Engaging Students in Authentic Research in Introductory Chemistry and Biology Laboratories

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Abstract

Engaging students in research early on in the college experience may help reduce the number of students who drop out of STEM after experiencing one of the gateway courses, such as the introductory laboratory courses. Typical introductory laboratories do not show students the nature of scientific careers, the application of science in everyday life, and how science is interdisciplinary. Undergraduate research programs, such as UROP at the University of Michigan have been successful at engaging students early on in their academic life in research-based experiences. However, scaling up has been difficult. One approach is incorporating authentic research experiences into the course curriculum, specifically introductory laboratory courses. Authentic Research Connection (ARC), funded by the Howard Hughes Medical Institute (HHMI) at the University of Michigan, College of Literature, Science & Arts is bringing faculty-led research projects into two of the largest introductory science laboratories, introductory biology and introductory chemistry, that together enroll approximately 3500 students each year. Faculty members involved in ARC design a semester-long research project that builds on and adds to ongoing research in their laboratory. Preliminary assessment of the research sections consisted of a pre and post survey of students in control, non-research sections, and the intervention, research, sections of ARC. The survey data showed that the research sections significantly maintained student's interest in biology/chemistry than the non- research sections.

Introduction

One of the important issues facing higher education is the retention of science majors[1]. Undergraduate students who conduct research early on are more likely to stay in STEM[2, 3]. Course-based undergraduate research experiences (CUREs) are an emerging trend that have shown similar gains in retention as shown by students who conduct apprenticeship-style research[4, 5, 6]. One major gap in our understanding of CUREs is the variability in design and implementation as well as what parts of a CURE are needed for students to achieve similar gains as apprenticeship-style research[4]. We propose a model for a research-based course that can be applied across disciplines and evaluate its effectiveness.

The Authentic Research Connection program (ARC) was established in 2015 as a joint project between the Department of Chemistry and the two Biology Departments (Molecular, Cellular and Development Biology and Ecology and Evolutionary Biology) in the College of Literature, Science & Arts (LSA) at the University of Michigan. It is currently funded by the Howard Hughes Medical Institute (HHMI) to increase access to authentic research projects, including contributing to publishable research that moves science forward; using the scientific method of hypothesis generation, testing, and interpretation; and participating in an intergenerational research community (faculty, postdoctoral fellows, graduate students, undergraduate students). Two gateway introductory laboratory courses were targeted; Biology and Chemistry that together enroll approximately 3500 students each year.

The objectives of the project are to:

1. Create and implement a model to incorporate faculty-led research projects into introductory Chemistry and Biology laboratories.

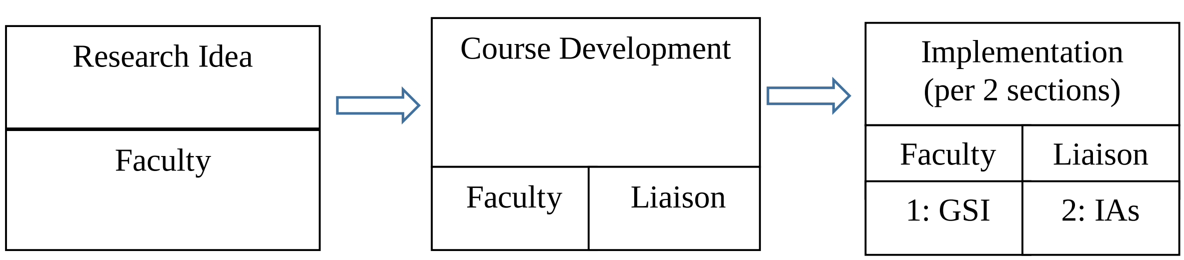
2. Determine whether authentic research in introductory laboratory classes has an impact on students' attitude, interests, confidence and self-efficacy in STEM and ultimately on graduation rates of STEM majors.

