Mapping the development of applied critical thinking skills in engineering technology majors

Dr. Beth Carle, Rochester Institute of Technology (CAST)

Dr. Carle joined RIT in 1996 and is an associate professor in the Manufacturing and Mechanical Engineering Technology (MMET) Department in CAST. Her research interests include critical thinking, STEM education, and program assessment. Beth serves as an ABET program evaluator.

Dr. Jennifer Schneider, Rochester Institute of Technology

Dr. Jennifer Schneider is the Eugene H. Fram chair in Applied Critical Thinking in Academic Affairs and a professor in the Civil Engineering Technology, Environmental Management & Safety within the College of Applied Science & Technology at RIT. She is responsible for leading the university wide effort to infuse applied critical thinking across the RIT student experience. In addition, she leads the RIT Collaboratory for Resiliency & Recovery, supporting the data to decision pipeline in emergency response and recovery, a local volunteer HAZMAT commander, and has been recognized for her work in situational awareness and decision-making.

Dr. MICHAEL E LONG LONG, Rochester Institute of Technology

Dr. Michael E. Long is a Research Analyst at the Rochester Institute of Technology. Prior to the current position he was a research scientist specializing in agent-based modeling of complex systems and taught statistics in the College of Science. He also has diverse technical and managerial experience in product development and manufacturing, holds 19 patents, and was an international consultant in Yield Management.
Mapping the development of applied critical thinking skills in engineering technology majors

Beth Carle, Jennifer Schneider, and Michael Long

Rochester Institute of Technology, Rochester, New York, USA

Abstract

Many universities have efforts related to infusing the teaching and learning of critical thinking, particularly for engineering, engineering technology and computing related majors. This paper describes an applied critical thinking initiative at the Rochester Institute of Technology (RIT) and its implementation within engineering technology. The Mechanical, Manufacturing, and Electrical Mechanical Engineering Technology (MMET) students practice critical thinking skills in general education courses, academic program courses, and experiential learning experiences such as co-operative education. Since employers are seeking critical thinking skills, this paper discusses the assessment of that competency through experiential learning opportunities for students. Mapping and analysis of the progression of the competency through academic program, student, and employer data showed a developmental path through ‘problem solving’ and ‘design’ related opportunities in many forms for students to demonstrate applied critical thinking skills.

Keywords

Applied critical thinking, student achievement, experiential learning assessment.

INTRODUCTION

Many popular press and scholarly sources note a growing awareness and need for critical thinking among college graduates¹. Regional accreditation bodies, such as the Middle States Commission on Higher Education (MSCHE), require degree programs to offer a curriculum designed so students acquire “critical analysis and reasoning proficiency”². Moreover, specialized accreditors, such as ABET, include aspects of critical thinking in the general criteria for accreditation³. A survey of employers was conducted for the Association of American Colleges & University (AACU) by Hart Research Associates to determine employer priorities and consensus on what knowledge or skill every student should attain from a college education. Eighty-two percent of employers indicated they want colleges and university to “place more emphasis” on critical thinking and analytical reasoning⁴. Since the business/employer community is the recipient of our efforts, we focused our attention on the evaluation of the demonstration of critical thinking skills in the technology driven fields of engineering, engineering technology and computing. However, the implications of this work extend to all disciplines, including the liberal arts, and perhaps shows that the application of critical thinking is the connecting thread of a professional education.

THE RIT INITIATIVE

Many universities have efforts related to infusing teaching and learning of critical thinking. Through the generous support of an anonymous donor, in 2012 RIT established the Eugene H. Fram Chair in Applied Critical Thinking to guide a university-wide initiative to embed critical
thinking, competencies through the teaching, learning and the student experience across programs and constituencies. Notably, RIT’s assessment definition guides evaluation of the overall competency. “Critical thinking refers to those processes required to understand and evaluate complex claims of various sorts. It involves the evaluation of information, evidence, arguments, and theories, and the contexts in which these are encountered. It entails the questioning of different and competing perspectives, and challenging the (sometimes hidden) assumptions and inferences that determine what will count as evidence or argument. Critical thinking is learning to think in a disciplined and evaluative manner, to analyze and interpret the processes by which various claims are made and reliable conclusions are reached.” The RIT initiative is grounded by applied critical thinking pedagogy, faculty scholarship, and professional preparation through practice. Intentionally, the application of critical thinking is systematically integrated within multiple opportunities for students to practice and broaden critical thinking skills, in general education courses, academic program courses, and experiential learning.

