CRITICAL THINKING AND ENGINEERING EDUCATION

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Abstract *– This paper is on the cultivation of critical thinking in undergraduate engineering education. The quality of our thinking determines the quality of what we design, produce, or build as engineers. As is the case for many professionals, graduates of engineering schools need strong critical thinking skills in a world of rapid change and greater complexity. Critical thinking is essential to get to the root of problems and to develop reasonable solutions. Engineers need to continually improve and learn throughout their professional lives. Our goal is to help undergraduate engineering students perceive the usefulness of critical thinking and grasp the principles of critical thinking. The anticipated educational benefits for engineering students are improved thinking skills and increased ability in identifying and comprehending a problem, determining the key parameters in a problem, making meaningful connections, and developing higher quality solutions. Assessment aspects of this project are also discussed.*

INTRODUCTION

What is critical thinking? It is possible to find many definitions of critical thinking [1]-[2] such as the examples below.

"An active, purposeful, organized cognitive process we use to carefully examine our thinking and the thinking of others, in order to clarify and improve our understanding." [3]

"Critical thinking is simply the careful, deliberate determination of whether we should accept, reject, or suspend judgement about a claim - and of the degree of confidence with which we accept or reject it. The ability to think critically is vitally important; in fact, our lives depend on it. The way we conduct our lives depends on what we believe - on what claims we accept. The more carefully we evaluate a claim and the more fully we separate issues that are relevant to it from those that are not, the more critical is our thinking." [4]

"Critical thinking is the use of those cognitive skills or strategies that increase the probability of a desirable outcome." [5]

According to Paul and Erder [6], "...critical thinkers are clear as to the purpose at hand and question at issue. They question information, conclusions, and points of view. They strive to be clear, accurate, precise, and relevant. They seek to think beneath the surface, to be logical, and fair... Critical thinking is that mode of thinking – about any subject, content or problem – in which the thinker improves the quality of his or her thinking by skillfully taking charge of the structures inherent in thinking and imposing intellectual standards upon them... A well-cultivated critical thinker raises vital questions and problems, formulating them clearly and precisely; gathers and assesses relevant information, comes to well-reasoned conclusions and solutions, testing them against relevant criteria and standards; thinks open-mindedly, recognizing and assessing assumptions, implications, and practical consequences; and communicates effectively with others in figuring out solutions to complex problems... It entails effective problem-solving and communication abilities..."

As Facione stated [7], critical thinking goes beyond the classroom. According to Facione, core critical thinking skills are interpretation, analysis, inference, explanation, evaluation, and self-regulation. He addresses the approaches to life that characterize critical thinking and states that good critical thinkers approach specific problems, questions, and issues with clarity, orderliness, diligence, reasonableness, care, persistence, and precision.

If supervised properly, Wheeler and McDonald report that writing allows students to develop and use critical thinking skills [8]. They provide classroom examples, address practical issues, and explain how writing enhances active learning.

There are critical thinking appraisal tests, such as certain ACT tests and Watson-Glaser Test [9]. It seems that it is not possible to measure critical thinking but it is possible to assess it. In addition, there are institutions and universities that can serve as resources in the subject of critical thinking (e.g., [10], [11]). They are very useful to gain valuable insight and gather information. Longview Community College maintains a website [10] that has a wealth of information with many useful links. Faculty members interested in critical thinking should also be aware that the National Science Foundation Chautauqua Short Course Program offers short courses on enhancing and promoting critical thinking.

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As is the case for many professionals, graduates of engineering education need strong critical thinking skills in a fast-changing world of increasing complexity. Critical thinking skills can be applied in professional and personal life, and are especially important to engineering education and engineers in solving problems, and designing products, systems, or processes.

GOALS, ANTICIPATED BENEFITS, AND ASSESSMENT

Most of our students are willing to work hard and like making things. As engineering educators, we can build on these qualities. Keeping our students in a listening or responsive mode is not educationally sound. An appropriate general goal for engineering educators would be to encourage our students to continually improve and keep learning throughout their careers. In this context, excellence in thought needs to be systematically cultivated. Engineering students need to be able to state the problem (or question) clearly and break it into sub-questions. They need to be able to identify their assumptions and determine whether they are justifiable. They should gather sufficient information and avoid unsupported conclusions. All information used should be clear, accurate, and relevant to the question.