At the University of Michigan, the introductory laboratory components of both biology and chemistry are taught independently from the lecture courses. Introductory Chemistry laboratory (Chem 125/126) is 2 credits and is broken down into lecture (1 hr.), and a combined discussion and laboratory session (3 hrs.). There is no prerequisite for this course and the Chemistry lecture course (Chem 130) is not required to be taken concurrently, although this is strongly advised. The lab focuses on hands-on experience including experimental design, data analysis, and oral communication skills. It is typically taken during the freshman year by both STEM and non-STEM majors (the latter are predominantly premed majors). Introductory Biology laboratory (Bio 173) is also 2 credits and is structured as a lecture (1hr) and laboratory (3hrs). However, the prerequisite for this laboratory is an introductory biology course (Bio 171 and/or 172) or AP Biology credit. It is typically taken in the sophomore year by students in the biological sciences and premed majors.

ARC Model

Faculty members involved in ARC design a semester-long research project that builds on and adds to ongoing research in their laboratory. Designated members of their research group, from postdocs to undergraduates, serve as liaisons to the course instructors and students. Figure 1 below shows how each research section is created and implemented. Faculty members identify research projects from their laboratories that can fit in the constraints of a 14 week long semester. After a project is identified, the faculty member works with a postdoc or senior graduate student (the "liaison") to create student lab protocols that can be conducted within the constraints of the introductory teaching laboratories. Additional equipment/chemicals required for the experiments are identified and approved by building management and safety officers prior to being added to the teaching laboratories.

Figure 1. Authentic Research Connection Model



Faculty' research projects conducted within these laboratory courses have been named research streams. Each research stream starts off with 2 sections of the introductory laboratory course.

Students who wish to take the research stream fill out an application and wait for approval. Ideally, we would like to randomly select participants from among the students who apply to facilitate comparison between participants and nonparticipants. However, since this was the first time the courses were being offered every student who applied was offered a seat in the course.

Supervision and instruction during the laboratory period is primarily handled by a Graduate Student Instructor (GSI) and an Instructional Aide (IA), who is an upper level undergraduate student. Ideally, both the GSI and IA are already working with the faculty member in their research laboratory and so are familiar with the research questions and protocols. IAs assist in preparing samples, chemicals, and equipment setup prior to the laboratory time. They also assist in conducting experiments and answering questions during the laboratory. The postdoc or graduate student liaison, along with the faculty member, work with the GSIs and IAs and the student participants to ensure that class procedures confirm to the research protocols.

Over a semester, students hear presentations by the faculty member on the overall research goals and particular projects, discuss relevant hypotheses and design appropriate tests of those hypotheses with guidance from the faculty member and research group liaisons, learn basic skills to implement those tests, collect and analyze data in the laboratory with a GSI and IA, and write up their results in science journal paper format. At the end of the semester, student teams present their results in a symposium or poster session to which the entire research group of the faculty member, as well as other members of the departments are invited. Eventually each research stream will ramp up to a maximum of 4 laboratory sections. Data collected during these research streams may be used by the research group to write journal articles or used as preliminary exploratory data to write research grants.

Assessment

The University of Michigan Institutional Review Board (IRB) gave approval to work with human subjects in all aspects of the assessment (IRB # HUM 00094780). Surveys were given at the beginning (pre) and end (post) of the semester to both the research (intervention) and non-research (control) sections. Additionally, we conducted interviews of students in both the research sections and the non-research sections. Longer-term studies will also incorporate student grades, majors, and eventual graduation in STEM.

