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

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***Abstract* — Many universities have efforts related to infusing the teaching and learning of critical thinking, particularly for engineering, technology and computing related majors. This paper describes an applied critical thinking initiative at the Rochester Institute of Technology. The ability to think critically is not only developed and demonstrated in a classroom or course. 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.

I. Introduction

Many popular press and scholarly sources note a growing awareness and need for critical thinking among college graduates [1]. 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 accreditation [3]. It is easy to see why this skill set is so important, particularly for the technology driven fields of engineering, technology and computing, however the implications of this extend to all disciplines, including the liberal arts, and perhaps is the linchpin in a well-rounded education.

The Association of American Colleges & Universities (AACU) launched the Liberal Education and America's Promise (LEAP) initiative in 2005 [4]. AACU worked with business leaders to craft a national campaign focused on advocating for the importance of strong intellectual and practical skills for college graduates, expressed through "essential learning outcomes," including: inquiry and analysis, critical and creative thinking, written and oral communication, quantitative literacy, information literacy, teamwork, and problem solving. Students are to be provided with an opportunity to practice these skills throughout their academic career [4]. Higher education institutions have widely supported intellectual and practical skills linked to critical thinking as essential to success during undergraduate students' academic experiences. Critical thinking has proven challenging to define, assess, and improve on in either general education or the disciplines [5]. 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. Critical thinking and analytical reasoning were included in the area of intellectual and practical skills and 82% of employers indicated they want colleges and university to "place more emphasis" on these skills [6]. 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 workplace.

This paper describes the development and design of a Rochester Institute of Technology (RIT) university-level initiative in applied critical thinking (section II), and its relationship to academic programs and the student experience in engineering, computing, and technology related majors. Section III presents our analysis of experiential learning assessment data. Section IV discusses our findings, followed by the conclusion in section V.

II. 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 curricula, scholarship, and the student experience across programs and constituencies. Notably, the RIT effort is in *applied* critical thinking, and in this view, critical thinking is an active process. Recognizing that critical thinking can take many forms, RIT supports a broad implementation, reflecting the context in which it is applied. 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." [7]. The RIT initiative is grounded in the development of applied critical thinking pedagogy, faculty scholarship, and professional preparation through practice. Central to the process are multiple opportunities for students to practice critical thinking skills in general education courses, academic program courses, and experiential learning experiences.

A. Student Achievement of Critical Thinking Skills

Before any institution can gather data on how well students are demonstrating critical thinking, in any aspect of the educational experience, they have to move beyond their definition of critical thinking and then determine and align the key competencies in a framework to support the attainment of critical thinking skills. Each of these supporting competencies are scaffolded within the curriculum to support student development and assessment.

This competency is achieved through integration of critical thinking pedagogy throughout the engineering, technology and computing major curriculum, spanning both the general breadth and the professional depth of a degree program. To begin, pedagogy focuses on the use of evidence and information literacy through increasingly rigorous application of expertise. In this case, 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 others' arguments and suppositions 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 design entirely new approaches to issues and problems. In this case, professors look for a willingness to look for sources, continuous evaluative thinking and, many times, a process that includes the iterative 'pivot points' that are indicative of 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- and team-directed in their active thinking, and professors assume the role of guide and mentor.

RIT's General Education Framework clearly articulates critical thinking as essential to the general education of every student at RIT, and as such, general education courses provide learning experiences designed to achieve associated student learning outcomes. The following student learning outcomes articulate the critical thinking knowledge and skills RIT values and measures within the general education curriculum [7]:

- Use relevant evidence gathered through accepted scholarly methods and properly acknowledge sources of information
- Analyze or construct arguments considering their premises, assumptions, contexts, and conclusions, and anticipating counterarguments
- Reach sound conclusions based on logical analysis of evidence
- Demonstrate creative or innovative approaches to assignments

B. Professional Proficiency through Critical Thinking

Currently, through the development of a program assessment plan, all undergraduate degree programs, including those in computing, technology, and engineering, have mapped at least one of their program goals and corresponding student learning outcomes to this university learning goal. 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, this maps to a single signature senior multidisciplinary design course and problem that encompasses diverse majors and domains. Interestingly, foundational 'lower division' student learning outcomes should be predicated on information literacy (accesses and synthesizes information), a key component of any undergraduate program; however, examination of the student learning outcomes related to this competency are much more varied, and are linked to foundational skills such as 'calculate' or'explain.', Since employers are looking for professional capabilities in their new employees, it makes sense that informational and technical competence is a building block of professional practice that supports higher level applied critical thinking.