As an example, design and problem solving projects are integral parts of all Mechanical, Manufacturing, and Electrical Mechanical Engineering Technology (MMET) program courses, with increasing complexity and integration of multiple domains as the students’ progress towards their capstone experiences. Approximately half of freshmen courses are in the engineering technology core. This allows opportunities to help students immediately begin developing their critical thinking and analytical skills and highlights the importance of these skills. As a part of their first class, students follow a rigorous industry-standard design process that requires critical thinking at every step in the project: develop design criteria, evaluate multiple concepts to the criteria, build, predict trends from their test data, reflect upon performance and incorporate improvements, repeat the cycle, compete, document, and finally reflect on their project, teamwork, and process. Along the way the students develop their teamwork and leadership skills, orally defend their assumptions and decisions, and communicate their process in both written and oral forms. Grading of the project is primarily on process with only 20% on performance. Two years later, in their dynamics class, students cycle back to the same project. The objective criteria for the performance of their device remains the same. With more advanced knowledge, analytical skills, and critical thinking skills the dynamics students produce devices that, while similar to freshmen, perform 11% better on objective assessments. Students reflect upon their project now and their earlier efforts. While many programs have comparable courses, our emphasis on thinking and reflection creates a connection not only between courses but also for the student experience and metacognition abilities.

**Student Achievement of Critical Thinking Skills**

Critical thinking competency is achieved through integration of critical thinking pedagogy throughout the engineering, engineering technology and computing major curricula, spanning both the general breadth and the professional depth of a degree program. To begin, professors carefully challenge what students know and believe, pushing them to stretch their thinking. Following a gradually expanding context, students are then asked to analyze diverse positions and, ultimately, construct arguments and positions using their own capacities. This exercise ultimately leads to the ability to evaluate arguments and draw conclusions that are supported by both evidence and analysis of that evidence. Turning that process around, students then progress toward multivariate problem solving, first within their own domain, and eventually through integration of diverse views and sources, likely in a multidisciplinary team. This effort is the first indication of the
evolution into professionalism. Finally, students are given the opportunity to demonstrate creative or innovative approaches that encourage the development of new approaches to issues and problems. In this case, professors look for a willingness to look for sources, continuous evaluative thinking and, many times, the iterative ‘pivot points’ that are the process of innovation. At the beginning, much of the critical thinking is modeled for students by the professor. As their capacity to apply critical thinking increases, students are increasingly more self-directed and then team collaborative in their active thinking, and professors assume the role of guide and mentor.

Professional Proficiency through Critical Thinking

This effort is supported and validated through the development of a program assessment plan, and all undergraduate degree programs have mapped at least one of their program goals and corresponding student learning outcomes to critical thinking. Examination of curriculum and academic program instruction shows that approximately 90% of applied critical thinking academic program goals and learning outcomes at the mastery level are demonstrated through ‘problem solving’, ‘design’, and within ‘team-based’ assignments. In engineering and engineering technology, this maps to senior multidisciplinary design courses that encompasses diverse majors and domains.

It is important to carefully match the assessment to the applied critical thinking practice. First, while writing is an effective method to organize and demonstrate a thought process, it cannot be the only method of measurement of critical thinking because some great thinkers are not great writers. Second, one must guard against evaluating only the quality of the student result, and not the actions undertaken to get there. Inherently, applied critical thinking is a process, and particularly high quality practice can still produce flawed results. Third, high quality critical thinking draws from diverse sources and domains, and it can be difficult to evaluate those efforts, especially as new and creative approaches are employed.

RIT Applied Critical Thinking Milestone Assessments

RIT’s framework has evolved as we have refined our initiative. The overarching goal is to provide evidence of students’ abilities to demonstrate and achieve applied critical thinking skills that will serve them in the future. Table 1 below provides a summary of the university milestone assessments and RIT’s developmental approach to defining and assessing applied critical thinking skills, and are in addition to program- and course-level assessments. These university-level assessments draw from general education and academic degree program goals and student learning outcomes, experiential learning opportunities, the National Survey of Student Engagement (NSSE) and RIT’s Alumni Survey.

