How Engineering and Computing Students Demonstrate Critical Thinking During Required Co-op Work Experiences

Adrienne Decker
Eugene H. Fram Faculty Fellow in Applied Critical Thinking
Rochester Institute of Technology
Rochester, NY, USA
Adrienne.Decker@rit.edu

Jennifer L. Schneider
Eugene H. Fram Chair in Applied Critical Thinking
Rochester Institute of Technology
Rochester, NY, USA
jlwcem@rit.edu

Lauren E. Margulieux
College of Education & Human Development
Learning Technologies Division
Georgia State University
Atlanta, GA, USA
lmargulieux@gsu.edu

***Abstract*—This Research Full Paper will discuss the demonstration of critical thinking of undergraduate students through their required co-op experiences. Critical thinking is an important 21st century skill that is expressed through measurable outcomes such as the ability to successfully use information, design, analyze, and problem solve. At Rochester Institute of Technology, a primarily technically focused university with strong programs in engineering and computing sciences, there is a dedicated effort to enhance the critical thinking ability of the students on campus. This paper will discuss our initiative for the integration of critical thinking into the student experience. In addition, the majority of our students complete one or more paid cooperative education experiences to satisfy their degree requirements. Upon completion of the experience, the employers are asked to rate the student performance on several metrics, one of which is demonstration of critical thinking. By analyzing the data from these surveys, we have found that employers consistently rate our students as proficient and capable. Our analysis shows that there is a slight difference in critical thinking ratings based on field of study, but not based on term in which it occurred, or number of experiences students engaged in.**

Keywords—critical thinking, cooperative education, engineering education, computing education

I. Introduction

In 2012, the Rochester Institute of Technology (RIT) established the Eugene H. Fram Chair in Applied Critical Thinking to guide a university-wide initiative to explicitly integrate critical thinking across the student experience, including within teaching, learning and applied learning (experiential education) of all types, particularly cooperative and internship educational opportunities. Establishment of an initiative is the easy part, implementation of the effort can always be challenging. However, the university has made significant strides in its goal to impart to students the value critical thinking has and to demonstrate that it can be applied in any situation to guide considerations, actions, decisions and performance. The initiative has not attempted to declare a correct or single definition of critical thinking, but to use the available expertise across the university to create an environment that fosters growth in this area for all students. An RIT education also includes an emphasis on experiential learning through hands-on experiences like cooperative education. A majority of our programs require students to complete a cooperative education (co-op) experience prior to graduation. Due to the nature of these experiences in the "real world", they provide a unique opportunity for us to see how our students apply their critical thinking in context outside a course or other campus guided learning opportunity. Through the use of the post co-op employer survey, we have been able to analyze critical thinking ratings to examine our student's performance in this area.

II. Background

A. Critical Thinking

There are numerous instances of critical thinking being listed as a learning outcome for higher education from organizations like ABET, ACM, and IEEE [1-2]. In 2013, AACU reported the findings of Hart Research Associates who asked employers their priorities for what today's college students should learn. Critical thinking was one of their five learning outcomes for students to achieve before leaving college [3].

However, the definitions for critical thinking vary widely. Some of the topics that are included in the definition of critical thinking are: identify issues, recognize assumptions, determine important relationships, make correct inferences, evaluating data/evidence, conceptualizing, questioning, reasoning, synthesizing, and drawing conclusions. Further, while the ability to solve problems is related to critical thinking, not all definitions specify it [4-7]. In truth, critical thinking may be a mix of all of these things and may be different depending on the situation, context, or domain in which it is applied.

B. Teaching Critical Thinking

While many recognize critical thinking as an important skill, the question of how to teach students to think critically is a challenging one. Further, there are a number of ways a students can demonstrate critical thinking, even within their domain of study. Given the computing, engineering, and technology domain emphasis on problem solving, many teachers decide to use techniques like problem based learning (PBL), project oriented problem-based approaches, or simply

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project-based courses as a way to address the issue [8].

