Supplemental Material

CBE—Life Sciences Education

Fendos *et al*.

Supplemental Materials

Methods

STable 1. Demographics of pre-CURE focus group and interview participants*

	Experience	Female	Male
U[1]	1st year undergraduate	2 (0)	
	2nd year	1 (0)	2 (0)
	3rd year	5 (3)	7 (5)
	4th+ year	4 (4)	4 (4)
F	0-5 years as a professor	1	1
	6-10 years	2	3
	10+ years		1
P	Grad student, 1st year	1	1
	Grad student, 2nd year	3	2
	Grad student, 3rd year	1	1
	Grad student, 4th+ year		1
	LS[2] w/ bachelor's degree	1	
	LS[2] w/ master's degree	1	

*in first column: U = undergraduate, F = faculty, P = postgraduate

[1] parentheses indicate undergraduates with prior or ongoing MR experience at time of discussion

[2] LS = laboratory staff (e.g. technician, lab manager)

Exit (E) survey questions

(asterisks denote questions used for pre-post comparisons)

E1. I am:
a) male
b) female

E2. I am:
a) first-year undergraduate
b) second-year undergraduate
c) third-year undergraduate
d) fourth-year undergraduate
e) graduate student

E3. My current or intended major is:
a) biological sciences
b) medical sciences
c) other sciences
d) not science

E4. What topical track did you just finish?
a) biochemistry
b) cell biology
c) fish genetics
d) fly genetics
e) mouse genetics
f) plant genetics

*E5. Please rate your science abilities. I feel competent…

	agree	agree a little	disagree a little	disagree
…designing good hypotheses to test				
…writing good proposals for experiments				
…designing appropriate experiments to answer a scientific question				
…designing appropriate controls for experiments				
…conducting experiments without mistakes				
…collecting and understanding experimental data				
…interpreting experimental results and drawing good conclusions				
…presenting data and explaining my work to others				
…trying new things and being innovative				
…asking good questions about experiments and being curious				

E6. How much do you feel you learned in BIOS overall?
a) a lot
b) some
c) a little
d) none

E7. How much do you feel your lab skills improved compared to before BIOS?
a) a lot
b) some
c) a little
d) none

E8. How much fun did you have during BIOS?
a) a lot
b) some
c) a little
d) none

E9. How much did your overall science knowledge improve compared to before BIOS?
a) a lot
b) some
c) a little
d) none

E10. How much did your understanding of the scientific process improve compared to before BIOS?
a) a lot
b) some
c) a little
d) none

E11. How much did your critical thinking skills improve compared to before BIOS?
a) a lot
b) some
c) a little
d) none

E12. How much did you learn in BIOS compared to your expectations before BIOS?
a) a lot more than expected
b) a little more than expected
c) the same as expected
d) a little less than expected
e) a lot less than expected

E13. How interested are you in continuing research in the same area as your topical track?
a) very interested
b) somewhat interested
c) a little interested
d) not interested

E14. How interested are you in joining the lab of a professor who mentored in this track?
a) very interested
b) somewhat interested

c) a little interested
d) not interested

E15. Your interest in this track's area of research has increased or decreased?
a) increased a lot
b) increased a little
c) no change
d) decreased a little
e) decreased a lot

*E16. Which five skills do you think are most important in science? (select five)

- ◯ Designing good hypotheses to test
- ◯ Writing good proposals for experiments
- ◯ Designing appropriate controls for experiments
- ◯ Conducting experiments without mistakes
- ◯ Collecting and understanding experimental data
- ◯ Interpreting experimental results and drawing good conclusions
- ◯ Presenting data and explaining your work to others
- ◯ Trying new things and being innovative
- ◯ Asking good questions about experiments and being curious
- ◯ Getting along with other people in the lab

*E17. Which three words do you think best describe science?
[fill in 3 boxes]

*E18. How do you feel about doing lab work in groups or pairs?
a) very positive
b) a little positive
c) a little negative
d) very negative

*E19. How useful do you think it is to do lab work in groups or pairs?
a) very useful
b) a little useful
c) a little useless
d) very useless

*E20. How comfortable do you feel getting along with other people in the lab?
a) very comfortable
b) a little comfortable
c) a little uncomfortable
d) very uncomfortable

Follow-up (F) survey questions

F1. I am:
a) male
b) female

F2: I am:
a) undergraduate
b) graduate student

F3. What year were you matriculated into [university name]?
[fill in the box]

F4. My current major is:
[fill in the box]

F5. Did you participate in the BIOS program?
a) yes
b) no
c) don't know what BIOS is

F6. Authentic research is real research that tries to answer a question we don't know the answer to. Observing the migration pattern of a new bird species or removing a protein to see how it affects brain development are both examples of authentic research. Doing experiments in a classroom where the answers are already predetermined is not considered authentic research. Have you, either now or previously, been working in a university science lab to do authentic research? If you are a BIOS student, please only consider experiences <u>after</u> BIOS.
a) yes
b) no

F7. Have you been working in a university science lab doing authentic research in the last twelve months? If you are a BIOS student, please only consider experiences after BIOS.
a) yes
b) no

F8. Have you, together or in succession, joined more than one university science lab to do authentic research? If you are a BIOS student, please only consider experiences after BIOS. [this question was only posed to students who answered "yes" to question F6]
a) yes
b) no

F9. I feel I should improve my science competence some more before joining a university science lab to do authentic research. [this question was only posed to students who answered "no" to F6]
a) agree
b) agree a little
c) neither agree nor disagree
d) disagree a little
e) disagree

F10. I feel it is difficult to approach professors about doing authentic research in their lab. [this question was only posed to students who answered “no” to F6]
a) agree
b) agree a little
c) neither agree nor disagree
d) disagree a little
e) disagree

STable 2. Follow-up survey participants (columns) arranged by year of participation (rows), all undergraduates[1] in the same *School of Life Sciences*.