It is important here to mention a few cautions when assessing applied critical thinking. One must be careful to match the assessment to the 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.

C. *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) [8] and RIT's Alumni Survey [9].

TABLE 1: MILESTONE ASSESSMENT SOURCES

Milestone assessments				
Year 1	**Year 2**	**Year 3**	**Year 4**	**Alumni**
General education	General education	Academic degree program	Academic degree program	Alumni survey
		Exp. learning	Exp. Learning	
NSSE			NSSE	

D. *Student Perceptions of Critical Thinking*

In addition to direct assessment methods that are implemented in approved general education courses, the university uses the National Survey of Student Engagement (NSSE) data to capture student perception of their abilities related to critical thinking student learning outcomes. NSSE measures the extent to which first-year and seniors are engaged in educational practices associated with student success [8]. RIT's benchmark is the first-year and senior mean scores on the selected NSSE item should be on par with or higher than their Carnegie Class peers. This means if the mean score is not significantly lower than our peer mean score then we have met our benchmark. We map multiple NSSE items (below) to RIT's general education student learning outcomes included in the critical thinking domain [8].

- 4b. Applying facts, theories, or methods to practical problems or new solutions
- 4c. Analyzing an idea, experience, or line of reasoning in depth by examining its parts
- 4d. Evaluating a point of view, decision, or information source
- 4e. Forming a new idea or understanding from various pieces of information

E. *Alumni Perceptions of Critical Thinking*

We explored alumni perceptions of their RIT education by including 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 then 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. 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.

TABLE 2: RIT ALUMNI SURVEY DATA

Educational Outcome	**Importance**	**RIT Effective**	**Gap Score**
Problem Solving	97%	90%	7%
Critical Thinking	94%	86%	8%

F. *Experiential –Learning and Critical Thinking*

RIT is known as a leading career-oriented university. The majority of RITs programs, including programs in engineering, technology, and computing 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 work experiences before they graduate. Co-op at RIT is full-time paid employment and directly related to a student's field of study. A Co-op Work Report or Co-op Evaluation is completed by both the student and the employer after each experience.

At the end of every semester, students who have participated receive the Co-op Work Report from the Office of Career Services and Cooperative Education. All Co-op Evaluation Surveys include core items and questions regardless of the students' degree program, as well as program accreditation specific items.

At the end of every semester, employers are also 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. Beginning in 2013, the following critical thinking abilities were assessed on the employer evaluation form:

- Accesses and synthesizes information from appropriate sources

- Effectively solves problems by integrating a diverse body of knowledge and skills

III. 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.

A. 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 opportunity and 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 employer's scoring of student critical thinking capabilities with increasing academic level. We show the percent of students who meet the RIT goal of a score of 4 or higher on the scale. On the x- axis, we show the first, second, and third co-op experience in years 3, 4, and 5 of the college career. Figure 2 shows the mean value of the assessment of critical thinking by co-op employers.

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 technology and engineering 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.