However, that doesn't address the whole of the application of critical thinking and there have been attempts to integrate critical thinking into an existing course as done in [9-14], or to create an entire course for it on its own [15]. When looking at developing these skills in students, we see a focus on the use of written assignments through peer involvement [9] or reflection writing [11]. The use of questioning techniques was applied in an electrical engineering course [10], and in [12], students were asked to create argument maps when studying electromagnetic field theory to help aid in their critical thinking abilities, also argued for in [7]. Lastly, the case study analysis presented in [6] gives a picture of critical thinking applied in classrooms across multiple institutions using various techniques.

In [13-14], Barry L. Shoop discusses a Disruptive Innovations course that brings together students from different backgrounds and forces them to think about technology and innovation in new an interesting ways while engaging with their classmates in discussion and debate. And in [15], an entire course is devoted to critical thinking bringing together literature, philosophy, logic, and technical content.

C. History of the Fram ACT Initiative

In 2012, an alumni donor supported the creation of an initiative focused on the development of applied critical thinking at RIT named in honor of an RIT professor that the donor felt embodied critical thinking in his teaching. The goal of the initiative was to further develop and focus university driven critical thinking efforts to prepare students for their work in the 21st century economy.

This gift established the Eugene H. Fram Chair of Applied Critical Thinking. The efforts have grown to encompass all members of the campus community (faculty, staff, and students) and to showcase efforts of the teaching and scholarly contributions in what we call applied critical thinking (ACT). The effort aims to expose students to the importance of critical thinking as both a general skill as well as how to successfully apply that skill into their own domain of study.

D. Structure of the Fram ACT Initititave

The Applied Critical Thinking initiative is led by the Eugene H. Fram Chair in Applied Critical Thinking, who serves in the university office of Academic Affairs. The Fram Faculty Fellow, a position that guides the pedagogical portion of the work, supports the chair. Two advisory boards guide the overall initiative:

1. A faculty staff representative board that guides the implementation of the effort on each of RIT's campuses. The international campus locations have recently joined (2017) in the effort, so that implementation will follow the main Rochester campus. The input of the wider campus community was considered an important step in bootstrapping the initiative. Now, it is considered vital in continuing to grow the programs as the needs of the campus change.

2. An external advisory board, comprised of select alumni leaders who provide oversight, strategic direction, and inform trajectories of the effort.

E. RIT's Definition of ACT

One of the first tasks of the initiative was to set a frame for what applied critical thinking meant to both the initiative and to the RIT community. After consideration, the stakeholders determined that the application of critical thinking could be realized in various ways, and four constructs have developed to guide the effort. These variants recognize the need to speak to the audience and reflect the style of application of critical thinking (context in which it is exercised) and the overall purpose for that critical thinking. Therefore, we believe these frames are not competing, but complementary and instructive.

1. The RIT general education set of student learning outcomes definitions (See III A).
2. The ability to identify, analyze, construct, and evaluate evidence and arguments in a deliberate and rigorous way [16].
3. Critical thinking is accomplished by analysis of information to assess veracity and relationships; use of hypothesis and experimental results; application of multidisciplinary methods to support evaluation and possible creation of new ideas, products or views. Critical thinking also seeks to resolve weaknesses in thinking such as insufficient inquiry, ambiguity, unexamined assumptions, biases, and subjectivity [17].
4. Application of critical thinking connects the performance chain of knowing-doing-creating. We build the skills necessary to effectively comprehend and analyze a situation, and then develop and implement a strategy to solve a complex problem or manifest new ideas, both individually and collectively [18].

III. Applied Critical Thinking Across RIT

The Fram ACT Initiative has created several forms of engagement and support to further the goals of ensuring that students are functional applied critical thinkers. In this section, we will outline some examples of the different programs that students and faculty participate in during their time at the university. Figure 1 illustrates how the various parts of the definition of applied critical thinking combine in our student experience.