	pre-BIOS students			ex-BIOS students			non-BIOS students				
	2nd	*3rd*	*4th+*	*2nd*	*3rd*	*4th+*	*2nd*	*3rd*	*4th+*	Sum:	% total[2]:
2015	22	18	10							50	NA
2016		16	13	29			21			79	23.1%
2017			11	24	22		22	15		94	27.7%
2018				26	24	21	20	18	12	121	36.1%
2019				26	19	20	19	16	11	111	32.4%
Sum:	22	34	34	105	65	41	82	49	23		

[1]"2nd", "3rd", and "4th+", respectively, refer to students in their second, third, or a fourth or higher academic year
[2]percent of total *School of Life Science* undergraduates

STable 3. Follow-up focus group participants (columns) arranged by year of participation (rows), all undergraduates[1] in the same *School of Life Sciences*.

	pre-BIOS students			ex-BIOS students			non-BIOS students				
	2nd	*3rd*	*4th+*	*2nd*	*3rd*	*4th+*	*2nd*	*3rd*	*4th+*	Sum:	% total[2]:
2015	6	8	7							21	NA
2016		5	5 (2)	8						18	5.3%
2017			5 (1)	7	4		6	6		28	8.3%
2018				6	7	4 (1)	5	6 (1)	5	33	9.9%
2019				7	7 (1)	5	5	4	4 (1)	32	9.4%
Sum:	6	13	17	28	18	9	16	16	9		

[1]"2nd", "3rd", and "4th+", respectively, refer to students in their second, third, or a fourth or higher academic year; parentheses indicate students who had participated in a follow-up focus group from a previous year
[2]percent of total *School of Life Science* undergraduates

STable 4. Follow-up interviewees (columns) arranged by year of participation (rows), all faculty mentors (FM) or postgraduate mentors (PM) in the same *School of Life Sciences*.

	FM[1]		PM[2]			
	F	*M*	*<1*	*1-3*	*>3*	Sum:
2017	2	2	3	6	3 (1)	16
2018	2	2	2	3	2 (1)	11
Sum:	4	4	5	9	5	

[1]F = female, M = male

[2]PM cohorts arranged according to years of MR mentoring experience ("1-3" = one to three years; ">3" = more than three); parentheses indicate number of PMs who were professional lab staff, all others were graduate students

Results

STable 5. Frequencies of mention[1] for each MR challenge revealed in pre-CURE interviews and focus groups

Challenge theme[2]	*Faculty*	*Postgraduate*	*Undergraduate*
ineffective communication about the availability of MR opportunities	3 (37.5%)	2 (16.7%)	13 (52.0%)
ineffective communication about MR prerequisites	3 (37.5%)	4 (33.3%)	11 (44.0%)
low research competence when first starting a new MR experience	4 (50.0%)	8 (66.7%)	12 (48.0%)
significant time and energy required for undergraduate training during MR	3 (37.5%)	10 (83.3%)	14 (56.0%)
inconsistent undergraduate research contributions after training	6 (75.0%)	3 (25.0%)	4 (16.0%)
negative consequences associated with late MR starts	2 (25.0%)	6 (50.0%)	10 (40.0%)
inadequate support and guidance for postgraduates during MR	3 (37.5%)	9 (75.0%)	2 (8.0%)

[1]values outside parentheses indicate number of people mentioning each theme; values inside indicate percent of total
[2]row order corresponds to Figure 2

STable 6. Selected pre-CURE interview, focus group excerpts

Challenge theme	*Selected comments (U = undergraduate; P = postgraduate; F = faculty)*
1) ineffective communication about the availability of MR opportunities	(a) **U**: "Finding a lab, I think, is already one of the hardest parts of the process. Even though it is a graduation requirement, there is no list of labs we can look at to know which professor might want a student. So, I think, most of us end up asking a professor who taught one of our classes… This significantly restricts our options, often making it hard to find [research] topics we might find more interesting." (b) **U**: "I was very intimidated by the idea of having to approach professors and talk to them alone... I think many of my classmates are also reluctant to ask a professor whether they were looking for a student because we don't want to seem impolite or selfish... I think this is also a reason why many [undergraduates] try to ask [the postgraduates] who are acting as teaching assistants in their classes. It just feels more comfortable and [less intimidating] to talk to [a postgraduate] rather than [faculty]… I think the feeling of intimidation makes us less likely to take our time and talk to many professors [about potential MR opportunities]. In most cases, I think we feel lucky if someone offers us an opportunity, so we just take it without considering other options… If we felt more confident, like we had more control over the process, I think we would be more careful with our selections." (c) **P**: "When I was teaching a lab course, a lot of undergraduates would ask if I knew what labs are looking for students. I felt bad because I also didn't know… There definitely is a disconnect between the [undergraduate] research requirement and

	a lack of resources to help undergraduates find labs… I think it is true that undergraduates find us [postgraduates] easier to talk to but the truth is we usually don't know if our [faculty mentor] is interested in taking on an undergraduate…" (d) **F**: "As faculty, it is often hard for us to connect to students who might want to work in our lab... If we teach a class, we can advertise in the class but that only reaches a small section of the total population… Like for me, I only teach lower-level courses… Most of the students in my class aren't looking for a lab yet so, later, when they are looking, they usually forget about me and [forget] that I can be an option for them… this difficulty is felt most acutely by new faculty who have no students and need to recruit people quickly to start being productive."
2) ineffective communication about appropriate MR prerequisites	(a) **U**: "I actually wanted to work in a lab after my first year. But I was worried my lab skills wouldn't be good enough to do a good job and make a good impression… so I waited a long time before joining a lab in my third year… Since other students also seemed to be joining at around this time, I felt that was the appropriate amount of knowledge we should have before joining… No one ever told me this was the case… it was my own assumption… If I had the chance to do things [over] again, I think I would not have waited so long." (b) **U**: "When I was a second-year student, I really wanted to work on mice... because none of my classes had worked with mice, I felt like I had to wait until I learned more about them... Only later, after I joined a mouse lab, did I realize that was probably unnecessary, delaying my start…" (c) **F**: "When advising students about picking a faculty mentor, many students ask when it is a good time to pick a lab. I always tell them that prior [lab] experience doesn't matter. I tell them if they can learn quickly and independently, it won't matter what [research] topic they work on or when they join. For my lab, at least, this is generally true… However, I do know some faculty who have a different philosophy and refuse to take first-year and second-year students because they are not experienced enough… I think this inconsistency in advice can sometimes be difficult for students because they don't realize different professors can have different prerequisites."
3) low research competence when undergraduates first start MR	(a) **U**: "I joined a lab in my second year and found the experience very difficult. There were so many things I didn't know. I felt very bad and I didn't want to bother the other students with stupid questions so I tried learning by myself and made many mistakes… It probably took me a whole year to learn enough before I actually became useful in the lab… The experience was not good for my confidence…" (b) **U**: "I joined my lab at the start of my fourth year. I had already taken eight lab courses but I found those experiences didn't really transfer to my thesis work. Whereas the classes were very linear and explained thoroughly, my thesis required me to make my own decisions and solve problems on my own, something the classes never made me do... I think these differences were huge and resulted in many challenges… I feel most lab classes focus too much on getting the right answer, which is already pre-determined in the course design. What we need is the chance to think about and consider the unknown, which is more what we do in a real lab." (c) **P**: "I have mentored three different undergraduates so far. Clearly, upperclassmen do know a little more because they have done more coursework. But I find lab experience and basic lab operations are in lacking for everyone, even