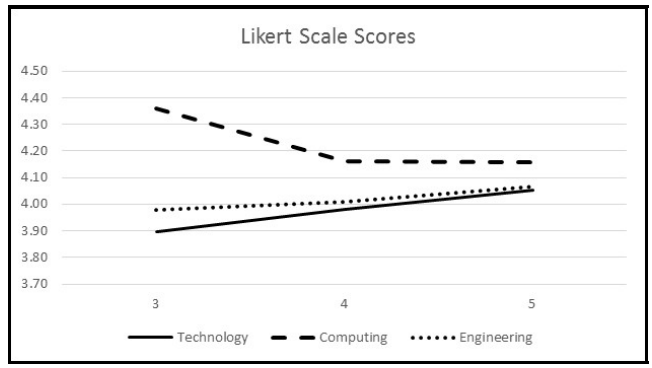

Fig.1. Co-op employer evaluation of critical thinking abilities, Likert Scale, reported by academic year

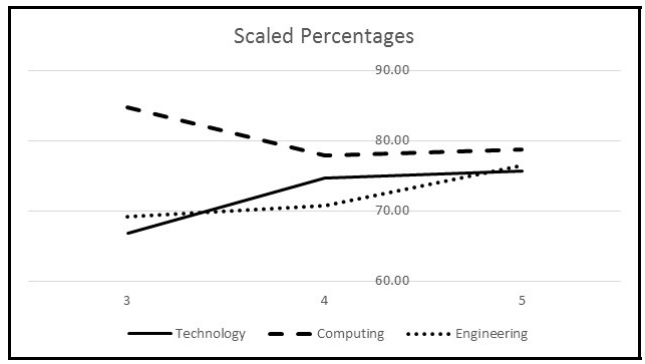

Fig.2. Co-op employer evaluation of critical thinking abilities, mean reported by academic year

Interestingly, Figures 1 and 2 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.

B. Student feedback:

We also investigated the student responses to the question "Describe how the experience encouraged, improved, or strengthened your critical thinking abilities?" The responses demonstrate the impact of the experience from students' perspectives. Responses were imported into SAS Enterprise Miner™ for text analysis. There were 1222 responses from the first and 545 responses from succeeding co-ops. Since this set was smaller, we simply compared initial co-op experience with later experiences. The files were subsequently parsed and then filtered to remove unnecessary terms and combine similar terms, such as "critical thinking" and "thinking critically". Finally, the responses were analyzed as the text topics that automatically associates terms and documents. Topics are collections of terms that describe and characterize a main theme or idea. Thresholds are used to determine if the association is strong enough to consider that the term belongs to the topic. As a result, documents and terms may belong to more than one topic or to none at all.

Tables 3 and 4 show the results from this topic analysis.

Table 3: First Co-op Experience

Topics and Terms Used	Number of documents
+problem,+solve,+solution,+find,+require	209
+improve,+ability,+critical think ability,+strengthen,+experience	208
+project,+task,+complete,+assignment,+time	175
+thing,+learn,+answer,+good,+time	170
+job,+require,+decision,+thing,a lot of	160
+learn,+solve,real,+apply,world	158
different,+project,+experience,+allow,+work	155
+design,+design,+product,+process,+material	140
+test,+test,+issue,+work,+figure	140
data,+analyze,+experiment,+determine,+require	135

Table 4: Subsequent Co-op Experience

Topics and Terms Used	Number of documents
+strengthen,+ability,+encourage,+job,+decision	96
+problem,+solve,+solution,+issue, different	91
+solution,+find,+time,+create,+project	83
+time,+thing,+good,+system,+figure	79
+job,different,+field,+require,+class	78
+design,+product,+challenge,+design,+customer	78
+task,+complete,+assignment,+plan,+project	60
+test,+test,+work,environment,+product	57
+data,+determine,+cause,analysis,+test	56
+learn,+apply,world,real,+thing	48

Our results show there is a notable shift in student responses. Initial co-op reports focus on problem solving, experience, and improvement in critical thinking abilities. Subsequent co-ops show orientation toward those actions and add (root) cause, analysis and design. Clearly, students see experiential education as an opportunity to practice and to demonstrate their ability to apply critical thinking in very measureable ways.

IV. 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. Our students, particularly those in the computing related majors, are well regarded in their ability to do this. 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.

