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Improving Inclusivity and Diversity in College STEM Programs through Metacognitive Classroom Practices

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Abstract:
We report on results from RIT's Project IMPRESS: Integrating Metacognitive Practices to Ensure Student Success, a 5-year NSF funded program to improve retention of first-generation and deaf/hard-of-hearing students in STEM disciplines. As part of IMPRESS, we have developed and taught a first-year course "Metacognitive Approaches to Scientific Inquiry." The course, which satisfies the Institute's Ethical Perspectives requirement, introduces students to a variety of metacognitive issues and practices including: developing a growth mindset; Bloom's and Perry's taxonomies for content and intellectual development; inaccuracy in self-assessment; lateral and longitudinal transfer of knowledge and experiences; and the benefits of self-reflection. Over 200 students in five years have taken the course, with very promising results. Retention of IMPRESS 1st-generation and DHH students into their 2nd, 3rd and 4th year are all above 80%, at or exceeding the institutional average. IMPRESS student demographics are inclusive: 35% are women; 32% from identities historically excluded from STEM disciplines; and 17% Deaf or Hard of Hearing (DHH). Retention results are consistent across these demographics.

In qualitative research focus groups students consistently report IMPRESS experiences as life-changing. Students recognize that issues and strategies learned in the class can be used in their other classes and that this class essentially teaches them "how to learn." Students also report great appreciation for a class in which disciplinary faculty (as opposed to academic or student support staff) demonstrate meaningful care for students as humans. Additionally, a quantitative study comparing IMPRESS students with a matched group of non-IMPRESS 1st-generation/DHH students found that IMPRESS students were more likely to report satisfaction with their choice of RIT as an institution.

In this paper we describe the curricular innovations that comprise the foundations of the Metacognition course and the latest analyses of retention and student satisfaction.

Introduction:
Considerable research has shown that lack of ability is not what drives students from STEM fields [1] [2]. Seymour and Hewitt [1] found that students who left STEM fields had similar qualifications and grades as those that stayed, indicating that it was not lack of ability that led

them to leave. Research has also documented how metacognitive awareness, or lack thereof, can be a critical obstacle to student success (*e.g*. [3] [4]). Weak students are least likely to realize their deficiencies, and consistently overestimate their performance [5] [6].
While Flavell [7] began his work on metacognition on young children, more recently researchers have begun to apply the theory to higher education, focusing on contextual learning and transfer [8] [9] [10]. Tanner [11] outlines four main areas where students often fail at metacognition: 1) knowing how to learn; 2) monitoring and assessing their own learning and understanding; 3) being reflective about learning and understanding; and 4) knowing how to strategize in order to resolve gaps in knowledge or recognize confusion. She also emphasizes the complex interplay between metacognitive ability, self-regulated learning [12] [13], and self-efficacy [14]. Our course targets all three of these areas. Additionally, we incorporate considerable research on the role of student identity, including societal impacts on learning.

The President's Council of Advisors on Science and Technology has emphasized that the demands for STEM professionals and a scientifically literate populace far outstrip the supply [15], and the report notes that an increase in retention in foundational undergraduate science courses can address a significant portion of the projected shortage. Studies going back to the 1990s [16] [1] [17] indicate that it's not enough to merely change teaching strategies, however; to persist in science, students must also feel like they belong. Therefore, in addition to explicit metacognitive activities dealing with content, we have developed *affective* activities that reinforce student identities and foster a sense of belonging.

<u>Institutional Context</u>
The Rochester Institute of Technology is a large, private technical institution (18K total students, 13K undergraduate, 8K in STEM). RIT's Carnegie Classification changed to a research doctoral-granting institution in 2016, and the university is changing rapidly from what was once a regional career-oriented "teaching school" into a modern research university. RIT is the third largest producer of undergraduate STEM graduates among all private universities in the nation. RIT is a primarily undergraduate institution enrolling approximately 13,000 undergraduate and 3,100 graduate students on its main campus in Rochester, NY. For a technical institution, the student body is relatively high in diversity, with more than 2,600 international students and 1,650 African American, Latino/a American, and Native American (AALANA) students. RIT hosts the National Technical Institute for the Deaf, with 1,300 deaf/hard-of hearing students taking courses alongside their hearing peers.

RIT is fairly unique in that DHH students in BS programs are fully integrated into classrooms and laboratories in STEM majors. The university provides sign language interpreters, real-time captionists, note takers, tutors and other support systems for students who have hearing disabilities. These students work and learn alongside their hearing peers, and both groups benefit from the various communication styles that a diverse population brings to the classroom.