	fourth-year students… Often, it is the simple things like adjusting the final volume after making a solution or using proper micropipetting techniques that they lack, things that we assume they should have learned [by now] but, for some reason, did not." (d) **F**: "[Our] undergraduates are usually very bright… Sometimes, I would even say they might be more creative and better problem-solvers than some of the [postgraduates] because the [postgraduates] often come from less competitive universities… Nevertheless, even most undergraduates struggle when they first join a lab, especially if they never had any lab experience in high school. I think high school lab experience makes a big difference. If students have it, they usually can perform some basic operations, making their contributions more useful earlier."
4) significant time and energy required for undergraduate training during MR	(a) **P**: "The biggest challenge for us, I think, is the loss of time to work on our own research… Sometimes, [undergraduates] can need a lot of attention so there might be a whole month where I am spending half of my time teaching them. This can be a very serious burden to me and delay my own progress towards publication and graduation. If my [faculty mentor] was a little more lenient about how I have to divide my time, I think I would feel better about [training undergraduates] but his expectations for results never change, meaning I have to maintain my normal level of productivity even if I am [mentoring someone]… Sometimes, this added pressure makes me lose patience with [undergraduates]... I feel bad about it when it happens because I know getting angry at them doesn't help because they can lose confidence or stop asking important questions… I know I am not alone in having these experiences…" (b) **F**: "There definitely is a lot of time lost when training [undergraduates]… Sometimes, I wonder if that time is ever recouped when they are finally trained… I think, on average, maybe we might [break even] between the time lost and the added productivity we gain… I also know [postgraduates] can feel a lot of pressure when they have to balance the demands of [mentoring] and doing their own research… I do try to help out sometimes by meeting with [undergraduates] as much as I can but the majority of the responsibility still falls to the [postgraduates]… I also think giving all [postgraduates] a chance to mentor at least one [undergraduate] is an important learning experience, especially for [graduate students] who want to be [professors]. So I often let [postgraduates] add the [undergraduate] they are training to their own project. I think this helps [postgraduates] feel a little better since the student is more useful to them. I also try to balance things so each [postgraduate] only has to mentor one undergraduate at a time… I think this practice is most fair [to postgraduates] but I know many other faculty aren't thinking about it in such a systematic manner. In fact, I think most other faculty end up assigning undergraduates to the nicest [postgraduate] in their lab because they know [that person] is least likely to refuse and complain… I know of cases where [postgraduates] refuse to mentor undergraduates... Only a few years ago, most [graduate students] wouldn't refuse, but now, with the changing culture, it is becoming more and more common, adding pressure on [faculty] to find new ways to accommodate [undergraduate mentees]. (c) **U**: "As an undergraduate, I often feel like a criminal in the lab because I don't know how to do anything. I need a lot of help from my [mentors]… I know

	receiving that help means my [mentors] are focusing less on things they need to do, like their own projects. I have tried to learn things by myself but some of the things I can't practice alone because they require equipment that can be dangerous or reagents that are expensive so I always need to be supervised… I feel very bad about this… and often worry I am annoying my [mentors] and wasting their time." (d) **U**: "I think it can be very hard for [undergraduates] to freely ask questions or request assistance because we know our [mentors] need to be busy doing other things… However, at the same time, I feel it is an unfair burden on us because most of us, I think, try to learn things on our own so that we don't bother [our mentors]… This can make our learning very inefficient and frustrating... I know my [postgraduate mentor] says our [faculty mentor] expects her to do experiments at the same rate, regardless of whether she is [mentoring] someone or not… I think these kinds of expectations are not good for either [postgraduates] or [undergraduates]." (e) **U**: "The greatest challenge of being [an undergraduate mentee] was having to learn most things by myself. Although there were other, more senior, lab members around, the [culture] in the lab was very tense. Everyone was very stressed and busy so I didn't feel comfortable asking a lot of questions. This definitely slowed my learning a lot… In the beginning, I thought it would not be such a big deal because the experiments I needed to do were conceptually simple… But after actually doing some of the experiments, I realized the work was much more complex and nuanced, requiring a lot of troubleshooting and trial and error… I think the trial and error was most time-consuming… If the [culture] had been different, I probably could have solved my problems much sooner and made more meaningful contributions." (f) **U**: "One of the things that has disappointed me the most about my [MR] experience is the lack of interaction with my [faculty mentor]… Almost all of my learning is through the [postgraduate mentor]… I think I have been lucky because my [postgraduate mentor] is very nice but I also know of other classmates who have [postgraduate mentors] who are not interested [in mentoring] or have no stake in the undergraduate's project, causing conflicts between [mentor] and [mentee]… I know one undergraduate who had an argument with his [postgraduate mentor]… Now, they don't even talk to each other and the student has to learn everything alone. I think this is very unfortunate… I also know there are some examples where a [postgraduate's] project gets more attention or support from the [faculty mentor] compared to an undergraduate's… I have one friend who has only talked to her [faculty mentor] once… I think these experiences are bad for student confidence because you feel your work and project are not important." (g) **U**: "One of my friends works in a lab where the expectations for his project are very unclear… When he talks to his [faculty mentor], he gets one set of instructions. When he talks to his [postgraduate mentor], he gets another… This kind of inconsistent guidance is very bad for undergraduates… and makes it difficult to focus our time in a meaningful way."
5) inconsistent undergraduate research	(a) **P**: "Even after undergraduates learn the experiments they need to know, I find their contributions can be very different. Some become very engaged in their work but others are just trying to meet their graduation requirement so the quality and