A. General Education Student Learning Objectives

A key in the university-wide adoption of critical thinking was the creation of a set of student learning outcomes (SLOs) for applied critical thinking that guide student learning expectations and the assessment of efficacy. The university's General Education Framework clearly articulates critical thinking as essential to the general education of every student, and as such, general education courses provide learning experiences designed to achieve associated student learning outcomes in every degree program. The following student learning outcomes articulate the critical thinking knowledge and skills that are valued and measured as part of the overall general education curriculum:

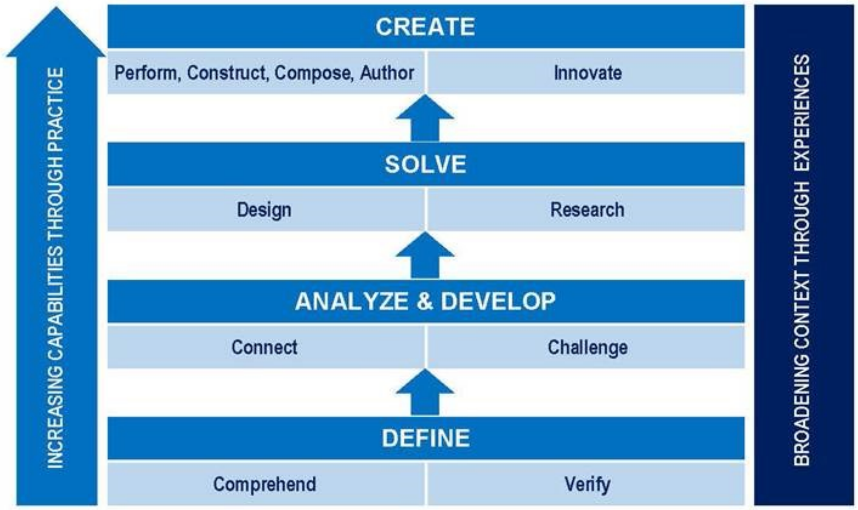

Fig. 1. Applied Critical Thinking Learning Progression at RIT

- 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

These SLOs frame both the pedagogical methods and the evaluation of student capability, and are supported by guiding rubrics, resources, and a growing library of best practice examples that faculty have shared and are available on the Fram ACT website (https://www.rit.edu/academicaffairs/applied-critical-thinking/resources).

B. *Development of Program Outcomes*

Beyond the general education SLOs, there are several additional opportunities to imbue critical thinking within the educational experience. Currently, the team is evaluating the critical thinking related data that is routinely collected as part of the ABET program accreditation and continuous improvement process, for example, in the area of "problem solving". Every profession has unique methodologies for solving problems, and each applies critical thinking skills in doing so. Consideration of this data may show the transfer of the general education ACT skill set to the professional (domain based) portion of the undergraduate degree program. To further build and broaden this transfer, the university is considering establishing a degree program SLO requirement for applied critical thinking in addition to the current general education requirements.

C. *Imagine Awards*

Each year, the university community comes together for Imagine RIT: Innovation and Creativity Festival. This is a campus-wide event that showcases the innovative and creative spirit of students, faculty and staff. Visitors experience the breadth and depth of the university through interactive presentations, hands-on demonstrations, exhibitions, and research projects set up throughout campus [19].

Since 2015, the Fram ACT Initiative has given awards for Excellence in Applied Critical Thinking for exhibits at Imagine RIT. The award is open to all students with an exhibit at Imagine RIT and the judging is not based on the output of the exhibit, but rather the use and quality of the application of critical thinking as part of the creative process in their preparation of the exhibit or performance.

An examination of award winners shows that projects and exhibits represent a large cross-section of the majors and students on campus:

- commercializing a pumice roofing tile design in Nicaragua (business and engineering)
- educating the community on how to achieve Sustainable Development Goals by proper recycling and composting (sustainability institute)
- interactive platform to educate about violence in health screening (school of health sciences)
- platform to share one's mood with others through smartwatch or similar device (new media)
- robotic eye construction (engineering)
- sustainability choices consumers make (sustainability institute)

D. *Speakers Series and co-sponsored events*

The Fram Signature lectures and lecture series bring to the campus scholars and distinguished practitioners from broad areas of expertise to discuss critical thinking and its application in their domains. The lectures themselves are open to the entire campus community, but in the day or two preceding the lecture, the invited guests have spent time visiting classrooms, meeting with student project groups, and meeting with small groups of faculty and students in their areas of expertise. The lectures have brought in experts in complex systems, computer science, education, literary criticism, systems science, user experience, and user interface design.