In 2016, RIT enrolled more than 750 transfer students, with about 70% coming from a community or junior college. RIT also has an unusual socioeconomic diversity, with 30% of RIT full-time undergraduates receiving financial assistance through the Federal Pell grant, almost twice the estimate for comparable institutions [18].

IMPRESS and the Metacognition course

The IMPRESS program is described fully elsewhere [18], and includes a summer bridge program, a credit-bearing academic course that is part of the general education program, and participation in the Learning Assistant Program. Here we focus on the stand-alone course "Metacognitive Approaches to Scientific Inquiry." The course examines metacognition in STEM learning, and in particular identifying and avoiding bias when gathering evidence in STEM fields. Content of the course includes a wide variety of topics, and learning theories in particular, drawing from sources such as *Mindset* [19], *How People Learn* [9] [10], motivation [20] and Bloom's Taxonomy [21]. Students learn about the learning theories, but also carry out activities and participate in case studies to actively examine their own learning and biases.

Because sense of belonging to a greater community is such a strong component of student identity ("I am an engineer") and success, the course focuses not just on learning and assessment of learning, but also has a greater context of societal factors that impact a student's ability to learn and persist. Therefore topics such as gender bias [22] and stereotype threat [23] are important component of course content. Because these topics can be difficult to internalize and discuss in an open forum, the course builds towards these topics, starting out with relatively easier topics (*e.g*. Mindset and Bloom's Taxonomy) and moving towards issues of belonging and identity by the end of the 15-week semester.

An important aspect of the course is that it is incorporated into the students' general education requirements and is not an extra burden of credits taken in addition to required program and general education coursework. RIT requires students to take a course that addresses identification of ethical questions, and the Metacognition course addresses the outcomes and has assessments that examine students' ability to identify and address ethical scientific questions through case study presentations.

Course content

The course is scaffolded to begin with easier, less "threatening" topics (e.g. mindset, Perry's Scheme, Bloom's Taxonomy), and move towards more personal or difficult topics (e.g. identity, belonging, bias) (Table 1). To prepare for class, students read primary literature, popular press versions of studies, watch TED talks and video interviews. A typical class consists of: 1) a review/question period of the readings/video, 2) an activity carried out as a class or in groups, 3) small group discussions, and 4) a reflective period.
Activities have been designed around each of these topics. For example, for Bloom's Taxonomy, learning can be improved by making explicit the Bloom level at which students are expected to perform within a class [21]. Students work in groups to identify levels of questions on their own homework and quizzes, and also design their own questions to illustrate each level. We have made use of several lines of research have metacognitive tools that make students aware of the various cognitive performance levels (e.g. remembering vs. synthesis vs.

evaluation) and have students "Bloom" their assignments to compare across disciplines [24] [25].

Additionally, each week we include a reflection period in class. Sometimes this is oral reflection with other group members, sometimes written in the form of a worksheet, or sometimes in the form of a quiet reflective time (QRT). QRT can be either guided ("Think of a time when you were successful at a difficult task") or unguided, and require the students to sit quietly for 2-10 minutes without stimulation. For some students this is difficult, but research shows that time for reflection leads to more innovative and creative responses [26].

Table 1. Examples of topics, readings and associated learning outcomes

Topic	**Readings**	**Activity/Learning Outcomes**
Mindset	Selected chapters from *Mindset* [19]	Compare and contrast growth and fixed mindsets
Bloom's Taxonomy	Primary literature with examples [25] [24]	Classify questions from STEM courses; create their own questions
Motivation	Selected chapters from *Drive* [20]	Examine and describe their own motivations; participate in Pink Time [13]
Self-Assessment	Primary Literature [5], Popular press article [27]	Describe the Dunning-Kruger effect; examine how it affects one's ability to predict performance
Experts and Novices	Selections from *How People Learn* [9]	Compare and contrast how experts and novices approach problem solving
Self-efficacy	Primary literature [28]	Identify the four sources of self-efficacy; apply them to oneself
Stereotype Threat	Videos of Claude Steele interviews [29]	Describe stereotype threat; discuss methods for overcoming negative impacts of stereotype threat
Underrepresented groups	Popular press articles [30] [31]	Identify barriers to underrepresented groups feeling a sense of belonging in STEM fields (*e.g*. women in tech)

Interwoven with the topics and activities are three "case studies" that the students produce in groups (usually 3-4 students per group) to present to the class in a formal presentation. The case studies are designed to examine three distinct sets of topics/issues:

1) **Working in groups, consensus making and conflict resolution**. In this case study, students are given a packet of letters of recommendation and a hiring scenario (described in [32]). Students are placed in groups to maximize conflict over who should be hired, and then must document not only who they should hire, but *the consensus process by which they reached this conclusion*. This exercise focuses students on the process of working in a diverse group, and part of the grade on their presentation comes from explaining how the decision was reached with input from all members. Because

they are put into groups with others who think differently than they do, the exercise also encourages the students to examine their ability to work with others who are different from themselves.