contributions after training	volume of their work can be very limited… In most cases, I think productive students are either very conscientious or really enjoy the research topic… Students who are less productive are usually less interested in the research topic… I think a more organized process to let students explore their interests and find topics they like earlier would help a lot in encouraging more productivity later." (b) **P**: "As a [postgraduate], we prefer [undergraduates] who are really interested in the research topic… Sometimes, I think the undergraduate research requirement forces students to participate in topics they aren't really interested in, forcing us to invest time and energy into students who really won't be that productive… In this sense, I think a system that allows students to explore their interests more would be extremely beneficial… As things are now, many undergraduates just find the first [MR opportunity] available without really having the chance to explore their interests." (c) **F**: "I like the idea of [MR] but I find, in practice, that [such opportunities] are often more trouble than they are worth. I think many undergraduates join a lab only because they are required to, not because they really want to contribute. I think these kinds of students are the biggest challenge for us, probably even an unfair burden for many [faculty]… When students are active contributors, I think it is because they really like the research topic and find the experiments interesting." (d) **F**: "Classes can be very disruptive to research productivity. Especially here at [university name], undergraduates have many classes so there often is little time during the semester to learn or contribute in a substantial way... Usually, I find [undergraduates] learn the most and contribute the most during winter or summer break but both of these periods are short, limiting the time to make meaningful contributions… Especially for [undergraduates] who join a lab as fourth-year students, having one or two breaks is usually only enough to get trained, limiting benefits for the lab."
6) negative consequences associated with late MR starts	(a) **U**: "I think it is true that [mentors] prefer students who join [a lab] earlier. I started [my MR experience] in my third year and received a lot of attention from my [postgraduate mentor]. A friend of mine joined a year later and the same [postgraduate] did not seem to like talking to her… So, one day, I carefully asked why and he said it was because he already knew she had started [MR] too late to make any meaningful contributions… The way he said it, he made it seem like she was a disrespectful parasite, someone who just wanted to meet their graduation requirement and give nothing back to the lab in return." (b) **U**: "Another problem [associated with late MR starts] is that [mentors] might pay less attention to you. I think many [mentors] assume students who join a lab in their fourth year are already destined to be less productive so they spend less time with them… Sometimes, I feel like it is almost like an unspoken punishment… The problem is that no one tells us before we are considering [MR opportunities] that [mentors] usually want us to be around for a long time so some of us don't realize it until it is too late." (c) **U**: "I think there are several negative consequences to joining a lab late. The first is joining a lab that you don't really like. I know some friends who couldn't find a lab with a [research] topic they were interested in... so they had to settle for a lab with a topic they really weren't that interested in… Another problem is having conflict in the lab. I know [another friend] who joined a lab and was assigned a

	[postgraduate mentor] who really didn't want to help her. [My friend] couldn't get any help and had to learn everything by herself… She was miserable the entire time but, because she had joined in her fourth year, she had no opportunity to change… Had she joined earlier, she would have had some time to switch to something better… I think this [extra time] is something undergraduates don't think about but need to consider… If things don't work out, you want to have the extra time in case you need it to make a change… (d) **P**: "I think starting in your fourth year is too late to make any meaningful contributions. When I was an undergraduate, I also joined a lab in my fourth year… Compared to my classmates, I felt like I spent a lot of time in the lab, especially during the summer… But even for me, it took the whole year to really master my experiments… so I wasn't able to contribute much meaningful to the lab… Now, as a [postgraduate], I have mentored three undergraduates. Two joined in their fourth year, one joined in third… The one that joined earlier definitely has been more productive." (e) **P**: "I also find short tenures are less useful. In our lab, undergraduates often take the role of doing small jobs for the lab… As a [postgraduate], I sometimes depend on them to prepare materials or set up experiments. When [undergraduates] keep leaving, those tasks have to be [redeployed] among the other members of the lab so there is a delay in productivity. If undergraduates joined earlier and stayed longer, there would be fewer disruptions, improving productivity for everyone… Sometimes, I think this makes me reluctant to teach [experimental techniques] to undergraduates who join our lab in their fourth year because I know they will just learn how to do things, use [lab supplies], and leave, not really providing any benefit to others in the lab…" (f) **P**: "I think I feel less motivation when I am asked to mentor [an undergraduate] who joins the lab late… If a student joins earlier, I can benefit from their presence because I can train them in experiments related to my project and have them do things that benefit me… But, if a student joins late, they really only have enough time to learn a few things, without contributing much to the lab… Also, I think there is more pressure to train undergraduates quickly when they join late so that can also feel very uncomfortable... I think that pressure may be a reason why some [postgraduate mentors] are discourteous to students who join the lab late." (g) **F**: "I know accepting [undergraduate apprentices] is an important service and tradition in science… [MR opportunities] are a really important step in the training of competent scientists… In my lab, I have a strict policy against accepting students in their fourth year because I have found one year is only enough for them to learn some experiments… not contribute meaningfully. I think the lab needs to receive some meaningful benefit in return for the investment it makes… not just provide a free service of research training… this is too unfair to us, especially when we are using our grant money to pay for [lab consumables]." (h) **F**: "I agree undergraduates who join late are often less useful contributors. At the same time, joining too early might be even worse because [those students] know even less and might need more time and attention… I do agree third-year students are more productive than fourth-years but I have seen second-years [go either way]. Some can be incredibly productive while others are very slow to learn."
7) inadequate	(a) **P**: "I think it is a common experience for most [postgraduates] that [faculty] do

