

4.1 Initiative I: First-Year Innovation Experience

All COE students begin their COE degree programs by taking a two-semester freshman engineering sequence: Introduction to Engineering I and II. For the Innovation Initiative, COE collaborated with the UA Honors College to adapt these courses for innovation instruction. These courses, embedded with literature-informed innovation material, became known as the Honors Innovation Experience I and II. Innovation-minded students can elect to take these Honors Innovation courses in place of Introduction to Engineering I and II. Characteristics of these courses are outlined below.

Honors Innovation I Course

To launch their innovation studies, Innovation I leads students on an exploration of innovation topics, using seminars and discussions with industry professionals who are experts in innovation and entrepreneurship. Students then apply these concepts to an innovation project. Recent projects have focused on topic such as: idea generation, product life cycle, perceived user value, business/product strategy, product costs and marketing channels, intellectual property, introduction to product development, and lean start-ups. Each topic includes relevant readings, expert seminars, assignments, then participation in discussion.

All Innovation I students are also assigned a project challenge to help them apply the innovation concepts learned. While all Innovation I students are assigned the same project idea, each student works independently, applying innovation concepts as they are presented during class. By the end of the first half of the semester, the students should know the market for their improved product, the minimum viable product, the perceived user-value for their innovative improvements, the cost, the competition, the overall viability, the manufacturing processes, and distribution paths. Faculty mentor students on the processes, while faculty with subject matter expertise mentor students on their specific topic. This guided path through innovative improvements of an existing project is a means of providing one approach to the process. Not all future projects will follow this approach, but it covers most elements the students will need.

A recent Innovation I project challenge was to make innovative improvements to an existing product familiar to all students - a backpack. Throughout the semester, students received assignments related to recent seminar topics, applying those principles and techniques to developing innovative improvement(s) to the backpack. For example, students interviewed potential customers to better understand consumer needs, determining the perceived user-value of innovative improvements versus other options available. During the second half of the semester, students put together a plan to evaluate project revision ideas, write a project description paper, and deliver a project description presentation.

In preparation for Innovation II, all Innovation I students propose original project ideas for their next semester's work. In fall 2018, 49 students submitted over 220 project ideas. These submitted project ideas were rated on each project's innovativeness and feasibility for implementation during a semester. Once project idea rating was completed, the list of rated ideas (unattributed) is given back to the students, allowing each team to choose one of the rated project ideas as their Innovation Experience II semester project.

Honors Innovation II Course

> The second semester in Innovation Experience II, students take the information they learned during the first semester and implement. They review their proposal, make revisions after new feedback, and revise their plan. They take their project through validating the idea, validating the market, performing a cost analysis, designing, and determining the minimum viable product and the perceived user value. Teams build their prototype or proof of concept, test and redesign. Along the way, students present their work, receive feedback and do iterative improvements. The semester finishes with submission of a project paper, a symposium poster, and give a presentation based on their analysis, results, retrospective, and future recommendations. The process is mentored by the course faculty, but each team is also mentored by an industry professional and/or faculty member with a subject matter expertise.
>
> Not every team's project is successful. Some students may not make it to the prototype or proof of concept stage, or their project may fail in the testing phase. If this is the case, students are tasked with identifying why it failed and what they would do differently. The sooner the team identifies that the idea has failed, the better, as some teams pivot mid-semester to start another project, even though they may not have time to make it to the end of the cycle. Learning that a project can fail is extremely important when the situation arises. In industry, determining that a project will not work early can save millions of dollars and often somebody's career.

There are many benefits to the students from the Innovation I and II experience. Students learn how to work in interdisciplinary and multi-college teams, learning to work with different types of people whose communication skills and areas of expertise are different. They learn how to look at things differently, figure out what they can and cannot do, learn that they are innovative, and find the innovation in being innovative. Students get to interact with and learn from innovation faculty and industry experts throughout the year early in their academic career.

Each year, the popularity of Innovation I and II has increased, going from 19 students in fall 2016 to 49 students in fall 2018. While enrollment in Innovation I and II was limited to only COE students during its first two years, the course was opened to College of Business students beginning in Year 3, allowing for interdisciplinary teamwork.

Partnerships with industry professionals are critical for teaching innovation, and in helping universities develop the talent needed for engineering innovators. In Innovation I and II, the majority of presenters are innovation experts from industry, industry professionals serve as subject matter consultants and mentors, and they also serve as symposium judges. Involved are professionals from startups to midsized to major corporations, with the people themselves senior leaders who are involved and lead innovation.

4.2 Initiative II: Engineering Senior Design/Capstone Experience

Initiative II focuses on COE seniors - students on the cusp of beginning their engineering careers. The Engineering Senior Design/Capstone Experience provides authentic industry experiences.