2) **Examining teaching/learning aspects of their own courses**. The second case study has students examine some aspect of their own STEM coursework. Students make observations, give surveys, assess questions, *etc*. within their majors courses to come to a conclusion about teaching and learning. Simultaneously, they must devise a method for quantifying input of group members to the project. In this project, students are typically grouped by major.
3) **Confirmation Bias in Science Controversies**. The last case study comes after a series of activities in class that focus on confirmation bias, and asks students to examine the process by which they search for and select evidence for a controversial scientific subject (*e.g*. hydrofracking, GMOs, *etc*.). Students must then come to consensus in their group about a particular controversy, and also document what evidence they used and how they assessed the quality and potential bias of that evidence.

Students are also required to do weekly self-reflections in the form of guided reflection forms (GRFs). GRFs are a way to get and give feedback from/to students about course content, and also co-curricular issues. Examples include confusing aspects of the course, time management, how to build a network, where to find resources to support the student, *etc*. [33]. Students fill out an online form that guides them through a forked series of questions and reflections, and the instructor then can respond to each student individually. As instructors, we get valuable feedback from students about what aspects of college life they are struggling with [34] [35], and we can help point them to campus resources and/or a specific person who can help them. We also can provide support for positive and negative experiences they encounter, as well as find out what aspects of the course are working (or not) for students.

Course assessments consist of homework exercises, weekly GRFs, participation and case study presentations. Homework typically consists of short essays, reflections, worksheets or other out-of-class assignments that reinforce and extend classroom discussions and readings.

<u>Results and Lessons Learned</u>

Logistics

Over five years, 10 sections of Metacognitive Approaches to Scientific Inquiry have been taught, with typically 24 students per section, leading to approximately 240 students enrolled in the course. Enrollment is restricted to first-year students with STEM majors (*e.g*. science, computer-related fields, mathematics, engineering, and engineering technology). All students enrolled in the course are either first generation or D/HH.

Each May, after students have declared their intent to enroll at RIT and paid their deposit, a mailing about the IMPRESS program goes out to all eligible students (FG and/or DHH STEM majors). Students are invited to submit an application to attend the summer bridge program and/or indicate interest in enrolling in the fall academic course. An enrollment list is created that takes into account student requests, but also prioritizes underrepresented identities, including women and AALANA students. Prioritized lists are then circulated to professional advisors, who create first-year student schedules and assist with enrollment. The result of this effort is that IMPRESS student demographics are inclusive: 35% are women; 32% from identities historically excluded from STEM disciplines; and 17% Deaf or Hard of Hearing (DHH). More IMPRESS students are drawn from engineering fields (57%) than others (CS/tech: 23%; Science 20%) simply because of the greater number of engineering students on campus.

Retention

At the start of our project, the institutional average for 2-year retention of D/HH and FG students in STEM was 60%, and 4-year retention was 50%. We sought to raise these rates to the institutional average for all students, and we were successful in that goal (Figure 1). IMPRESS students are more likely to be enrolled full time than their peers, and the retention rate within RIT (but not necessarily STEM) is even higher. Some of these students have gone into the Health Sciences College, which means they are in STEM-related field (though not technically STEM).