RIT's decision to include critical thinking in both general education and academic program goals and outcomes is reflected by many other academic institutions. Various rubrics exist to assess the student's ability to critically think, scoring student examples through demonstrated levels of competence as 'inadequate/limited/adequate/proficient/ advanced', 'limited proficiency/some proficiency/ proficiency/high proficiency', 'insufficient/ acceptable/ high' or even 'weak/ unacceptable/ acceptable/ strong' and so on [10,11,12, 13]. Whatever the specific scale, each of these rubrics for assessment show the process that supports the development of critical thinking within the course and the program.

Many institutions have also adopted standardized testing such as the Collegiate Learning Assessment (CLA), or the revised CLA+ [14], or the work by Robert Ennis [15]. 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. As reflected in the typical Bloom's educational taxonomy [16], development of professional practice through student demonstrated critical thinking requires an ever increasing expectation and rigor within the academic program. As noted in our effort here, there is a distinct and crucial contribution to developing critical thinking by the academic program courses, 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

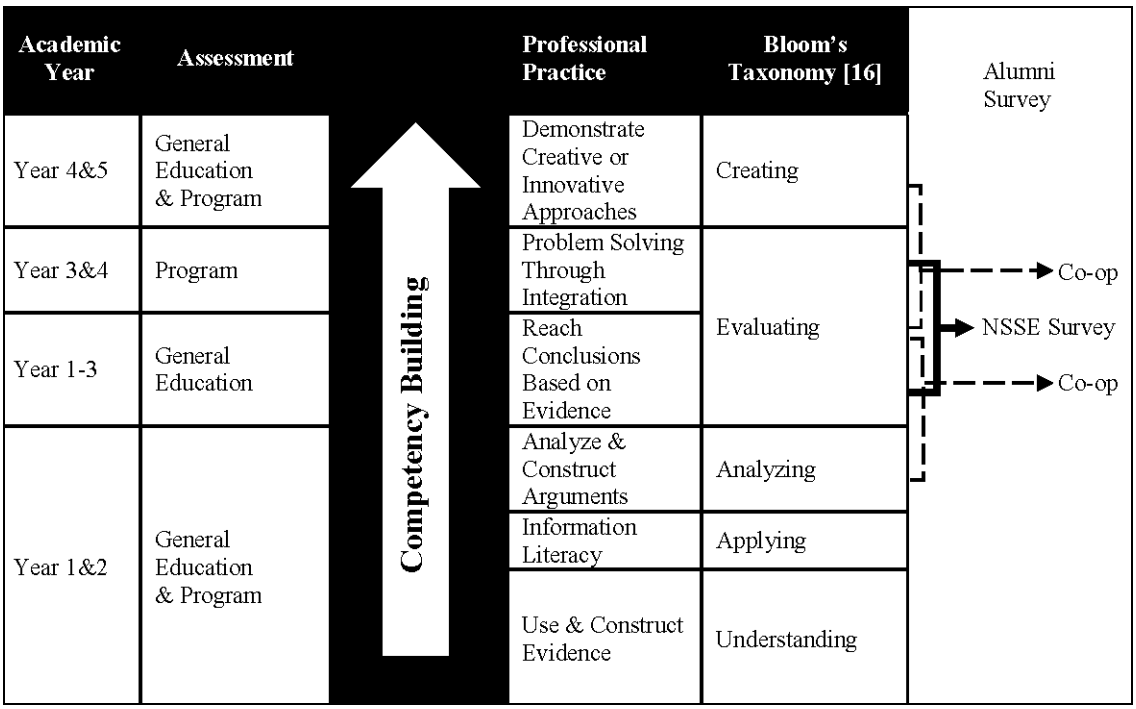

Fig.3 Map of the development of the applied critical thinking skills in engineering, technology and computing related majors at RIT

graduates that can apply the skill in various broad and deep constructs. Further, *applied* also speaks to our roots and mission as a career oriented university. The careers of tomorrow will require professionals to apply their skills in new ways as they encounter and create opportunities.

V. 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 also because 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 student ability to think critically can be built through the integration of pedagogy and outcomes in both general education and academic program courses. Our results also show that students benefit from high quality experiential learning opportunities to practice and demonstrate their applied critical thinking skills.

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