<table>
<thead>
<tr>
<th>Table 1 Milestone assessment sources</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Milestone assessments</strong></td>
</tr>
<tr>
<td>Year 1</td>
</tr>
<tr>
<td>General education</td>
</tr>
<tr>
<td>Exp. learning</td>
</tr>
</tbody>
</table>

2018 ASEE Mid-Atlantic Spring Conference, April 6-7, 2018 – University of the District of Columbia
Alumni Perceptions of Critical Thinking

We explored alumni perceptions of their RIT education using a new module on the 2014 RIT Alumni Survey. We asked alumni to respond to 16 high-level educational outcome areas (knowledge or skills) that reflect the mission and programs at RIT. We asked for feedback on the level of importance and how effective RIT was in supporting their development in each of the areas. The alumni that responded (n=1349) rated the critical thinking educational outcome as second in importance to problem solving, as seen in Table 2. Critical thinking was also rated by alumni as second only to problem solving in terms of RIT’s effectiveness in supporting their development. Problem solving is generally considered a core aspect of critical thinking. MMET alumni who responded (n=28) followed the same order of importance and effectiveness as the entire RIT sample, though 2-6% lower.

Table 2 RIT alumni survey data

<table>
<thead>
<tr>
<th>Educational Outcome</th>
<th>RIT Importance</th>
<th>RIT Effective</th>
<th>RIT Gap</th>
<th>MMET Importance</th>
<th>MMET Effective</th>
<th>MMET Gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem Solving</td>
<td>97%</td>
<td>90%</td>
<td>7%</td>
<td>93%</td>
<td>88%</td>
<td>5%</td>
</tr>
<tr>
<td>Critical Thinking</td>
<td>94%</td>
<td>86%</td>
<td>8%</td>
<td>88%</td>
<td>83%</td>
<td>5%</td>
</tr>
</tbody>
</table>

Experiential -Learning and Critical Thinking

RIT is known as a leading experiential and career-oriented university. The majority of RITs programs require students complete experiential learning (cooperative education or co-op), in addition to their coursework. This gives our students the opportunity to apply and practice their knowledge and essential skills within meaningful full-time, paid work experiences in their field of study before they graduate.

At the end of every semester, employers are asked to provide feedback regarding individual students who have worked for them in a co-op experience. Employers completing the evaluation are asked to rate the student on his or her performance on specific items on a Likert scale of 1 to 5 where 1 = poor and 5 = excellent. Students complete a similar form reflecting on core items as well as program specific items. Beginning in 2013, critical thinking abilities were assessed on the employer evaluation form.

METHODOLOGY AND RESULTS

Since employer expectations are key to career and professional success, our effort focused on the experiential learning component of an RIT education. In particular, we were examining whether students’ abilities met or exceeded employer expectations and whether students also believe the co-op experience exercised their abilities to critically think.

Employer assessment:

Experiential education (co-ops) generally occur in the third and fourth year, with many programs including an additional fifth year requirement during a student’s academic career (some bachelor’s programs are five years), and are an effective measure of students’ professional competencies. Co-op employment records for the academic years 2013-2014, 2015-2016, and 2015-2016 (fall term)
were joined with student enrollment files for the same period, yielding 4,745 records. Using the non-parametric Mann-Whitney-Wilcoxon test on the Likert scaled evaluations, results were obtained at a 95% confidence level. Figure 1 illustrates the mean value of the employer’s scoring of student critical thinking capabilities with increasing academic level. On the x-axis, we show the first, second, and third co-op experience in years 3, 4, and 5 of the college career.

Summary of analysis:

- There was no difference in evaluations by gender, p-value = 0.42.
- Results show that co-ops year 3, 4, and 5 are not all the same, p-value = 0.041, and subsequent tests showed that year 5 had higher evaluations overall and had higher evaluations than year 3 and 4 with a p-value = 0.039, based on paired t-test, sign test, and a signed-rank test.
- Computing related majors had statistically higher evaluations than the other programs with a p-value of 0.0038, indicating a difference between the three colleges.
- On average, the evaluations via Student t-test, Sign Test, and Signed Rank Test, from the student’s last co-op were higher than the student’s first coop, p-value < 0.0001.

![Figure 1 Co-op employer evaluation of critical thinking abilities, Likert Scale, reported by academic year](image)

Interestingly, Figure 1 shows computing related majors have highest scores in the initial co-op. This may be due to the fact that computing students are able to perform at a much higher level than employers expect for a student more than a year from graduation, and subsequent performance expectations related to critical thinking rise as the student reaches graduation.