The Fram ACT initiative also sponsors smaller events throughout the academic year in conjunction with the academic units on campus. These events can be in the form of discussion groups, traditional lectures, local conferences, student showcases, or other synergistic activities. All of these efforts are aimed at engaging the campus and wider community in the development and use of applied critical thinking skills.

E. Programs for Faculty

While the Fram ACT initiative has many programs targeted at students, there are also programs targeted at faculty who want to improve or highlight their use of critical thinking in the classroom.

1) Teachers on Teaching

The Fram ACT initiative routinely partners with our teaching and learning center on campus to offer special sessions of their *Teachers on Teaching* workshop series focused on applied critical thinking. These sessions are organized for small group discussion with one or more faculty members leading the discussion about their particular use or implementation of critical thinking teaching techniques in the classroom and invite others to participate in the discussion, bring their own experiences, and learn from each other. The Fram ACT initiative has also partnered with the teaching and learning center to offer more intensive summer workshop experiences for those looking to refine skills in this area.

2) PLIG Awards

The office of the Provost offers a series of yearly awards for faculty-initiated projects that enhance student learning. There are two levels of awards, exploration grants and focus grants, with the former being the initial development of an idea and the latter engaging in further development or research of an already formed idea. Starting in the 2017-2018 academic year, awards in this program were requested in a focus area of applied critical thinking [20].

IV. Cooperative Education at RIT

Experiential education in various forms has been a longstanding hallmark of an RIT education. Within that broad focus, the cooperative education experience (co-op) for our students is a full-time, 35 hours or more per week, paid employment experience connected to a student's field of study. Currently, different programs of study have different requirements for co-op. Across campus, we offer 101 bachelor's degrees, 64% of which require specific co-op experiences as a graduation requirement, and 39 dual bachelor's/master's degrees, 49% of which require co-op experiences as a graduation requirement.

Table I shows the ratio of required versus optional co-op experiences by college degree programs. Each program also sets the number of required co-ops, shown in the table as well. Even if not required, co-op experiences are always highly encouraged for students.

Students who have completed two years of study are eligible to begin fulfilling their co-op requirement and are supplemented through the university's office of career services and cooperative education with guidance and a robust job posting system by which employers can recruit co-op students [21]. Upon acceptance of a co-op offer, students inform the university of their intention to co-op via the co-op website and if during a semester, by registering for a special co-op class. This way, students do not lose continuous student status while engaging in co-op.

A. Employer Co-op Evaluation

Upon the completion of the co-op experience, employers are asked to fill out a survey about the student worker. Students do not receive credit for the co-op experience until

TABLE I. Required vs. Optional Co-Op Exeperiences for Degree Programs by College

College	Total degrees offered	Only optional co-ops required	1 co-op required	2 co-ops required	3 co-ops required	4 co-ops required
Applied Science and Technology	12 Bachelor's	1		1	1	9
	4 Dual Degree[a]	2			1	1
Business	7 Bachelor's	0	7			
Computing	9 Bachelor's	0		7	2	
	3 Dual Degree	1			1	1
Engineering	21 Bachelor's	0				21
	15 Dual Degree	1			3	10
Health Sciences and Technology	4 Bachelor's	2			1	1
	2 Dual Degree	2				
Imaging Arts and Sciences	20 Bachelor's	17	2	1		
Liberal Arts	16 Bachelor's	5	11			
	2 Dual Degree	1	1			
Science	16 Bachelor's	15	1			
	14 Dual Degree	13	1			

[a] Dual degree programs yield an undergraduate and graduate degree at the completion of the program (typically master's degree)

the supervisor completes the form, and employers are generally good about doing so in a timely fashion

Employers are asked to rate the students on a 5-point Likert-type scale where 5 is excellent performance and 1 is poor performance. There is also a choice for not applicable. The performance areas are: critical thinking, creativity and innovation, writing, communication, cultural diversity, information literacy, initiative, collaboration/teamwork, ethics, self-reflection, leadership, reliability, quality of work, quantity of work, quality of technical preparation, overall performance, and finally asks if the student would be competitive for permanent appointment (yes/no).