Our goals are helping undergraduate engineering students begin to understand how important critical thinking is, instilling in the student a love for thinking and respect for the power of thinking, helping them grasp the principles of critical thinking, and developing the student's ability for critical thinking. If grasped and cultivated properly, this will help them become more successful in their professional lives as engineers and as leaders among other professionals. Critical thinking is an essential need if they are to get to the root of problems and issues, and develop reasonable solutions. We realize that one learns more in life after school than in school. Our aim is to provide a key to young women and men during their undergraduate years. How well they use it in the future will still be up to individual students and vary from person to person.

Improved critical thinking skills in the student would result in increased ability to identify and comprehend a problem. Also, they would be able to determine the key parameters in a problem more successfully. With higher levels of critical thinking, one can substantially improve analysis on complex engineering problems and expect higher quality solutions.

We view assessment of this project as a three-stage process. Short-term assessment will consist of three elements. Our subjective assessment based on classroom observations and discussions will be recorded. We plan to interview a number of students to have a better understanding of how it seems from their side. Finally, in multiple-section classes, we plan to compare certain indicators (e.g., level of success in class, results in a standardized test on critical thinking) for a section in which determined efforts are made to cultivate critical thinking skills with a section taught as in the past.

Intermediate-term assessment will consist of two elements. At three points in time in the engineering student's undergraduate education, we plan to use a written survey designed to gage the impact of our efforts and a standardized test on critical thinking. The first time will be the beginning of their first sophomore-level engineering course, which is Thermodynamics. The second will be at the mid-point in their undergraduate years, our course in Heat Transfer. Finally, immediately before they graduate, we will do it at the end of the Senior Design Project course, which is taken by graduating seniors only.

Long-term assessment will consist of surveying two- and five-year alumni to have an understanding of the level of our long-term success. Appropriate questions for the interviews and surveys are in the formulation stage and evolving.

MAIN FINDINGS TO DATE

This section will summarize our experience and main findings thus far in our ongoing project on critical thinking and engineering education. This is a project with a large scope and has a long timeline. We believe that the following findings are warranted at this stage and would be beneficial to an engineering educator who is planning to embark on a similar critical thinking project.

Most people think they are already critical thinkers. This is a widespread self-delusion that needs to be overcome in the process of cultivating appropriate critical thinking skills. The most important ingredient in critical thinking appears to be a set of attitudes such as an intellectual disposition, a sense of responsibility to learn and use most effective analytical tools, and dedication to the principles of critical thinking [12].

Most seminars and workshops offered on critical thinking do not appear to be effective. Studying the subject or reading books about it do not seem to help much either. They don't address the fundamental issues. Most participants of such workshops simply expect some exercises and this attitude is not conducive to critical thinking. There is no magic bullet. A realistic conception and a systematic approach over a period of time are necessary.

A course in symbolic logic provides a sound foundation in the principles of reasoning. However, it seems that this is neither absolutely necessary nor sufficient. Yet there is some evidence to conclude that it helps a person who is committed to become a better critical thinker. With the possible exception of symbolic logic, critical thinking is not something one can learn from books or courses alone. Once its principles are grasped, they must be cultivated, practiced, and made second nature. Becoming a critical thinker is a process. It can improve with practice. One starts as a beginner and progresses in stages to become good at it. As engineering educators, we can play a vital role in the beginning phase of this process.

What can be done in a classroom environment to help students to become better critical thinkers? In addition to keeping all of the above in mind, an educator can take specific steps to stimulate, foster, and improve critical thinking in the student. Demonstrating critical thinking skills in the classroom and explaining how this would help them are essential.

At the present time, the authors are experimenting with a number of apparently very promising classroom activities. The challenge before us is sorting out which ones are most suitable in the context of engineering education. In general, questions that can be answered by using a methodical procedure to estimate an unknown quantity can be used for this purpose. Carefully-selected engineering problems, as well as certain types of mathematics and probability questions, provide ample opportunities in this regard. Studying how increasing or decreasing a key parameter in an engineering problem would affect other variables and results is also helpful. In addition, uncertainty analysis has been found to be a good subject in the development of critical thinking skills.

Finally, engineering educators need to search for ways to make critical thinking more palatable to the student. Examples that illustrate the power of critical thinking generate enthusiasm in the student.

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