Survey Instrument

The survey focused on student attitudes, interests, and self-efficacy in STEM in both introductory Chemistry and introductory Biology laboratory courses. We used a modified compilation of four independent published instruments, which we called Research Based Course Assessment (RBCA). We present in this paper only 5 factors from the RBCA survey, which are summarized in Table 1, see Appendix A for actual questions. The interest factor is actual two different set of questions, initial and maintained. Factor 1, initial/maintained interested, was originally designed to measure students' interest in psychology[7], and then modified for chemistry students[8]. For this study we modified it further for Biology students by replacing "chemistry" with "biology" in the survey questions. Factor 2, efforts belief, as explained by Ferrell et al.[8] can be seen as part of students' ability. Students who have high ability and display high effort will most likely be a stronger student and vice versa[8, 9]. These attributes in students have been shown to have a positive effect on students' persistence[10]. As with Factor 1, Factor 2 was designed for Chemistry students and was modified to include Biology students as well. Factors 3 and 4 were designed by Bauer[11] for Chemistry students and modified to include Biology students. They both measure how students feel about the discipline as a whole, rather than about a specific course. The factors intellectual accessibility, F3, and interest and utility, F4, are designed to measure the extent to which students feel that mastery of the discipline is obtainable and useful, respectively. Factor 5, Laboratory Ability, measure how confident students were in conducting typical tasks in laboratory (i.e. interpreting lab data, using equipment in the lab, collecting data, developing hypotheses, writing a lab report, etc.). This sub factor was originally designed for Biology students[12] and extended to Chemistry in this study. All five factors were adjusted to a 5-point scale. The RBCA survey was first piloted in non-research sections of the introductory Chemistry laboratory during summer 2015 and adjusted based on student interviews.

Table 1. Survey Factor Descriptions

Factor Number	Factor Name	Factor Description	Survey Source
F1	Interest: Initial & Maintained	Designed to measure students' initial interest and the maintained or "hold component of situational interest"	Harackiewicz et al.[7] Ferrell & Barbera[8]
F2	Self-Perceived Ability	Measures students sense of ability, which can reflect on a student's persistence	Ferrell & Barbera[8]
F3	Intellectual Accessibility	Students feel how obtainable the knowledge of the subject is to them	Bauer[11]
F4	Importance & Use	Students feel how useful and important the subject is to them	Bauer[11]
F5	Lab Confidence	How confident a student feels about completing laboratory-based tasks	Brownell et al.[12]

Analyses

To evaluate objective 2, we compared student means in each factor between the pre and post surveys in each of the research and non-research sections using paired t-tests. Additionally, we compared the research and non-research sections using unpaired t-tests. Cronbach's alphas were computed for all factors in the pre and post surveys to test the reliability of the factors. Cronbach alpha measures the internal consistency of items within a given factor[13 14]. A value around 0.7 or above is considered to have a sufficient internal consistency for each factor[13].

Results

ARC Model Implementation

Objective 1 was first implemented in Winter 2015, with only 2 research sections in Biology 173; however no data were collected. In Fall 2015 research sections in both introductory Chemistry and Biology laboratories were offered. Four sections of the same research stream were offered in Biology, and two sections of each of two different research streams were offered in Chemistry. Student numbers in both the research sections and non-research sections (Control) are shown in Table 2.

Current faculty-led research projects include: studies of the human microbiome (effects of diet on composition and functioning of the gut microbiome), studies of snow chemistry and climate change (how does salt incursion change reflective properties of snow and therefore feedback to climate change), and studies of solar energy conversion technology (comparisons of efficiency of solar cells incorporating different metals)

Table 2. Course Enrollment Information Fall 2015

	No. of Sections	No. of Students Enrolled
Biology		
Research	4	80
Non-Research	32	575
Chemistry		
Research	4	58
Non-Research	48	1044

Student Demographics

At the University of Michigan many students do not declare a major until the end of their second year or even their third year. Thus, most of the students in the chemistry and biology laboratory have yet to declare a major. The “pre” survey instrument asked students to identify their intended major. The majors were then grouped into engineering, science, undecided, and other, shown in Table 3 below. Students taking these introductory laboratories fall within the STEM fields.