B. *Research Questions*

Since co-op is a unique and valuable applied learning opportunity, it provides a way to assess a student's application of critical thinking as part of their professionalism. Our research questions (and hypotheses) for this study were the following:

- RQ1: Were there differences in critical thinking scores amongst the students from different colleges?
  - *H1: There will be differences and students in engineering and computing will have higher scores than the others.*
- RQ2: Was there a change in the critical thinking co-op score from a student's first co-op experience to their last?
  - *H2: A student's scores on critical thinking would increase from their first co-op to their last co-op.*
- RQ3: Is there a difference in critical thinking score for a student who does an optional co-op versus a required co-op?
  - *H3: Students would perform equally in either situation.*
- RQ4: Is there a difference in critical thinking score for a student who does a summer co-op versus a semester (fall or spring) co-op?
  - *H4: Students would perform equally in either situation.*
- RQ5: Is there a relationship between the number of co-ops a student completes and their critical thinking score?
  - *H5: Students who take more co-ops would have higher critical thinking scores because they have been able to apply this skill more often.*

V. Analysis of Co-Op Data

We were able to analyze data from the employer co-op form for individual students from the colleges of applied sciences and technology, business, computing, engineering, health science and technology, imaging arts and sciences, liberal arts, and science for the academic years 2014-2015 to 2016-2017 inclusive (three academic years). We are considering an academic year to include a fall term, spring term, and summer term.

In total, we have critical thinking ratings for 3594 students. More than half of the students, 2115 (59%) completed multiple co-ops, and the total number of co-ops completed was 7195. Table II shows the number of students in the analysis and how many co-ops each took. For most analysis, unless otherwise indicated, we used an average of the critical thinking ratings that students received from their co-ops. We could not use multiple ratings for a single student because that approach would have violated the assumption that all data points are independent when using General Linear Model analyses (i.e., t-test, F-test, regression). If we had used data points for students who completed multiple co-ops, the data points for a student would be related to each other because they are based on the evaluation of the same person.

It is important to note that due to the large sample size of this research, even small changes can result in statistically significant differences among groups, even if those differences are small. Therefore, we primarily discuss differences in terms of effect size rather than statistical significance to better represent the differences among groups. For omnibus ANOVA tests, we used ω^2, which tells us how much of the variance in the data can be attributed to the different groups. For example, a ω^2 of .03, which is a small effect size [22], means that 3% of the variance in data can be attributed to, say, which college the student belonged to. For pairwise comparisons between two groups, we used d, which tells us the difference between means using standard deviation as a unit of measurement. For example, a d of .25, which is a small effect size [22], means that the difference in means is equal to a quarter of the standard deviation.

A. *College*

We explored whether students in each of the colleges received, on average, different critical thinking ratings. We had, 919 participants from applied science and technology, 248 from business, 334 from computing, 1655 from engineering, 63 from health sciences and technology, 252 from imaging arts and sciences, and 10 from science. Because the number of students from each college varied widely, which violates another assumption of analyses based on General Linear Model, we used two analyses: one more conservative and one less conservative. The more conservative method, to satisfy the assumptions of the analyses, controls for number of students from each college by randomly excluding data points so that there are an equal number of students from each college. Because science (mean co-op score 4.08) and health sciences and technology (mean co-op score 4.33) had relatively few students, they were excluded entirely from this analysis. Of the remaining six colleges, liberal arts had the fewest students with 109. Therefore, 109 students from the remaining five colleges were randomly selected to be included in this analysis.