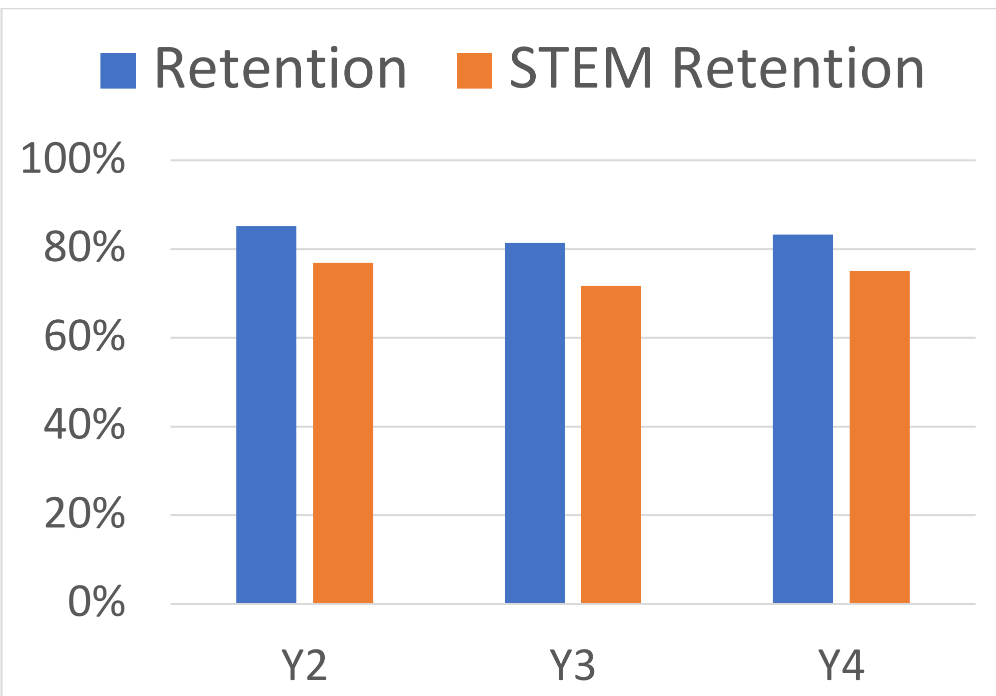

Figure 1. Cumulative retention rates of IMPRESS students staying enrolled at RIT (blue) and also retained within STEM majors (orange). The goal of the project was to improve the retention rates of D/HH and FG students at RIT in STEM at the beginning of the study (2-year retention: 60%; 4-year retention: 50%).