Table 3. Intended majors of students (from pre survey)

Intended Major	Biology Research N=70	Biology Non-Research N=503	Chemistry Research N=57	Chemistry Non-Research N=987
Engineering	5% (4)	8% (40)	35% (20)	39% (384)
Science	56% (39)	53% (266)	44% (25)	28% (281)
Undecided	10% (7)	11% (56)	9% (5)	19% (186)

Other (Nursing, Dental, PostBac, Public Health, Education, Kinesiology, Language)	29% (20)	28% (141)	12% (7)	14% (136)

Students' demographic data for both the biology and chemistry laboratories courses can be seen in Table 4 below. Response rates for the students in Fall 2015 who took both the pre and post survey for the Biology research and non-research sections were 72% and 71%, respectively. The response rates for the Chemistry research and non-research sections were 74% and 67%, respectively. The data shown are only for students who took both the pre and post surveys in both courses.

Table 4. Demographic data for students who took both the pre and post survey

	Biology Research N=57	Biology Non-Research N=415	Chemistry Research N=43	Chemistry Non-Research N=700
Gender				
Male	44% (25)	32% (134)	37% (16)	50% (349)
Female	56% (32)	67% (276)	63% (27)	50% (347)
Prefer Not to Say	0% (0)	1% (5)	0% (0)	0% (4)
Ethnicity				
Asian	23% (13)	18% (74)	21% (9)	20% (138)
Black American	4% (2)	3% (11)	2% (1)	3% (21)
Black non-American (eg. African, West Indian, etc.)	0% (0)	0% (3)	0% (0)	1% (8)
Latino/a or Hispanic	5% (3)	2% (9)	0% (0)	5% (33)
Caucasian	49% (28)	67% (276)	72% (31)	63% (440)
2 or more ethnicities	10% (6)	5% (21)	5% (2)	5% (36)
Native American	0% (0)	0% (0)	0% (0)	0% (1)
Hawaiian or Pacific Islander	0% (0)	0% (1)	0% (0)	1% (5)
Other	7% (4)	3% (11)	0% (0)	1% (9)
Prefer Not to Say	2% (1)	2% (9)	0% (0)	1% (9)
Academic Year Level				
Freshman	14% (8)	18% (74)	65% (28)	70% (488)

Sophomore	58% (33)	46% (191)	35% (15)	26% (181)
Junior	21% (12)	24% (100)	0% (0)	2% (17)
Senior	5% (3)	11% (46)	0% (0)	2% (11)
Other	2% (1)	1% (4)	0% (0)	0% (3)

Survey Reliability Test

The reliability of each factor was tested because the survey instrument used in this study was a modified version of published instruments. Cronbach alphas were calculated for all factors for both chemistry and biology, shown in Table 5. The item comprehensible/incomprehensible was excluded from F3: intellectual accessibility because, from interviews, students did not fully understand the statement. All alpha values for Biology and Chemistry pre and post surveys were 0.7 and higher and considered reliable.