TABLE II. Number of Co-ops Completed

Number of co-ops completed	Number of students	% of overall
1	1479	41%
2	1078	30%
3	655	18%
4	320	9%
5	62	2%

The more conservative analysis found that critical thinking ratings differed based on college, F (5, 653) = 6.49, p < .001, est. ω^2 = .05. About 5% of the variance in ratings can be attributed to the college that students belonged to, which is a small-to-medium effect [22]. Within this analysis, we found that students in liberal arts, imaging arts and sciences, and business had higher ratings than those in applied science and technologies and engineering with students from computing falling in the middle (see Table III). The mean difference between the highest scoring group, business, and the lowest scoring group, applied science and technology, was 0.38, p = .002, d = 0.52, which is a medium effect size [22].

For the less conservative analysis, we included all participants, except those from science and health sciences and technology, due to low sample size. General Linear Model, though one of its assumptions is equal number of data points among groups, can be robust (i.e., mostly unaffected) to violating this assumption. With all of the data points included, we found a similar pattern of results. The means for each college were within 0.06 from the more conservative analysis, and the standard deviations decreased by up to 0.05 for groups with large numbers of participants. The effect size for the omnibus analysis decreased to a small effect when all participants were included, F (5, 3516) = 20.95, p < .001, est. ω^2 = .03. The only difference in the post hoc analyses were that the college of computing group was statistically different from the lowest performing groups, Mean Difference = .19, p <.001, d = 0.27, with a small effect size that was similar to the previous one. Computing was still not statistically different from the highest performing groups, Mean Difference = .09, p = .44, d = 0.12.

B. *Change*

For participants who completed more than one co-op, we explored the change in their ratings from their first co-op to the last co-op, creating change scores by subtracting the first rating from the last rating. Table IV gives a summary of the changes we saw. Overall, there was not much of change, M = 0.16, SD = 0.92. We also explored whether change scores were different based on college. Science was excluded from this analysis because they had only two students that completed multiple co-ops. Overall, we did not find that change scores were different among colleges, F (6, 2103) = 1.19, p = .31, est. ω^2 = .004.

TABLE III. RESULTS BY COLLEGE

College	Mean Rating	Std. Dev.	Mean Diff.	*d*
Business	4.32	0.75		
			0.01	<.01
Imaging Arts & Sciences	4.32	0.74		
			0.02	0.05
Liberal Arts	4.29	0.72		
			0.11	0.15
Computing	4.18	0.70		
			0.22	0.31
Engineering	3.96	0.71		
			0.02	0.03
Applied Science & Tech	3.94	0.72		

C. *Required vs. optional*

We examined whether co-ops being required or optional for students affected their critical thinking ratings. Similar to the college analysis, there was a large discrepancy between optional (n = 147) and required (n = 3447) groups. Therefore, we again used two analyses. The more conservative analysis controlled for number of students in each group, so it included the 147 data points from the optional group and 147 randomly selected data points from the required group. Because we found the college was a predictor of rating, we used stratified random sampling for the required group, which means that the proportion of randomly selected data points matched the proportion of data points within each college. For example, engineering, which had 1655 data points, had proportionately more data points in the sample than computing, which had 334 data points. This quota-like restriction on random sampling ensured that the sample was representative of the full data set.

The more conservative analysis found that rating on required co-ops (M = 4.18, SD = .70) were lower than those on optional co-ops (M = 4.41, SD = .66), t (292) = 2.94, p = .004, d = 0.34, by a medium effect. The less conservative analysis, which included all data points, found a similar trend. That analysis also found that ratings on required co-ops (M = 4.09, SD = .72) were lower than those on optional co-ops (M = 4.41, SD = .66), t (3592) = 5.31, p < .001, d = 0.45, but the effect size was larger.

D. *Semester vs. summer*

We explored whether critical thinking ratings were different between co-ops completed during the semester or co-ops completed over the summer. For this analysis, there was not a large discrepancy between number of semester co-ops (n = 1842) and number of summer co-ops (n = 1752); therefore, only one analysis was used, which included all of the data. We found that there was a small difference between students who completed co-ops during the semester (M = 4.04, SD = .71) who were rated slightly worse than those who completed co-ops over the summer (M = 4.18, SD = .72), t (3592) = 5.89, p < .001, d = 0.21.