Industrial Engineering (IE) Senior Design is a two-semester project and in the most recent academic year, one IE project was an innovation project, whereby a team of 5 industrial engineering students (two of whom are honors students) work on a real-world problem presented by an industry partner – in this case, a large national logistics company. While many capstone projects ask students to refine solutions previously tackled by the sponsor (in other words, students provide refinements to a current solution), seniors partaking in the innovation project tackle problems that the industry sponsor has not solved and is often unsure how to approach.

For the innovation project, the team is tasked with a common yet loosely defined project - develop a way to increase company profits by 1% through innovation. This project requires that students thoroughly understand the customer profitability life cycle. Often, an industry sponsor wants to understand customer behavior, how customer retention is impacted by issues, such as pricing or sales representatives. They may want to better understand financial incentives, what the likelihood customers may change to a different vendor, or from one product to another, or whatever else the student team can envision. These industry sponsors also commonly want to understand how the data they currently retain can be utilized in other analyses. Or what additional data they should be collecting. Since the sponsor has not started work on addressing this project, the questions are seemingly endless with innovation a significant part of this open-ended very large project.

This two-semester project provides a wide, open-ended problem where students must study, define, determine what is important, and innovate solutions for the company. Although it is much more difficult than the traditional project mentioned earlier, it provides the students with much more growth opportunities, the need and opportunity to innovate, and to be more prepared to meet the need of their future employer. Students and mentors typically sign non-disclosure agreements. Author Schubert serves as faculty advisor for the team. More specifics include:

Semester I

In the first semester of the senior design course, the innovation student team must determine what is important to focus on and figure out potential models – it is a semester of discovery. The team meets with the company expert regularly with weekly or biweekly calls to exchange information on what they are working on and questions they have. By the end of this first semester, the student team will have an initial determination of which combination of areas are important factors on which to focus, what data is available and what additional data is needed. The team summarizes its findings in a written paper and orally presents findings to the industry sponsor, faculty and other students, addressing lessons learned and plans for ongoing work during the next semester to create a model from which they will make recommendations for the industry partner to meet their objective.

Semester II

In the second senior design semester, the students must utilize their innovation skills to identify a superior solution that is not just a point solution, but a means to understanding types of customers and a path for the company to reach their goal of increasing profits by 1%. Throughout the semester, they continue to interact with the industry sponsor. They receive additional data needed and refine the data, they create a series of sensitivity analyses, identify what was important, create a lifecycle model for different types of customers and provide a guiding model for how the company can attract the right customers and move customers along the right path to improve profit. The semester ends with a written report, a symposium presentation and poster session, plus a presentation and report to the company.

5. Conclusions

The US desperately needs innovative STEM talent to sustain the country's position as a global leader in science and technology. Universities can help meet the call for engineering innovators by providing engineering students with instructional innovation experiences. The literature review provided the theoretical background other institutions can use in developing their own innovation initiatives. The summary of the two-pronged Innovation Initiative illustrates how industry collaboration on real-world problems can help the nation develop engineering innovators.

Programs like COE's Innovation Initiative can present a symbiotic opportunity for students and industry. Industry can engage students on projects – projects that address hard, open-ended, unresolved issues and needs. Companies can commit an employee to interface with a class or a student team to answer questions or serve as project mentors, often benefitting both the student and the company. With Skype, the company and mentors can participate, even if they are beyond driving distance to the university. Interested industry professionals are invited to contact the authors for more information or to investigate becoming a partner with the UA COE Innovation Initiative program.

6. Future plans

The authors continue to work with COE faculty to infuse innovation topics into current courses, to develop new innovation courses, and to provide innovation projects. A sophomore innovation course is currently being developed. The COE is investigating the idea of an innovation curriculum track where students engage in innovation curriculum spanning first-year to senior year. The courses may be existing courses adapted to include innovation topics or projects, or they may be newly developed courses on innovation. The COE is furthering partnerships with companies to provide expertise, funding and projects, and to provide internships that will create innovation experiences for engineering students. This will provide companies some value while helping to provide engineering students with the innovation skills they need to meet the future needs of the company.

References

Aghion, P., Akcigit, U., Bergeaud, A., Blundell, R., and Hemous, D., Innovation and Top Income Inequality, 2016. https://scholar.harvard.edu/files/aghion/files/innovation_and_top_income_inequality.pdf

Amabile, T., Conti, R., Coon, H., Lazenby, J., and Herron, M., Assessing the work environment for creativity. *Academy of Management Journal*, 39:1154-84, 1996.