support and guidance for postgraduates during MR	not participate [in mentoring]. This puts a lot of pressure on us to balance our own research with [mentoring]… Most [postgraduates] have never taught anyone before so the process is learning for them too… This can often diminish the quality of undergraduate learning… I think it would be better if [postgraduates] could receive better guidance from [faculty mentors] about how and what to teach [undergraduates].” (b) **P**: “Sometimes, a lack of faculty guidance can result in clashes with [undergraduates]. Because [our] undergraduates are so smart, they sometimes have different ideas about how to do an experiment or how to proceed with a project. Because we, as [postgraduates] are also still students, sometimes we lack the skills to keep the undergraduates focused on their [assigned tasks]… This can cause tension between [undergraduates] and [postgraduate mentors]… When [faculty] remove themselves from these interactions, I find the situation often becomes worse… That kind of tension, I think, is bad for everyone.” (c) **P**: “Although I think [MR training] is a very important service to provide and a good way for [postgraduates] to give back, I don’t feel it is prioritized very much… Faculty generally seem to care much more about research results than training so a lot of smart and talented undergraduates often seem to receive less attention than they deserve… I feel very lucky because I did receive a lot of attention from my [mentors], especially my [postgraduate mentor]. I hope that some changes can be made so more undergraduates can enjoy [fruitful] experiences.” (d) **P**: “I also agree [MR training] is important to provide because we all benefitted from it before becoming graduate students… I know I received a lot of help from [my MR mentor] so I often feel like I want to do a good job for [my own mentees]. At the same time, I think the current environment is very unfavorable for good mentoring. There is so much pressure to produce good [research] results that I think undergraduates are often the first to be neglected.”

STable 7. Most influential MR challenge, as chosen[1] by pre-CURE interview and focus group participants

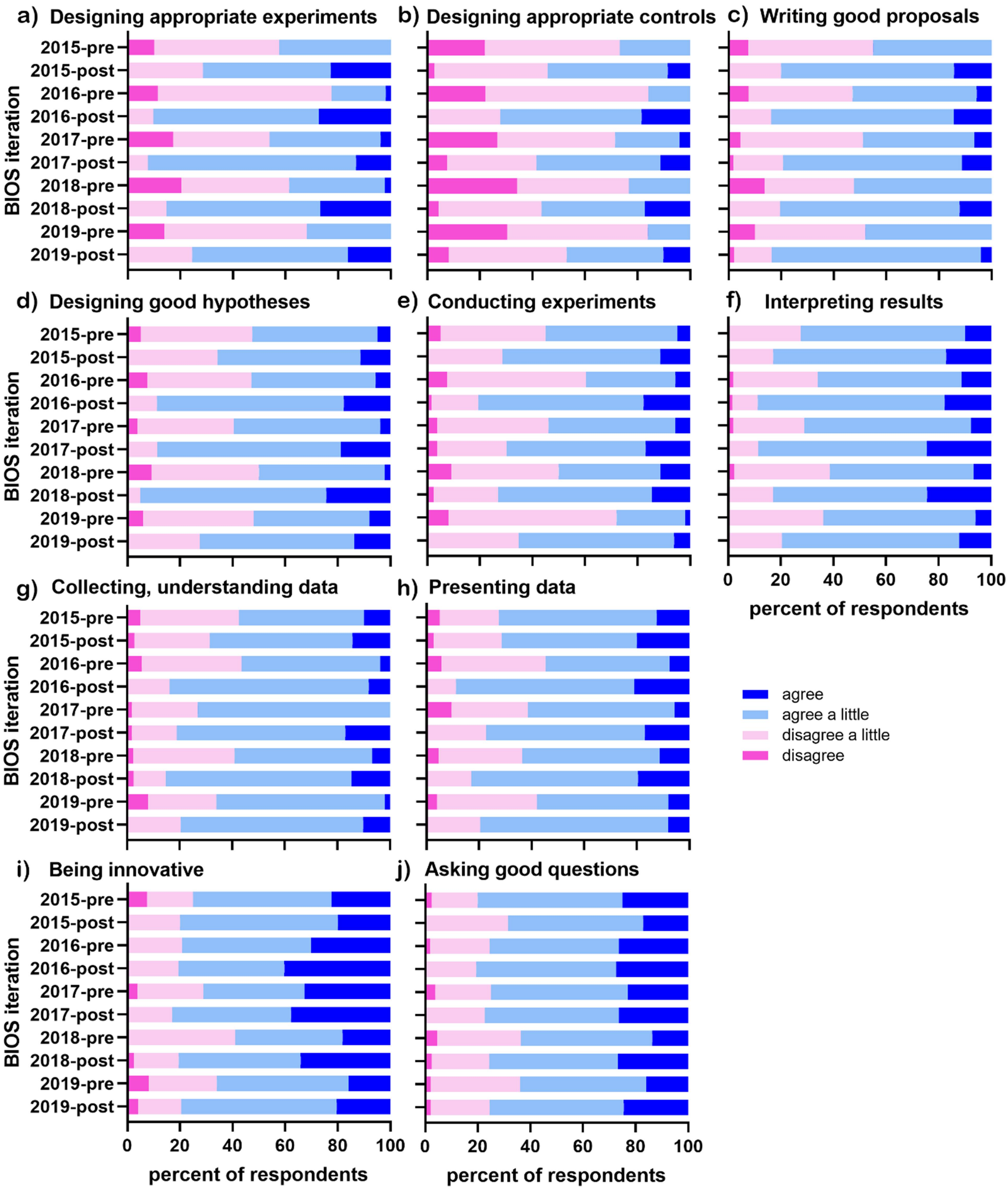
Challenge theme[2]	*Faculty*	*Postgraduate*	*Undergraduate*
ineffective communication about the availability of MR opportunities	0 (0.0%)	0 (0.0%)	0 (0.0%)
ineffective communication about MR prerequisites	0 (0.0%)	0 (0.0%)	0 (0.0%)
low research competence when first starting a new MR experience	1 (12.5%)	1 (8.3%)	1 (4.0%)
significant time and energy required for undergraduate training during MR	3 (37.5%)	9 (75.0%)	22 (88.0%)
inconsistent undergraduate research contributions after training	4 (50.0%)	0 (0.0%)	0 (0.0%)
negative consequences associated with late MR starts	0 (0.0%)	0 (0.0%)	0 (0.0%)
inadequate support and guidance for postgraduates during MR	0 (0.0%)	2 (16.7%)	2 (8.0%)