E. *Number of Co-ops*

Last, we examined the correlation between number of co-ops that students completed and their average critical thinking rating. We found that number of co-ops was not related to average score, r = -.002, p = .90. We also explored whether students' first ratings correlated with the number of co-ops that they completed. Interestingly, students' first ratings negatively

TABLE IV. DIFFERENCE IN RATING FIRST CO-OP TO LAST CO-OP

Difference (last score – first score)	Number of students	% of overall
-4	1	0.005%
-3	6	0.2%
-2	58	2%
-1	354	16%
0	1029	49%
1	507	24%
2	136	6%
3	12	0.5%
4	1	0.005%

correlated with number of co-ops whether we included all students, $r = -.18$, $p < .001$, or only students who completed more than one co-op, $r = -.10$, $p < .001$. This finding means that students with lower ratings on their first co-op were more likely to complete more co-ops in the future. The correlation does not imply causality, though, so it would be incorrect to assume that lower ratings caused students to complete more co-ops, primarily because an a priori analysis of the data shows us that students who are completing more than one co-op are coming from programs that require more than one co-op. Therefore, it is most likely not scores from co-op that drive additional co-ops, but rather the requirement to complete more to graduate. Further, the evaluation of students co-op performance has many more ratings than critical thinking. It would be unwise to correlate this one low rating with repetition of the co-op experience.

F. Interactions

To better understand possible interactions among our three predictor variables, college, required or optional co-ops, and semester or summer co-ops, we conducted analyses that examined multiple predictor variables at once. We first looked to see if ratings were dependent on both a co-op being required or not and if it was during the semester or summer. Ratings did not depend on whether the co-op was required or not and completed over the semester or summer, F (1, 3593) = 0.01, $p = .83$, est. $\omega^2 < .01$. Second, we examined whether the college of the student and whether the co-op was completed during semester or summer influenced ratings. Ratings did not depend on whether the co-op was completed the semester or summer and the student's college considered together, F (5, 3516) = 1.60, $p = .16$, est. $\omega^2 < .01$. Since the students' college greatly influenced whether co-ops were required or optional, we did not run that interaction analysis because it violated the independence assumption.

VI. DISCUSSION

Overall, we have seen from the data that our students were able to (according to their employers) demonstrate critical thinking "on the job". Across the 7195 co-op rankings, we saw 10 rankings of 1 (poor performance), 141 rankings of 2, 1518 rankings of 3, 2936 rankings of 4, and 2585 rankings of 5 (excellent performance), with an overall mean ranking of 4.1. We feel this is a positive result and that are students are clearly demonstrating a proficiency in critical thinking. In terms of our research questions and hypotheses, we have a number of interesting results and more potential questions and areas for inquiry.

A. RQ1: Differences among colleges

Our hypothesis was that students in engineering and computing fields (colleges of applied science and technology, engineering, and computing) would score higher than those in the other fields (business, health sciences and technology, imaging arts and sciences, liberal arts, science). This hypothesis came about, in part, because of the belief that those disciplines are very heavily involved in the teaching of problem solving and solving for new problems in new circumstances, a key notion related to critical thinking.

However, our analysis showed that students in liberal arts, imaging arts and sciences, business, and computing had the highest ratings, followed by applied sciences and technologies, and engineering. While all domains received high scores in critical thinking, we find it interesting that our analysis does not seem to support our initial hypothesis that "problem solving" disciplines would be exceptional critical thinkers. Our analysis suggests that diverse domains develop critical thinkers, and that critical thinking is a broadly applied skillset, across the liberal arts, business, engineering, computing and technology.

There are also several factors that could contribute to the distribution of employer ratings such as: differing definitions of critical thinking among the domains and supervising employers, differing expectations for the student critical thinking (higher or lower), and the diverse contexts and expectations for student effort. It is important to note that while the groups in applied science and technology and engineering had lower ratings compared to the other groups in our analysis, their mean critical thinking ratings were still 3.94 and 3.96 respectively, relativity high ratings. These findings support our effort to continue integration of applied critical thinking methodologies within the broad general educational and the domain specific program related curriculum.

