Critical Thinking in STEM Through Liberal Arts Paradigms: Transference of Skills

Nathan K. Mitchell
Division of Social Sciences
Prairie View A&M University

Abburi Anil Kumar
Department of Electrical and Computer Engineering
Prairie View A&M University

Abstract

This paper addresses the well-known need for critical thinking in the sciences and engineering. In some areas, standard engineering pedagogy serves students well, in others, this is not the case. Our thesis is that a solid foundation or training in the liberal arts helps students to better deal with the complexities of modern life and build critical thinking skills that could be transferred to solving engineering problems. The basic tenet is, when addressing an issue in engineering, say in judging which design is more human friendly or human safety, there is a potential for a conflict, which might be better understood in the framework of a liberal arts paradigm. This paper demonstrates how various methodologies used to teach critical thinking in the liberal arts could be adapted for engineering and science education. We suggest using "global thinking" routines and other reflective practices, common in the liberal arts, will help students to improve learning and critical thinking skills. Such a "bridging of two cultures" a la C.P. Snow demonstrates the effectiveness of liberal arts in STEM disciplines.[1a]

Introduction

Developing critical thinking skills among college students is often touted as a primary goal of higher education. Educational advocacy groups, accrediting bodies, employer groups, and higher education commissions have identified critical thinking as an essential skill for an informed and "career ready" person.[1,2,3,4] Despite intense interest, there is not an agreed-upon definition of critical thinking which has made it difficult for academics to respond. Paul, Elder, and Bartel found in a study of 38 public institutions and 28 private institutions that 89% of faculty thought critical thinking was important, but only 19% could identify an operational definition for critical thinking.[5] To get a better handle on how to measure and assess critical thinking, the American Association of Colleges and Universities (AAC&U) has identified critical thinking as "habit (s) of mind characterized by the comprehensive exploration of issues, ideas, artifacts, and events before accepting or formulating an opinion or conclusion" as a part of its *Valid Assessment of Learning in Undergraduate Education Initiative*.[1] Being able to evaluate evidence and use that evidence to make decisions or solve problems seems to be the common thread that connects the expectations of academics and other stakeholders. According to Claris and Riley, engineering education does a good job of promoting these skills-based elements of critical thinking - solving problems, thinking logically, and conducting, but does not do well in getting students to think critically about engineering itself.[7] In an engineering environment, critical thinking is the intellectually disciplined process of actively and skillfully conceptualizing, applying, analyzing, synthesizing, and/or evaluating information gathered from, or generated by, observation, experience, reflection, reasoning, or communication, as a guide to belief and action.[8] Questions relating to engineering's impact on social, political, cultural, and economic systems are not often addressed in standard engineering curricula. This paper demonstrates how various pedagogies in the liberal arts like the "global thinking" routines developed by Boix Mansilla could be adapted for engineering and science education and could address these deficiencies.[7]

Liberal Arts are Needed in STEM

There are numerous articles in the popular and academic press that highlight Big Tech's desire to employ individuals with humanities and social science backgrounds. Writing in an opinion piece for CNBC, Ravi Kumar, the president of Infosys states, "By investing in liberal arts graduates, we gain people with human-centered skills who can approach problems in entirely new ways, contributing to out-of-the-box thinking in a digital age".[9] It is estimated that 3.5 million workers will be needed to fill STEM jobs by 2025.[10] Kumar suggests that some those trained in liberal arts can help fill the vacancies because they have "human-centered skills who can approach problems in entirely new ways".[8] Jeffery Selingo's seminal work, *There is Life After College*, identifies these individuals as "T-shaped".[11] They have deep knowledge in their field but can operate in many different contexts and can learn and grow.