[1]undergraduate participants were asked to vote by show-of-hands during focus groups while faculty and postgraduate interviewees were asked individually; values outside parentheses indicate number of people choosing each theme while values inside indicate percent of total
[2]row order corresponds to Figure 2

SFigure 1. The BT module's micropipetting rubric: some rubric items assessed *process* (black text) while others assessed outcome (red text).

	0 points	**1 point**	**2 points**	**3 points**
Chose proper micropipette matching volume to be transferred	No	Yes		
Changed pipette tips to avoid cross-contamination of reagents	No		Yes	
Demonstrated first and second stops on micropipette plunger	2< mistakes	1 or 2 mistakes	Yes	
Made sure tip(s) did not touch other things	2< mistakes	1 or 2 mistakes	Yes	
Only tip(s) made contact with liquids during transfer	No		Yes	
Made sure liquid in tip(s) did not backflow or drop out	No		Yes	
Affixed tip(s) to pipette appropriately with fingers only	No			Yes
No liquid residue remained in tip(s) after transfer	No		Yes	
Final volume of product was similar to instructor's standard	No	Slightly different		Yes
Final color of product was similar to instructor's standard	No	Slightly different		Yes

SFigure 2. Pre- and post- exit survey response distributions when BIOS learners were asked to self-assess science process skill competences (differences in Figure 4).



STable 8. Exit focus group excerpts.

Discussion theme	*Selected excerpts, all from BIOS learners*
1) self-assessed learning gains	(a) "We had daily opportunities to write proposals, do experiments, and think about experimental design so I think we really had many chances to get better at those… When interpreting data and doing experiments without mistakes, I think that depended somewhat on which [topical track] you were in because some tracks offered more opportunities to redo the same experiment… Even though we had many opportunities to make decisions about our experiments, most components of the experiments were already designed for us so I can understand why many students did not feel the chance to do real innovation… Maybe that is why students said they did not improve in innovation." (b) "I think the repetitive nature of BIOS was very important in improving our skills… BIOS was filled with diverse tasks with specific goals that really gave us the opportunity to think about each task in different ways… Even if it was the same experiment, having a different objective each time allowed us to practice and think about each task differently… I think this was very effective in helping me master each experiment… When we had fewer opportunities to practice, I think we naturally improved less." (c) "One of the big differences between BIOS and other lab courses is that BIOS gives us the chance to practice many things more than once. In other classes, usually we only get one chance to try a new experiment… I don't think you can learn any experiment properly that way... In BIOS, we get to have three, sometimes more, chances to practice the same experiment. Although the repetition can be boring sometimes, I think it is essential for really mastering each skill." (d) "BIOS is the best research class I have ever taken. Even though it was challenging at times to be working every day, the experiments were very fun and I feel I learned a lot more than I thought I would… I definitely feel BIOS has helped me become a better scientist... One of the things I really liked about BIOS was that you learned about each experiment through stages… In most [other] lab courses, you are expected to learn everything about a new experiment all at once. In BIOS, you learn about different aspects on different days. I think this really helped us absorb and understand the information better, without [feeling overwhelmed]." (e) "I was so happy that BIOS is so different from [other science courses]. [In other courses], there is no chance to be creative and solve problems. Everything is explained from the beginning so you are just copying what someone else has already done. In BIOS, I felt like the learning was tailored to the students with a focus on the learning process, not just getting the right answer… Mistakes were not penalized the same way as in other classes so I felt more comfortable asking questions and really exploring each experiment… I think this helped my learning a lot... I also feel knowing what your mistakes are was very helpful because you could focus on your own personal goals. It was almost like a game, with each new day being a new opportunity to level-up my research skills." (f) "One of my seniors had taken BIOS last year and she convinced me to join this year… She spoke so glowingly of her experience that I had to try. To be honest, when I saw the schedule, I was a little skeptical… I actually felt regret because the

	schedule looked so full and busy… I thought it was going to be a lot of work. Once the program started, however, time just flew by and I was shocked at how much I was enjoying myself… I really felt like I learned a lot in both [topical tracks], a lot more than I expected. I will, for sure, be recommending BIOS to new students… next year.” (g) “BIOS felt like real research to me, not just a class... In other science classes, there is no discovery and everything is very linear so it doesn’t feel interesting… In BIOS, I was allowed to work on a real [scientific question] and my work felt important because I could see how it connects to real problems scientists are trying to solve in the real world…” (h) “The best part about BIOS was the unknown. Each experiment had something new for us to discover and that was very exciting. I especially liked the parts where we could discuss and debate what the results were going to be before doing the experiment. That part felt almost like a game… Sometimes, I wanted to use my phone to find the result early but I always resisted because [not knowing] made it more interesting.” (i) “Before BIOS, if I had to [participate in an MR experience] right away, I think I would have made many mistakes and felt horrible, losing a lot of confidence… Because BIOS is kind of a safe environment where we are allowed to learn and make mistakes together, I feel I was able to grow through those mistakes and gain a lot of confidence in my abilities… I also think BIOS was very enjoyable because it felt like we were always trying to solve a new puzzle… The [double-blind] experiments were especially exciting because we got the chance to discover new things that no one else has before. I think that really helped me feel [engaged] in [learning activities] even though the schedule was very tight and busy.” (j) “When I first started BIOS, I had never taken a lab course before, even in high school… Now, I feel much more confident, and I feel like I could actually do meaningful work in a lab… I also feel a lot more confident about knowing what I know and what I don’t know. This helps me ask better questions and seek guidance when I need it.” (k) “Definitely, my ability to pipette and do SDS-PAGE improved immensely… But I think, more importantly, my ability to understand experimental design and use controls is what improved the most. Before, I didn’t even properly understand what controls are or why you need them. Now, this is one of the first things I look for… I think this is a really critical change in my development as a scientist. I think this really made me feel a lot more confident in my abilities...” (l) “I think it is really important to not forget how helpful [undergraduate teaching assistants] were. Although [postgraduate instructors] did spend more time with us, I sometimes feel the [undergraduate assistants] were even more helpful because they had already taken [BIOS] before. I think this allowed them to understand our needs a little better and provide more useful feedback and instruction, especially when things weren’t working… In some cases, a [postgraduate instructor] might be teaching [an activity] for the first time. In cases like this, I sometimes found [undergraduate assistants] understood the activity bettter.”
2) research interest changes	(a) “I really enjoyed my time in [track name]… The experiments were very interesting and the [postgraduate mentors] were very nice. I am already planning on joining [faculty name]’s lab next semester.”