**DISCUSSION**

The ability to think critically takes time and practice to develop. The opportunity to exercise critical thinking in a meaningful way requires students see it as a normal and ubiquitous part of their education, whether or not it is actually labeled as ‘critical thinking’. The key to developing the competency is to bridge the divide that can exist between general education and academic program courses. While students certainly understand the need for a broad preparation they sometimes do not deftly link that to their growing professionalism. Our efforts to teach and model critical thinking are intentionally integrated across the curriculum for this reason. There are two areas of opportunity in the cross-over that occurs in earnest about year two and three of a student’s academic carrier. First, students are actively tying together concepts and leveraging general education within program courses. This is expressed and measured by informational literacy.
through their ability to access and synthesize information from appropriate sources, evaluate and construct arguments, and reach conclusions based upon evidence. The second crucial crossover is especially exercised and measured in the final college year (year four or five). Here, students move beyond literacy to integrated problem solving, innovation and creativity. In this case, students are expected to address an unscripted and open ended challenge, within a changing context.

Many institutions have also adopted standardized testing such as the Collegiate Learning Assessment (CLA), or the revised CLA+, or the work by Robert Ennis. These assessments are useful because they provide both a baseline to measure performance improvement and an external benchmark. At this point, RIT has not adopted these external tools, and is focusing on two key actions, (1) the integration of applied critical thinking across the curriculum to support the development of the competency, including its integration into first year general education courses to serve as both an introduction and as a baseline measurement; and (2) continued evaluation of experiential learning and alumni data as a means to assess the attainment of competency in applied critical thinking. Academic program courses bring a distinct and crucial contribution to developing critical thinking by building upon and linking to the broader general education contribution. Employers are looking for professionals that can effectively function, and to do that, a professional must be able to consistently employ critical thinking. The challenge here then, is to provide both a broad (general education) proficiency in critical thinking and a deep (programmatic domain) proficiency in critical thinking. At RIT, this is why the effort is termed applied critical thinking, because our effort is aimed at creating graduates that can apply the skill in various broad and deep constructs.

CONCLUSION

Competency in critical thinking results from consistent practice. RIT’s initiative in applied critical thinking is aimed at ensuring students have the opportunity to build this crucial skill set throughout their academic career within general education courses, program courses and experiential learning. Intentionally, we have assessed our efforts by examining the experiential learning component of our programs, not only because that represents an external validation of applied critical thinking, but it is also an opportunity to practice those skills in a meaningful way. The analysis shows that most engineering, technology and computing graduates are proficient in applied critical thinking. We find that the students’ ability to think critically can be built through the integration of intentional pedagogy and outcomes in both general education and academic program courses, and also through reoccurring pedagogical connection and learning assessments within programmatic courses. Our results also show that students benefit from high quality experiential learning opportunities to practice and demonstrate their applied critical thinking skills, and employer feedback presents a unique and valuable opportunity to evaluate their demonstration of critical thinking and professionalism.

ACKNOWLEDGMENT

The authors would like to acknowledge the Fram Advisory Boards for Applied Critical Thinking at RIT, Professor Emeritus Eugene Fram, and Dr. Clarence Sheffield of the Rochester Institute of Technology for their support and contributions to the creation and development of this initiative.
REFERENCES


Beth Carle

Dr. Beth Carle is an Associate Professor of Mechanical, Manufacturing, & Electrical Mechanical Engineering Technology at Rochester Institute of Technology. She is a Program Evaluator for ETAC of ABET. Dr. Carle received her Ph.D. and M.S in Nuclear Engineering from University of Illinois and B.S in Mechanical Engineering from the University of Pittsburgh.

Jennifer Schneider

Dr. Jennifer Schneider is the Eugene H. Fram chair in Applied Critical Thinking in Academic Affairs and a professor in the College of Applied Science & Technology at RIT. She is responsible for leading the university wide effort to infuse applied critical thinking across the RIT student experience. In addition, she leads the RIT Collaboratory for Resiliency & Recovery, supporting the data to decision pipeline in emergency response and recovery, a local volunteer HAZMAT commander, and has been recognized for her work in situational awareness and decision-making. Dr. Schneider earned her Ph.D. from the University of Massachusetts School of Medicine and Dentistry and B.A. from Roberts Wesleyan.

Michael Long

Dr. Michael E. Long is a Research Analyst at the Rochester Institute of Technology. Prior to the current position he was a research scientist specializing in agent-based modeling of complex systems and taught statistics in the College of Science. He also has diverse technical and managerial experience in product development and manufacturing, holds 19 patents, and was an international consultant in Yield Management. Dr. Long received his Ph.D. in Physical Chemistry & Mathematics from Wayne State University and B.S. in Chemistry and Mathematics from the University of Toledo. He completed a Post-Doctoral Fellowship at Cornell University.