Atkinson R., Mayo M., Refueling the U.S. Innovation Economy: Fresh Approaches to Science, Technology, Engineering and Mathematics (STEM) Education, Washington, DC: *The Information Technology and Innovation Foundation (ITIF)*, p. 35, 2010. [E-book] Available: https://itif.org/publications/2010/12/07/refueling-us-innovation-economy-fresh-approaches-stem-education

Chang, P., Hsiau, S., Yeh, T., and Wu, J., The Development and Implementation of the Technological Creativity Course: An Interdisciplinary Approach, 2000 International Conference of Engineering Education, *ICEE 2000 Conference Proceedings*, Taipei, Taiwan, 2000.

Consumer Technology Association, *2017 Innovation Scorecard*, Arlington, VA: The Consumer Technology Association, p11, 2017. [E-book] Available: https://www.cta.tech/cta/media/policyImages/policyPDFs/2017-Innovation-Scorecard_FINAL_web_20160629.pdf

Conwell, J., Catalano, G., and Beard, J., A Case Study in Creative Problem Solving in Engineering Design, *Journal of Engineering Education*, 824:18-24, 1993.

Cropley, D., Cropley, A., Fostering Creativity in Engineering Undergraduates, *High Ability Studies*, *Journal of the European Council for High Ability*, 112:207-219, 2000.

Crowe, C., Higgins, E., Regulatory Focus and Strategic Inclination: Promotion and Prevention in Decision Making, *Journal of Organizational Behavior and Human Decision Processes*, 69: 117–132, 1997.

Dennard, R., Creativity in the 2000s and beyond—Motivation and Leadership Remain Essential for Nurturing Creativity and Providing an Environment in Which It can Flourish, *Research Technology Management*, 436:23–25, 2000.

Eisenberger, R., Rhoades, L., Incremental Effects of Reward on Creativity, *Journal of Personality and Social Psychology*, 814:728–741, 2001.

Elfman, L., Can Interdisciplinarity Attract More Women and Minorities to Academia? *Diverse: Issues in Higher Education*, 2007. http://diverseeducation.com/article/10232

Estrin, J., *Closing the Innovation Gap: Reigniting the Spark of Creativity in a Global Economy*, McGraw-Hill, 2008.

Estrin, J., Innovation: Crucial to Our Future, *Huffington Post,* October 4, 2018.

Fila, N., Purzer, S., and Rami, C., Cultures of Innovation Among Chemical, Civil and Mechanical Engineering Students: A Qualitative Study, *2014 IEEE Frontiers in Education Conference (FIE),* October 22-25, 2014, pp. 1-7, 2014.

Franklin W. Olin College of Engineering, About Olin: Overview, 2010, accessed: February 11, 2018. www.olin.edu/about_olin/overview.aspx

Friedman, R., Forster, J., Effects of Motivational Cues on Perceptual Asymmetry: Implications for Creativity and Analytical Problem Solving, *Journal of Personality and Social Psychology*, 882:263–275, 2005.

Friedman, R., Forster, J., The Effects of Promotion and Prevention Cues on Creativity, *Journal of Personality and Social Psychology*, 816:1001–1013, 2001.

Friedman, R., Ronald, S., and Forster, J., Implications for Creativity and Analytical Problem Solving, *Journal of Personality and Social Psychology*, 882:263–275, 2005.

Garvin, D., Roberto, M., What you don't know about making decisions, *Harvard Business Review*, 79:108-116, 2001.

Harrington H., Voehl F., eds., *The Innovation Tools Handbook, Volume 1: Organizational and Operational*, 2016. https://books.google.com/books?id=8e4bDAAAQBAJ&printsec=frontcover#v=onepage&q&f=false.

Howes, A., Kaneva, D., Swanson, D., and Williams, J., Re-envisioning STEM education: curriculum, assessment and integrated, interdisciplinary studies, *Vision for C&A Royal Society Report,* The University of Manchester, August 2013, p. 56, 2013. https://royalsociety.org/~/media/education/policy/vision/reports/ev-2-vision-research-report-20140624.pdf, accessed January 31, 2018.

Jamrisko, M., Lu, W., Benchmark: Here are the Most Innovative States in America in 2016, *2018 Bloomberg L.P.*, 2018. https://www.bloomberg.com/news/articles/2016-12-22/here-are-the-most-innovative-states-in-america-in-2016

Jamrisko, M., Lu, W., The U.S. Drops Out of the Top 10 in Innovation Ranking, *Bloomberg Technology*, January 23, 2018. https://www.bloomberg.com/news/articles/2018-01-22/south-korea-tops-global-innovation-ranking-again-as-u-s-falls , accessed January 31, 2018.