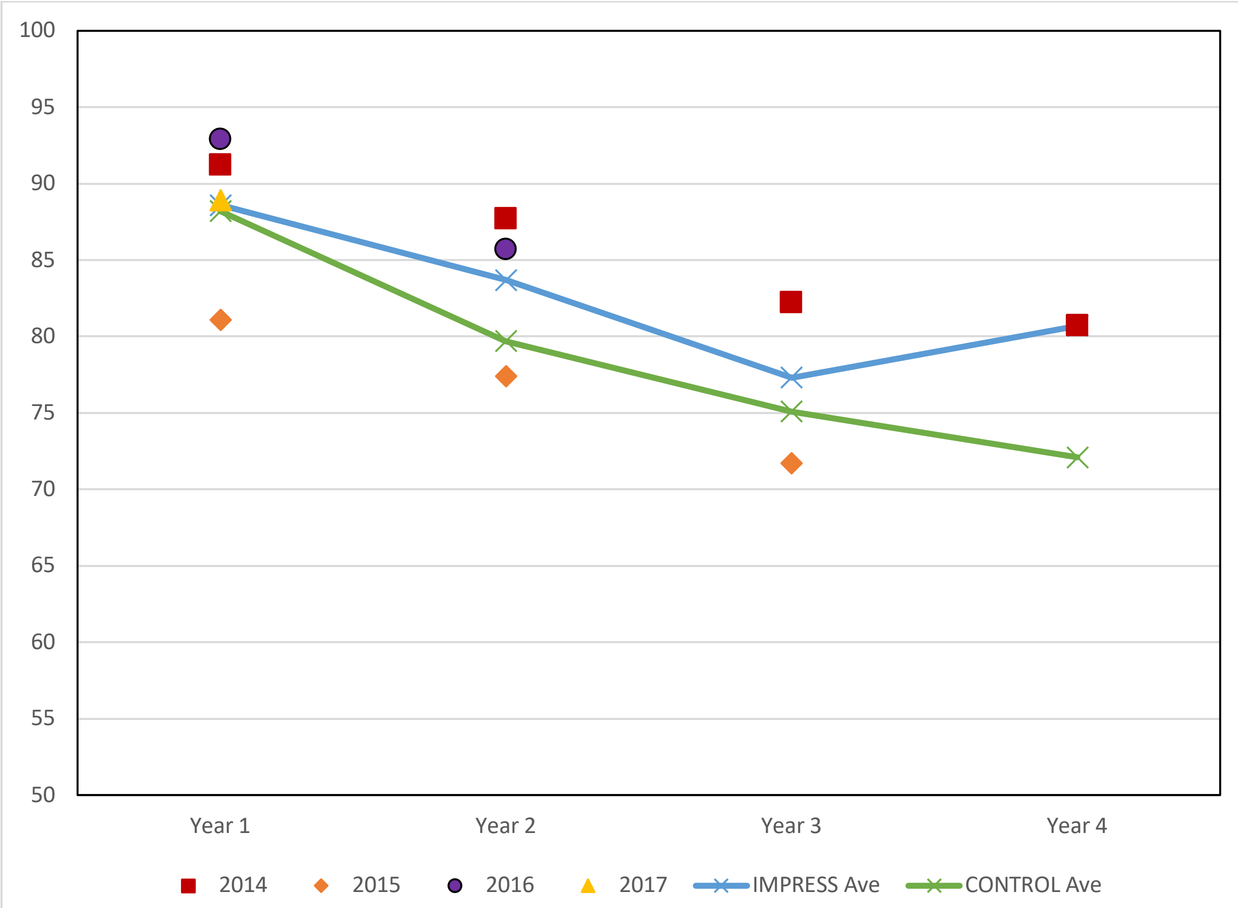

Figure 2. Retention rates of the first four IMPRESS cohorts (n=211). The average of the IMPRESS cohorts is shown in blue. The "control" average is for all other RIT STEM students who are D/HH or FG (n=1833). Note that the demographics of these two groups by gender and race/ethnicity are not similar, as the IMPRESS group has higher percentages of women and AALANA students.

The average retention of the students in the IMPRESS cohorts is higher than the institutional average for STEM majors who are D/HH or FG (Figure 2). Because only one cohort (2014) has reached the 4-year mark, it is hard at this point to draw generalizations, and we do not yet have graduation rates, as most of the technology and engineering programs at RIT are 5-year programs, which include a mandatory year of co-operative education. Indications are at this point that the IMPRESS students are more likely to remain in STEM. We also know they are 7% more likely to remain enrolled full time after the first year, indicating that they are more likely to be on track for on-time graduation.

The IMPRESS average was impacted by lower retention rates in the 2015 cohort, which was anomalously low (Figure 2, orange diamonds). Because the class size is small, relatively minor fluctuations in student drop-out rates can have fairly large shifts in the retention rate.
As part of an external study looking at how efforts to improve retention varied across institutions, the IMPRESS students (n=47) were surveyed alongside FG non-IMPRESS students (n=708) to gage their sense of belonging in their majors and at RIT. In a two sample Z test, IMPRESS students responded more negatively to the question, "if I had to do it all again, I

would go somewhere else" (p=0.027), indicating that they were much more likely to choose RIT again and felt RIT was a good choice of colleges.

Lessons Learned

We suggest that if possible, it is important to ensure the class has >30% proportion of women; for many women in technology or engineering, the class may be the only one that has significant numbers of other women enrolled. The class discussions are enriched by the presence of a diverse community, and female students feel more comfortable speaking out when they do not feel like the sole representative of their gender and major in the room.

To date, all sections of the course have been team-taught by scientists. Team teaching provides a broader range of experiences to illustrate concepts from the course. It also provides an opportunity to model behavior of scientific debate and disagreement in an academic environment. The course does not necessarily need to be team-taught to be successful.

Incorporating D/HH students into a mainstream RIT course is not unusual as there are more than 1200 D/HH students on campus, with >200 D/HH students matriculated into BS programs at RIT. D/HH students are supported by a team of faculty and staff, including instructional faculty, interpreters, captionists, notetakers, tutors and NTID support faculty [35]. Significant resources are available on campus to assist faculty with inclusive teaching practices for deaf students (e.g. [36]), including how to place students for group work, working one-on-one, and classroom strategies. This mainstreaming may be more difficult in other campuses, but it is possible if the resources are available to fully support the student.

We originally envisioned that many faculty would teach the course from the perspective of a variety of STEM disciplines, but as yet, only four faculty have served as instructors. The course approach requires relatively small class size (24 per section) and thus the small number of participating faculty limits the number of students that can be reached. The lack of participation is not due to disinterest; rather, the combination of lack of faculty time to teach a new course, given the demands of major/program courses, and also a lack of training in the area of metacognition discourages participation. The course falls within the general education curriculum, and many STEM faculty are dedicated to teaching within the context of STEM programs. Incorporating aspects the course into a first year experience or first year seminar, would be ideal. Alternatively, lessons and exercises could be adapted into majors courses in individual disciplines.

As new work is published and we become more aware of existing work, we have refined and updated the course. For example, *Pink Time* was incorporated after one of us saw a conference talk by the authors at a T-Summit meeting and has greatly enriched our conversations with students about motivation. Currently the class readings on underrepresentation focus on gender (e.g. women in computing), but these will be updated to include other groups, such as LGBTQ+ and D/HH individuals, and the concept of intersectionality.

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