Table 5. Cronbach's Alpha

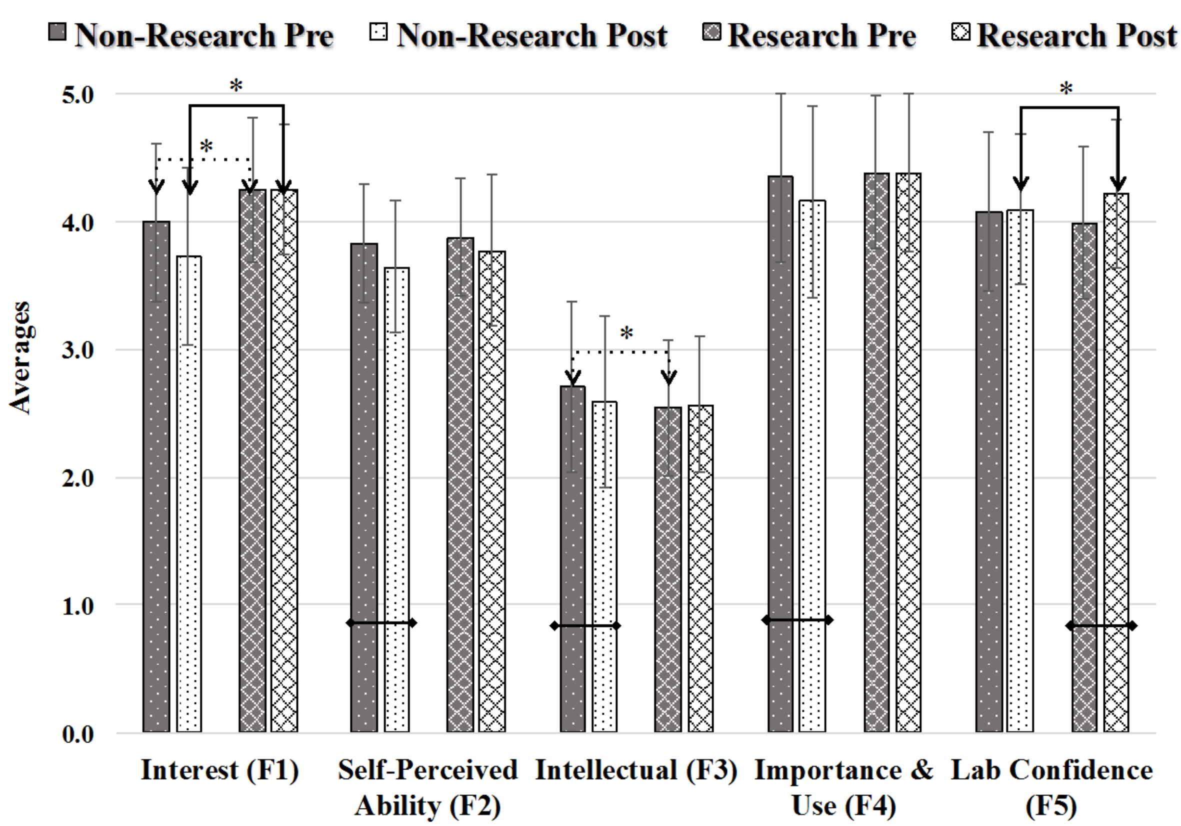
	Factor Name	No. of Items	Cronbach Alpha	
Biology			PRE	POST
F1	Initial Interest	6	0.85	N/A
	Maintained Interest	6	N/A	0.85
F2	Self-Perceived Ability	9	0.70	0.74
F3	Intellectual	4	0.72	0.72
F4	Importance & Use	5	0.86	0.88
F5	Lab Confidence	8	0.90	0.90
Chemistry			PRE	POST
F1	Initial Interest	6	0.86	N/A
	Maintained Interest	6	N/A	0.86
F2	Self-Perceived Ability	9	0.74	0.72
F3	Intellectual	4	0.79	0.79
F4	Importance & Use	5	0.85	0.86
F5	Lab Confidence	8	0.89	0.90

The RBCA survey was modified to fit on a 5-point scale, 1.0 to 5.0. The closer to 5.0 the more interest in the subject (F1), the greater sense of ability (F2), the more obtainable the knowledge (F3), the more important/useful (F4), and the greater confidence (F5) the student felt.

Biology

We first compared all the factors in the pre survey between the non-research and research sections to see if both groups started at the same level and found only two of the five factors differed (Figure 1). The initial interest (F1pre) was significantly lower in the non-research sections than students in the research section. This is not unexpected because students in the research section have to apply to enroll which shows some enthusiasm for biology. Additionally, the non-research sections viewed biology as more intellectually accessible (F3). Over the semester, this same factor, along with self-perceived ability (F2) and importance and utility of the subject (F4) declined significantly in the non-research sections, while these three factors did not change significantly in the research sections. The interest factor could not be compared pre versus post for the research and non-research groups due to the differences in the actual questions. Therefore we compared research and non-research sections. Indicating benefits for student retention in STEM, participants in the research sections had a significantly higher maintained interest (F1post) and confidence in the laboratory (F5) than students in the non-research sections.