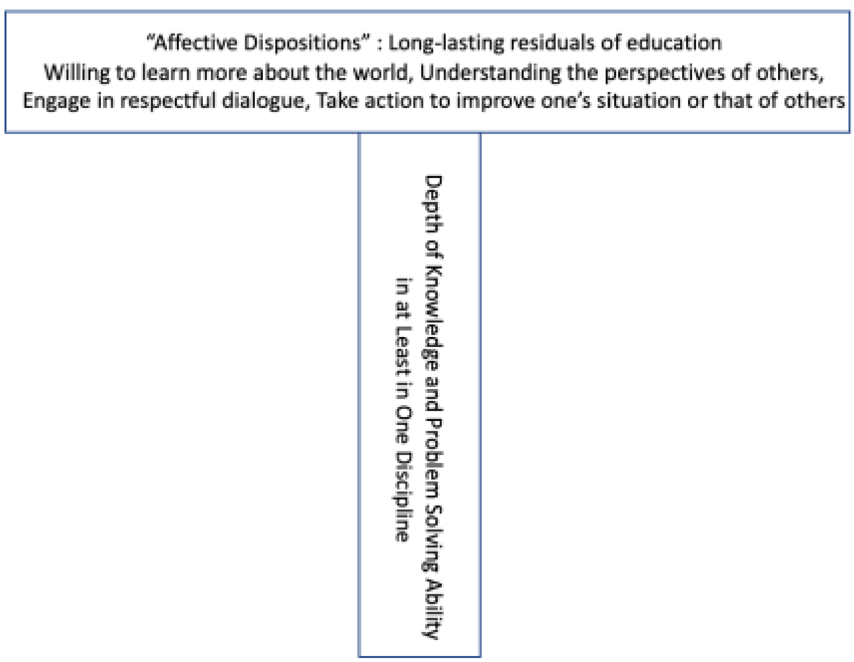

Figure 1 – T-Shaped Competencies

The heart of Claris and Riley's critique of engineering education is that there is not enough of a focus on developing these "T-shaped" individuals.[6] While focusing on developing skills is important, Claris and Riley argue that engineering educators must also address “the affective dispositions” of their students. Affective dispositions are long-lasting residuals of education, like being willing to learn more about the world, understand the perspectives of others, engage in respectful dialogue, and take action to improve one’s situation or that of others.[7] Traditionally, these dispositions and attitudes are developed in the core curriculum or liberal arts component of an undergraduate engineering degree program. Claris and Riley, and others suggest a greater need to incorporate such thinking into the upper-level content areas of the degree.[6] Engineers need to be able to solve complex problems, but they need to also be able to evaluate the why, how, and impact of solving those problems. Asking the “big” questions must continue past one’s experiences in the core curriculum.

Global Thinking Routines

The affective critical thinking dispositions identified by Claris and Riley are developed over time.[12,13] Boix Mansilla has proposed micro-teaching tools called “global thinking routines” (GTR).[7] These simple tools can be used across content areas, frequently, and over a course of an entire degree program to train students to ask deeper questions about their own motivations, incorporate the perspectives of stakeholders, engage with diversity, assess the impact of decisions, and take action. Instructors weave GTR throughout their courses and curricula and make it routine to ask big questions, reflect on the process, and critically evaluate the impact of decisions. A culture of critical inquiry can be developed within the class or program because reflection becomes commonplace. Table 1 below highlights some GTRs commonly used in liberal arts and humanities.

Table 1: Commonly Used Global Thinking Routines (GTRs)

Affective Disposition/ Attitude	**Explanation of GTR Process**
Motivation for Inquiry	*The Three Y’s* • Why might this [topic, question] matter to me? • Why might it matter to people around me [family, friends, city, nation]? • Why might it matter to the world?
Perspective Taking	*Step-in Step-out Step-back* • Identify a person or agent in the situation you are examining • Step In: Given what you see and know at this time, what do you think this person might feel, believe, know, or experience? • Step out: What else would you like or need to learn to understand this person’s perspective better? • Step back: Given your exploration of this perspective so far, what do you notice about your own perspective and what it takes to take somebody else’s?
Engaging with Diversity	*How Else and Why?* • What I want to say is … (The student makes a statement). • How else can I say this? And why? • How else can I say this? And why?
Assessing Impacts or Taking Actions	*Circles of Action: What Can I do to Contribute?* • In my inner circle?

	• In my local community? • Beyond my community?
Adapted from Veronica Boix Mansilla's "How to be a Global Thinker" in Educational Leadership.[7]	

The GTRs highlighted above are formatted as reflection questions that can be integrated into engineering assignments or adapted as needed to get students to think more deeply about what they are designing, implementing, or building. In the liberal arts, faculty often ask students to identify a topic for a project and then reflect on why this topic is important to them personally or the field using the 3Y's. Students can connect their own motivations for studying something to the course material. These questions can be adapted to engineering education. In courses with difficult-to-understand material, instructors can ask students to connect conceptual tools to problems they care about or to larger course questions. Students perform better when their motivations are peeked. At the design stage, students can ask what motivates them to solve a particular engineering problem and to think about why a new technology or idea is important. Why was a particular technology developed? Why was it important for the developer or designer? Why was it important to their community? Understanding motivates can help students think about later impacts and who may or may have been left out of the design process.

The *Step-in, Step-out, Step-back* GTR can be used to help students understand diverse perspectives and learn from them. The modern workplace is made of teams. Graduates need to be able to engage in appropriate interactions with those that they may not agree with or fully understand. Solutions to technological, health or social concerns need to be developed from teams with diverse perspectives, or suboptimal outcomes can occur. We can help students explore these consequences through various case studies. In recent news, Microsoft, IBM, and Amazon put a moratorium on selling their software to the FBI or other law enforcement agencies until their quality improved.[14] As Najibi explains in a review of new technology trends, facial recognition software does not do a great job of classifying people of color, particularly black women.[15] Usually, cost-benefit calculations are used when deciding to deploy a certain technology, but who determines the cost? In our courses, we could ask students to explore what would have happened if more diverse perspectives were in the room. It is often remarked that because women and people are color are underrepresented in the tech field, these technologies were underdeveloped and causing problems for women and people of color in the "real" world. A better question might be asked of our students if we should have developed this technology at all?