B. RQ2: Change from first to last co-op?

Our hypothesis was that a student's scores on critical thinking would increase from their first co-op to their last co-op due to the fact that they were continuing their education, both practically, from doing more co-ops, and traditionally, by continuing in their schooling. There was not much difference found in between first and last co-op, with 49% of the students having no change in co-op score. Looking deeper at the data, we see that 681 students (32%) started with a rating of 5 in their first co-op and 837 students (40%) started with a rating of 4. It is hard for much growth to occur when 72% of the students already start with a high rating. Further analysis could reveal if the students who scored 3 or lower improved more in later co-op experiences.

C. RQ3: Optional vs. Required

We hypothesized that students would perform equally well in either situation, but the analysis showed that students who completed optional co-ops scored higher than those who completed required ones. It is possible that students who complete co-ops even though they are not required are simply the highest performing students in their discipline and would therefore achieve higher on all metrics. The only way to determine if that is the case is to analyze academic information about those students.

D. RQ4: Summer vs Semester

While the notion of summer internship is common in college years, the culture of RIT and co-op is that it can (and does) happen at any time. There is no difference to most students whether they co-op during the academic year or during the summer because when students are on co-op during the normal academic year, they are not allowed to take any classes on campus. Many of the companies that employ our students know about our required co-ops and do not simply schedule projects for summer as is common in many places, so students have opportunities throughout the year. However, the analysis showed that summer co-op students were rated higher. It is possible that these summer opportunities are more competitive, or of higher quality and attract a higher caliber student, thereby the higher ratings. Again, further analysis of student's overall academic performance could shed light on whether or not these summer co-op students are simply higher performing in general.

E. RQ5: Number of co-ops

Our hypothesis was that the more co-ops a student completes, the higher their scores because they will have had a greater opportunity to demonstrate and practice their critical thinking. However, this was not the case. The number of co-ops was not correlated with their ratings. Recall that in this analysis, we needed to use the average rating if a student had multiple co-ops.

However, the interesting finding that a lower rating on first co-op was related to taking more co-ops is one that caused us to think about why this could be the case. Our current theory is that programs with more required co-ops would have students taking them sooner in their academic career when perhaps their critical thinking skills are not as developed. Students who only need to take one co-op to graduate can do so at any time and may choose to wait until they are closer to finishing their degree to ensure they have advanced skills to enable them to secure a more selective experience more closely related to their expertise and targeted entry job.

VII. Conclusion and Future Work

After several years of work on the Fram ACT Initiative, a number of university-wide programs have been created to engage faculty, staff, and students in applied critical thinking. To measure the current impact of the initiative and the success of our students, we looked at critical thinking ratings of students from employer surveys of their co-op experiences for the past three academic years.

The results of this analysis showed us that our broad efforts have paid dividends across our campus. The implementation of general education student learning outcomes has had an impact for all domains, not just for the engineering- related, technology, and computing majors. Therefore, the ability to apply critical thinking is not predicated upon a "problem solving" orientation per se. It must be noted that the differing employer expectations of performance, and of the definition of quality critical thinking may have an impact on our findings. It is also quite possible that due to the number of required co-op experiences for computing, engineering related and technology students (as many as 4 required terms for some programs), students are starting the experiences earlier and have not yet developed the ability to fully demonstrate those skills in the employment setting. More work and analysis may need to be done to determine if and when in an academic career the co-op is completed impacts the rating for critical thinking.

We would also like to examine some of our alumni data about critical thinking to determine if upon reflection, the co-op played an important role in developing their critical thinking skills. In addition, we are exploring the inclusion of student learning outcomes for critical thinking that specifically address problem solving integrated into our already existing general education requirements and degree-program level learning objectives targeting critical thinking and problem solving in domain-specific ways.

However, overall, we are encouraged by the fact that all of our students are showing high level of ability in critical thinking while engaging in these co-op experiences (an average rating of 4.1 across all ratings). We feel that our efforts are having an impact and are looking forward to engaging with the on-campus community to further determine ways to integrate more critical thinking best practices across the university experience.

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