Figure 1. Biology Research Based Course Assessment (RBCA) Survey Results Fall 2015



Legend: Within each factor, the non-research sections (dots) are on the left and the research sections (x's) on right. Within each pair, pre is on the left (shaded) and post (white background) on the right

* Significant difference, p-value <0.05

Significant difference between **pre** research and **pre** non-research, p-value <0.05

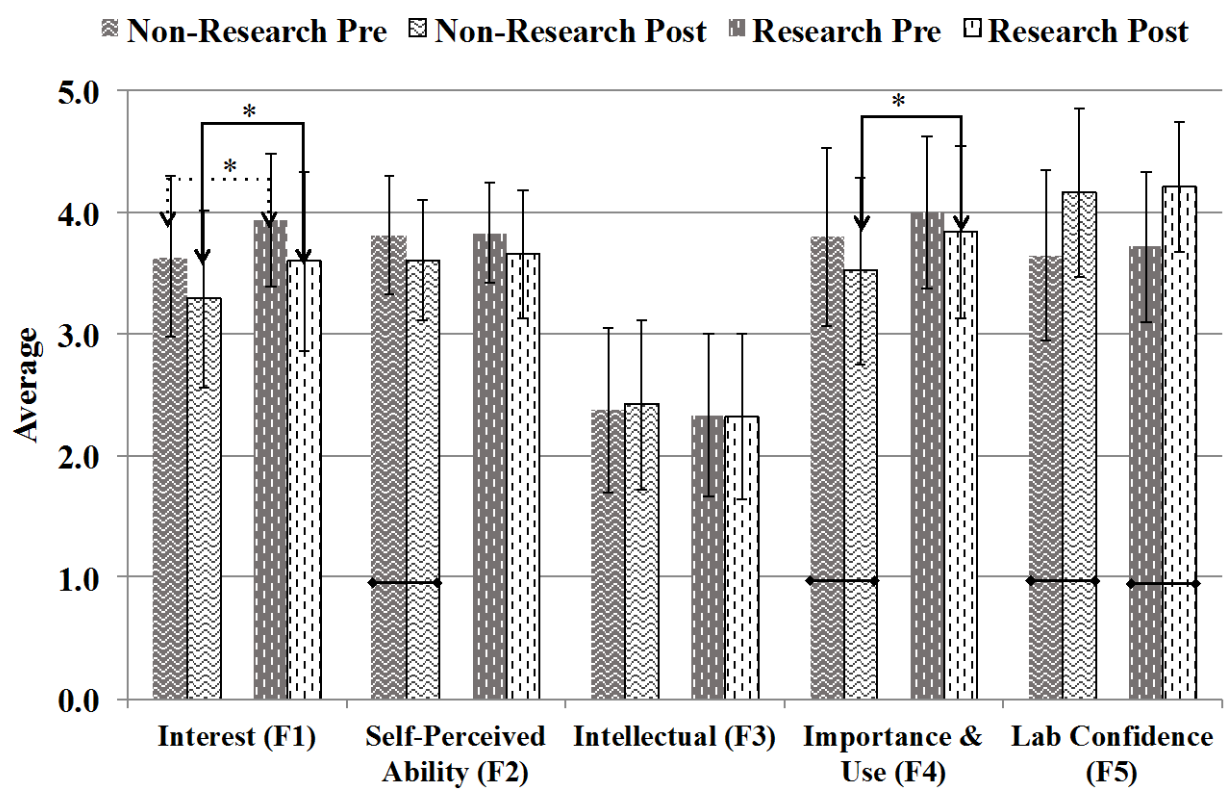
Significant difference between **post** research and **post** non-research, p-value <0.05