	(b) "I think my interest and excitement in biology has increased a lot. Before BIOS, I felt like all the things we were learning were just from a textbook so it felt unconnected from real problems... I really wasn't anticipating having the chance to get involved in meaningful research but BIOS showed me that even [first- and second-year students] can get involved and contribute to important work… This is definitely something I want to continue doing next semester and next year." (c) "I actually found the experiments quite boring, so I lost interest after the first week… But since the [postgraduates] were always working so hard, I said on the survey that my interest increased a little. I know some other students in that track who also exaggerated on the survey by saying their interest had increased... I think these are polite lies." (d) "Before BIOS, I thought the experiments in [track name] would be colorful and exciting… I always imagined [topic name] deals with very important questions related to climate change and the future of human survival so maybe my expectations were a little too high… When I finally started the track, much to my surprise, I found the actual work was quite tedious and uninteresting even though the fundamental question was still important." (e) "I was actually very grateful to get to experience [track name] and realize I don't like it… It wasn't my first choice but I thought there might be something there that I would find interesting if I tried it… As a student, I think it helps a lot to know early on what topics you are not interested in so you can pick something better for your [thesis research] later. Since your [thesis topic] is what you have to spend the most time on, I think it can be very beneficial if you are already naturally interested in it." (f) "I think the most important thing about BIOS is the chance to learn about yourself and your own interests… Before BIOS, I was very sure I wanted to learn more about [track name] but the experience in that track allowed me to quickly realize I was actually interested in something else. As a [rising second-year student], I think these experiences are truly invaluable, especially if you can have them early."
3) science conceptualization changes	(a) "I think the biggest change in my perceptions about science is that I realized science can be a lot of work and take a lot of time… In high school, I think many of us imagine working as a scientist to be an exciting job where every day, every experiment gives you the chance to have new discoveries. It is kind of an immature outlook on science, but I think that is where most students start… It is only when we start working in a lab and do real research that we understand how involved and complex it is…" (b) "I think student perceptions about [the importance of] good hypotheses might have decreased because that was one of the steps in the scientific process we spent the least amount of time on… If we spent one hour making predictions and writing proposals, we probably spent six, seven, or eight hours actually doing experiments. I think this discrepancy in time, in conjunction with the fact that experiments are more difficult, might have contributed to the decrease [in perceived importance]." (c) "I think, before BIOS, many of us didn't realize how difficult science can be and how slow it is in creating results… I think I was naively under the impression that every experiment gives a new discovery so I never realized that most experiments are repeats or controls or even failed experiments… I think this might explain why

	many students may have started deemphasizing the importance of designing hypotheses and being innovative… associating science more with words like 'arduous' and 'difficult'…" (d) "One of the worst feelings doing experiments is making mistakes… I think, before BIOS, many of us did not appreciate how easy it is to make a mistake during experiments and how costly mistakes can be in wasting time and materials… That is definitely one of the important realizations I made during BIOS." (e) "For me, I think I always imagined science is something you can do alone… I always had this image of working by myself and feeling peaceful and free… Maybe because I am a shy person, I was also hoping for this kind of solitude by working in science… Now that I have experienced BIOS, I realize good science is very collaborative. Not only do I have to understand what other people are doing but they also need to know what I am doing. Even though this realization destroyed my hopes of being quietly alone, I think it is a very important realization that made me feel more comfortable working with others and more confident in feeling a need to work with others." (f) "In high school, we are often told about innovation and the importance of being creative... Now that I have experienced BIOS, I feel that creativity is not nearly as big of a part of the process as I thought… In fact, the simple things like not making mistakes and having good controls, making sure you are repeating your results, even though these things may seem tedious, I now understand they are much more important than being creative or innovative."
4) cooperative activity perception changes	(a) "I think my opinion about working with others has changed in two ways. First, I think I now understand better how important it is for people working in the same lab to be a team. Since I was in the mouse track, I think I was able to experience, very directly, how other people can depend on my work and how my work can depend on others. As a student, however, I feel that [cooperative learning] has both advantages and disadvantages. When we were doing proposals or reports, I think it was very useful for students to talk to each other and debate different ideas. Sometimes, I think some students have very bad ideas but the process of debating is already valuable because it helps me practice my own thinking and help me learn how to convince others… When doing experiments, however, I think [cooperative learning] is maybe not so good. If someone I am working with makes a mistake, that will negatively affect my performance and my result so I think that is very unfair to me… I would much rather do experiments by myself so, if I fail, I know it was because of something I did wrong, not because of something someone else did." (b) "I think I understand the value of interacting with others and having my ideas and thoughts tested… Especially when doing the proposals, the debates were very fun and interesting… But when doing experiments, I did not like having to share time with other students when using microscopes or other equipment. I think this diminishes the amount of useful learning I get to do… I understand we have to share equipment because we can't have a hundred microscopes but I think [cooperative learning] has its advantages and disadvantages… so maybe some activities should have it while others don't." (c) "I think my opinion of [cooperative learning] has decreased a lot. Maybe I was unlucky but I had several experiments ruined by my [lab partners]. Even though I