The *What Else and Why*? GTR challenges students to ask questions related to appropriate communication. As applied to engineering education, faculty members might ask students to think about the best way to communicate a finding to different cultural audiences, stakeholders with diverse backgrounds, or clients with differing abilities. Students need to "slow down" their communication to be deliberate with their word choice and phrasing the make the most effective impact.[7] It is important to develop and practice these critical "soft skills" in a classroom setting, so they can perform at high levels in the workplace. As with the other GTRs, integrating these evaluative questions throughout an academic program makes them automatic and a part of a student's normal communicative practice.

Asking students to consider the *Circles of Action* GTR focuses their attention on the actions that they could take to reasonably address a problem or concern in their organizations, local communities, national community or the world. This type of thinking encourages students to consider small personal actions, as well as larger organizational or public policy actions. To implement this GTR, Boix Mansilla suggests that students visually map out potential strategies or opportunities for addressing a problem.[16] The questions posed in the GTR then encourage students to think how a strategy may change if implemented more narrowly in an organization or more broadly for a community. In engineering education, this GTR could be used during the early design phases to encourage students to think through a scope of a problem or the quality control phase of a project to get students to think about how to address negative impacts.

A good case study for this type of GTR would be the problems discovered by the invention of Blue LEDs: The Nobel Prize in Physics in 2014 was awarded for the invention of Blue Light-Emitting Diodes (LEDs). While this invention led to innovations in lighting in various environments, including street lighting, it also led to problems for older people whose retinas could absorb only about 50% of what a much younger retina could absorb.[17] The rest goes into glare, making it dangerous for driving for everyone. Interestingly enough, around the same time the blue LED was being developed, research papers on the topic of the connection between light and the body were being published in widely read journals such as *Science* and *Nature*. The culture of research, however, does not incentivize looking beyond one's own discipline. This state of affairs is partly because the structure and culture of academia do not encourage an understanding between fields. Since the problems with this technology have now been identified, engineering students can map out potential solutions or impacts. Instead of focusing on a narrow view of a specific innovation, the students could map out potential impacts on individuals, organizations, or other communities. Students can then think about the types of actions they could take to address these problems.

Summary and Conclusions

The pressure to provide undergraduates with marketable skills is very high, but the need to create critical thinkers who ask big questions and reflect on their practice as engineers is essential. This note described common global thinking routines used in liberal arts and their potential applications in engineering education. These tools help students to develop long-lasting critical thinking dispositions over time and can be used in a variety of curricula. These routines are well used in the academy. James Madison University is a comprehensive research university with a heavy science, technology, and engineering focus and has adopted thinking routines to help encourage ethical reasoning in its curriculum and co-curriculum. The program was so successful that the university administration has bought into the process and tries to use the reflection questions to guide decision-making. Their *Eight Key Questions* program focuses on eight simple questions that help students make good decisions.[18] Critical thinking in engineering and the sciences is not just about solving complex problems but thinking about engineering itself, the impact of technological innovations, and who is involved in the creation of new ideas.

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NATHAN K. MITCHELL
Dr. Mitchell currently serves as a Professor of Political Science and Director of the B-GLOBAL Quality Enhancement Plan. He received his Ph.D. in Political Science from Texas Tech University. His research interests focus on the scholarship of teaching and learning, program assessment, and state and local politics and policy. His recent work has addressed topics relating to the integration of open educational resources into core curriculum courses, removing barriers to learning like food and housing insecurity, and chronicling how minority serving institutions responded to the COVID-19 pandemic. Recently, he was awarded the TAMU System Chancellor's Medallion for Diversity, Equity, and Inclusion for demonstrating "high levels of meaningful engagement in activities that promote a culture of diversity, equity, and inclusion." He is currently working on a manuscript of best practices in "globalizing" general studies curricula.

A. ANIL KUMAR
Dr. Kumar obtained his Ph.D. in Physics from the Indian Institute of Science, Bangalore, India. After working on various research projects on device modeling and communication theory aspects, he focused on what he recognized as proper preparation in STEM disciplines at the middle and high school levels. Imperative for better college-level performance. He worked with multiple school districts on state and national standards, relevance of science in the global economy, and expanding opportunities for students, teachers, and faculty in STEM disciplines. For over five years, he directed Project XLR8 (ACCELERATE), a high school redesign project, funded by the Thurgood Marshall College Fund, with support from the Bill and Melinda Gates Foundation. He is currently working on a monograph on redesigning education. For his work in public education and his achievements in research, he was one of five faculty members in the TAMU System to have received the Distinguished Achievement Award from the Board of Regents, a recipient of the Thurgood Marshall College Fund's Outstanding Achievement Award for School Reform and the Harmony Public Schools Public Servant Award. He, along with two colleagues from Mathematics, is finalizing a book of Higher Mathematics for Science and Engineering. His current interests include researching the future of higher education and learning in the age of reengineered humanity.