Significant difference between **pre** versus **post**, p-value <0.05

Chemistry

Similarly, we compared all the factors in the pre-survey for the non-research and research sections and found only one factor differed out of five: as in biology, the research sections perceived Chemistry with a higher sense of initial interest (F1pre) (Figure 2) and also had a significantly higher maintained interest (F1post) than those in the non-research section. Also as in biology, over the semester self-perceived ability (F2) and importance and use (F4) declined significantly in the non-research sections, while these two factors did not change significantly in the research sections. Participants in both the research and non-research sections significantly increased their confidence in their ability to perform laboratory tasks; but, unlike in biology, the research and non-research sections did not differ in the post survey (F5).

Figure 2. Chemistry Research Based Course Assessment (RBCA) Survey Results Fall 2015



Legend: Within each factor, the non-research sections (zigzags) are on the left and the research sections (horizontal dash lines) on right. Within each pair, pre is on the left (shaded) and post (white background) on the right

* Significant difference, p-value <0.01

Significant difference between **pre** research and **pre** non-research, p-value <0.01

Significant difference between **post** research and **post** non-research, p-value <0.01

Significant difference between **pre** versus **post**, p-value <0.01

Discussion and Conclusion

The implementation of the model was very successful overall. One important lesson however is that we need to increase the flexibility in the syllabus so that students can repeat laboratory experiments when needed. This, of course, is not unlike what happens in authentic research laboratories. We also did not fully take into account the increase in laboratory prep time and staffing needed in the original budget model. We plan to increase the number of research streams in Biology and Chemistry in future years.

One important consideration in interpreting the results is that students apply, i.e., self-select, into the research sections. A bias is formed when students self-select a group. This bias can be seen when the pre factors were compared in the research and non-research sections. Some institutions are in the early stages of eliminating the self-select bias by converting all sections of a course in an academic semester, but that in turn eliminates a control group for comparison[15, 16]. In Biology F3: intellectual accessibility, and in both courses F1pre: initial interest, were significantly different at the beginning of the semester. Differences in the pre factors are not unexpected and are the reason why we focus interpretation on the pre-post comparisons within each type of section, as well as on differences between sections at the end of the course when sections started out the same for a given factor.

Students in the research sections for Biology became more confident in their laboratory skills (F5), while the students in the non-research sections did not change in confidence level. This is presumably because the structure of the research sections gave students more ownership and room to repeat experiments in the project than in the non-research sections. This type of authentic research in introductory laboratories also maintained student interest in the subject when compared to the non-research sections. Students in Chemistry for both the research and non-research sections became more confident in their laboratory skills (F5). This is probably due to the fact that the majority of the student participants are freshman who lack lab experience.

The research sections in Biology had relatively higher averages for four out of the five different factors (except Factor 3 intellectual accessibility) when compared to the research sections in Chemistry. This may be due to some specific differences between the Biology and Chemistry research sections. One difference to note is the actual nature of the research involved. Students in the Biology research sections are the subjects of the research. It is their own microbiome that they are studying which gives an increased ownership of the research. In the Chemistry research sections there are two different projects taught by two faculty; one creating a solar cell device and the other analyzing snow samples to investigate climate changes. Another difference is the academic year-level of the participants. Introductory Chemistry and Biology laboratory are taken mainly in the first and second year, respectively. First year students coming directly from high school might have a different perspective on STEM and learning then second year students. Lastly, this was the second time the Biology research sections were offered while it was the first time for the Chemistry research sections.

The maintained interest factor (F1post) in the non-research sections was significantly lower than the research sections in both Biology and Chemistry. Factor F2: self-perceived ability and F4: importance and use also significantly decreased for the non-research section for Biology and

Chemistry, respectively. While a distressing result for the value of the regular sections, the fact that this decline does not happen in the research sections is consistent with the hypothesis that engaging students in authentic research early on may have an impact on STEM persistence.