Kazerounian, K., Foley S., Barriers to Creativity in Engineering Education: A Study of Instructors and Students Perceptions, *Journal of Mechanical Design*, 129:761-768, 2007.

Keck, D., Cottingham, I., Using Innovation as a Catalyst for Integrating Business and Engineering Education, *IEEE Frontiers in Education Conference (FIE)*, pp. 1-7, Oct 12-15, 2016.

Kober N., Reaching Students: What Research Says About Effective Instruction in Undergraduate Science and Engineering, *Board on Science Education, Division of Behavioral and Social Sciences and Education*, Washington, DC: The National Academies Press, 2015.

National Academies of Sciences, Engineering, and Medicine, *Barriers and Opportunities for 2-Year and 4-Year STEM Degrees: Systemic Change to Support Diverse Student Pathways*, Washington, DC: The National Academies Press, p. 90, 2016. [E-book] Available: https://www.nap.edu/catalog/21739/barriers-and-opportunities-for-2-year-and-4-year-stem-degrees

National Science Foundation, *Investing in Science, Engineering, and Education for the Nation's future: Strategic Plan for 2014-2018*, 2014. https://www.nsf.gov/pubs/2014/nsf14043/nsf14043.pdf, accessed: February 11, 2018.

Office of Institutional Research, Enrollment Reports, University of Arkansas, Fayetteville, AR, 2018. https://oir.uark.edu/students/enrollment-reports.php

Rhoten, D., Pfirman, S., Women in Interdisciplinary Science: Exploring Preferences and Consequences, *Research Policy*, 36(1):56–75, 2007.

Sternberg, R., Williams, W., *How to Develop Student Creativity,* Association for Supervision and Curriculum Development, Alexandria, VA: Association for Supervision and Curriculum Development, 1996.

Stouffer, W., Russel, J., Oliva, M., Making the Strange Familiar: Creativity and the Future of Engineering Education, *Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition*, American Society for Engineering Education, Salt Lake City, UT, 2004.

Thousand, J., Villa, R., and Nevin, A., *Creativity and Collaborative Learning: A Practical Guide to Empowering Students and Teachers,* Baltimore: P.H. Brookes, 1994.

Von Oech, R., *A Whack on the Side of the Head: How You Can Be More Creative*, Rev. ed. New York, NY: Warner Books, p. 196, 1990.

Wilde, D., Changes Among ASEE Creativity Workshop Participants, *Journal of Engineering Education*, 823:167–170, 1993.

Zou, T., Mickleborough, N., Promoting collaborative problem-solving skills in a course on engineering grand challenges, *Innovations in Education and Teaching International*, 52(2)148-159, 2015.

Biographies

Carol S. Gattis is the Associate Dean Emeritus of the Honors College and an adjunct Associate Professor of Industrial Engineering at the University of Arkansas (UA). She earned her B.S., M.S. and Ph.D. in Electrical Engineering from the UA. Her research focuses on STEM education and program development. Her most recent NSF grants were awarded for development of programs to help close the STEM labor gap, to increase the number of students who complete a B.S. and M.S. in engineering with the experience to tackle real-life problems in industry, and to develop recruitment and retention techniques to graduate a larger and more diverse engineering workforce. Her engineering teaching interests include engineering economics and operations research. Her Honors College interests included working with faculty to create innovative curricula for embedding international experiences and undergraduate research into curriculum. Dr. Gattis also serves as a consultant specializing in new program development.

Karl D. Schubert is a Research Professor and Director of Research for Innovation and Data Science Initiatives for the University of Arkansas (UA) College of Engineering and College of Business. He earned a B.S. in Chemical Engineering from the UA, an M.S. in Chemical Engineering from the University of Kentucky, and a Ph.D. in Engineering from the UA. His research includes innovation, technology, data science and interdisciplinary project-based active learning methodologies. Karl held senior-level corporate roles that included CIO, CTO, and Global SVP of Engineering and Development. He has strong experience in interdisciplinary innovation and technology, data science and lifecycle management, operations, global business, through enterprise, midrange, small companies and start-ups. Dr. Schubert has authored two books and been awarded nine patents. He is an elected charter member of the Arkansas Academy of Chemical Engineers and an elected Fellow of the Institute of Engineering & Technology.

Michele Cleary is the President of Cleary Scientific Intelligence, LLC. Her firm provides program evaluation consulting and composition expertise, supporting scientific clients from proposal development, to project assessment, to final manuscript development. She writes widely for academia and industry with a focus on health economics and life science concerns. She is currently the features writer for the International Society of Pharmacoeconomics and Outcomes Research. A graduate of Macalester College, Ms. Cleary did her doctoral work at the University of Minnesota's Institute for Health Services Research.