Overall, the main conclusion from the preliminary data is that authentic research in the introductory laboratories is sustaining students' interest in Chemistry and Biology and increasing students' confidence in the laboratory. Longitudinal assessment over the next three to four years will show if these research-based laboratory experiences increase persistence in STEM by following student participants and controls all the way to graduation at the University of Michigan.

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Appendix A: Survey Questions

Factor 1Pre: Initial Interest

Strongly Disagree, Disagree, Neither Agree nor Disagree, Agree, Strongly Agree

1. I chose to take introductory *chemistry/biology* lab because I'm really interested in the topic.
2. I am really excited about taking this class.
3. I am really looking forward to learning more about *chemistry/biology*.
4. I think the field of *chemistry/biology* is an important discipline.
5. I think that what we will study in introductory *chemistry/biology* lab will be important for me to know.
6. I think that what we will study in introductory *chemistry/biology* lab will be worthwhile for me to know.

Factor 1Post: Maintained Interest

Strongly Disagree, Disagree, Neither Agree nor Disagree, Agree, Strongly Agree

1. This semester, I really enjoy the *chemistry/biology* material we covered in lab.
2. I am excited about what we are learnt in *chemistry/biology* lab this semester.
3. What we are studied in *chemistry/biology* lab is useful for me to know.
4. The things we studied in *chemistry/biology* lab this semester are important to me.
5. What we learnt in *chemistry/biology* lab this semester is important for my future goals.
6. What we learnt in *chemistry/biology* lab this semester can be applied to real life.

Factor 2: Self-Perceived Ability

Strongly Disagree, Disagree, Neither Agree nor Disagree, Agree, Strongly Agree

1. To tell the truth, when I work hard at *chemistry/biology*, it makes me feel like I'm not very smart. R
2. It doesn't matter how hard you work if you're not smart in *chemistry/biology*, you won't do well in it. R
3. If you're not good at *chemistry/biology*, working hard won't make you good at it. R
4. If *chemistry/biology* is hard for someone, it means that he or she probably won't be able to do really well at it. R
5. If you're not doing well at *chemistry/biology*, it's better to try something easier. R
6. When *chemistry/biology* is hard, it just makes me want to work more on it, not less.
7. If you don't work hard at *chemistry/biology* and put in a lot of effort, you probably won't do well.
8. The harder you work at *chemistry/biology*, the better you will be at it.
9. If a *chemistry/biology* assignment is hard, it means I'll probably learn a lot doing it.

Factor 3: Intellectual

Chemistry/Biology Is:

1.	Complicated	1 2 3 4 5	Simple
2.	Confusing	1 2 3 4 5	Clear
3.	Easy	1 2 3 4 5	Hard (R)
4.	Challenging	1 2 3 4 5	Unchallenging

5. Comprehensible 1 2 3 4 5 Incomprehensible (Omitted Based on Cronbach Alpha and Student Interviews)

Factor 4: Importance and Use

Chemistry/Biology Is:

1.	Worthwhile	1 2 3 4 5	Useless (R)
2.	Worthless	1 2 3 4 5	Beneficial
3.	Good	1 2 3 4 5	Bad (R)
4.	Interesting	1 2 3 4 5	Dull (R)
5.	Exciting	1 2 3 4 5	Boring (R)

Factor 5: Lab Confidence

Not Confident 1, 2, 3, 4, 5 Very Confident

1. Collecting data during *chemistry/biology* lab.
2. Using the equipment in the *chemistry/biology* lab.
3. Interpreting data during lab sessions.
4. Carrying out experimental procedures in the *chemistry/biology* lab.
5. Developing my own hypothesis.
6. Presenting lab results to lab members.
7. Writing an accurate full length lab report (intro, methods, results & discussion).
8. I will be successful in this *chemistry/biology* lab course.

Note: R denotes reverse coding