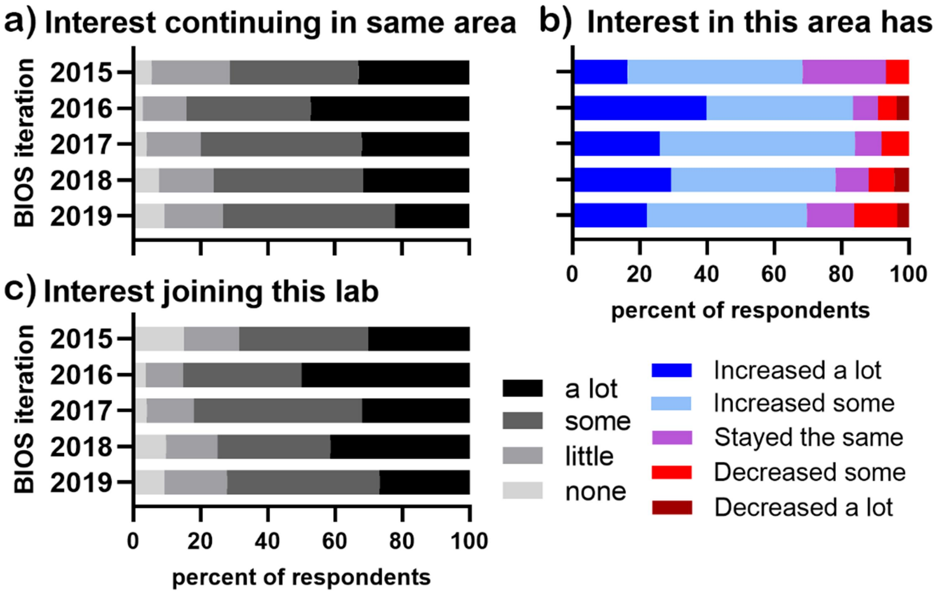
	did everything correctly, having the experiment's result ruined by someone else was very frustrating… I think it is better for students to do experiments by themselves so the result only depends on what they do… For proposals, I think working together can be more useful but reports I also feel should be a personal thing because that is where you present your results… those should also be done alone so only one's own mistakes [affect the outcome]... Even when the experiment is not graded, I think students will still feel bad about having their work ruined by someone else so I think even [formative lab tasks] should be conducted individually." (d) "Because I am a shy person, I usually didn't like working with others in high school. In BIOS, however, I could see some advantages. Sometimes, when an experiment is very complex, it is helpful to have more than one person there to remind you not to forget something or to catch you when you make a mistake… Also, during proposals and reports, I think it is very useful to have many people talk and share their ideas… So, even though I didn't like doing [cooperative learning] before, I now feel it has some [advantages] that are worth using it for… As a result of BIOS, I also feel a lot less shy now… Even though in the beginning I felt uncomfortable being forced to work with others, I now feel much more comfortable doing that and can see some of the values of it."

STable 9. The three BIOS outcomes learners found most valuable[1].

"I was able to...	2015	2016	2017	2018	2019	All
...improve my lab skills."	94.3%	95.2%	94.4%	87.8%	81.6%	90.6%
...have fun doing experiments and discovery."	54.3%	66.1%	66.0%	73.2%	73.5%	66.9%
...gain more science knowledge."	37.1%	54.8%	47.2%	29.3%	34.7%	40.8%
...explore my research interests."	42.9%	33.9%	32.1%	46.3%	46.9%	40.5%
...gain research experience earlier."	25.7%	21.0%	39.6%	41.5%	42.9%	34.3%
...have more interactions with professors."	45.7%	21.0%	11.3%	12.2%	12.2%	20.7%
...improve my resume and future job opportunities."	0.0%	8.1%	9.4%	9.8%	8.2%	7.1%

[1]reflection question administered at the end of BIOS with respondents allowed to choose three options; values are percent of total

SFigure 3. Exit survey response distributions when BIOS learners were asked to self-assess their research interest changes (averages reported in Table 3).



STable 10. Pre- and post- exit survey response distributions when BIOS learners were asked to choose the five skills they thought were most important in science[1].

	2015		2016		2017		2018		2019		All	
	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post
Conducting experiments without mistakes	12.5%	28.6%	15.1%	19.4%	9.6%	26.4%	11.4%	22.0%	8.0%	17.2%	11.3%	22.7%
Designing appropriate controls	90.0%	91.4%	81.1%	90.3%	84.6%	84.9%	68.2%	85.4%	88.0%	98.7%	82.4%	90.1%
Presenting data, explaining work	30.0%	42.9%	45.3%	54.8%	42.3%	45.3%	45.5%	43.9%	48.0%	55.8%	42.2%	48.5%
Writing proposals for experiments	10.0%	28.6%	28.3%	17.7%	26.9%	30.2%	34.1%	36.6%	16.0%	21.5%	23.1%	26.9%
Getting along with others	12.5%	22.9%	17.0%	21.0%	23.1%	13.2%	18.2%	26.8%	16.0%	15.0%	17.3%	19.8%
Collecting, understanding data	50.0%	68.6%	50.9%	62.9%	46.2%	56.6%	52.3%	41.5%	60.0%	42.9%	51.9%	54.5%
Interpreting results, drawing conclusions	70.0%	71.4%	58.5%	51.6%	53.8%	54.7%	65.9%	53.7%	54.0%	60.1%	60.4%	58.3%
Asking good questions, being curious	77.5%	51.4%	71.7%	67.7%	78.8%	62.3%	79.5%	78.0%	82.0%	90.1%	77.9%	69.9%
Designing good hypotheses to test	65.0%	51.4%	41.5%	21.0%	53.8%	30.2%	47.7%	46.3%	46.0%	40.8%	50.8%	37.9%
Trying new things and being innovative	72.5%	40.0%	75.5%	66.1%	71.2%	66.0%	77.3%	48.8%	78.0%	57.9%	74.9%	55.8%

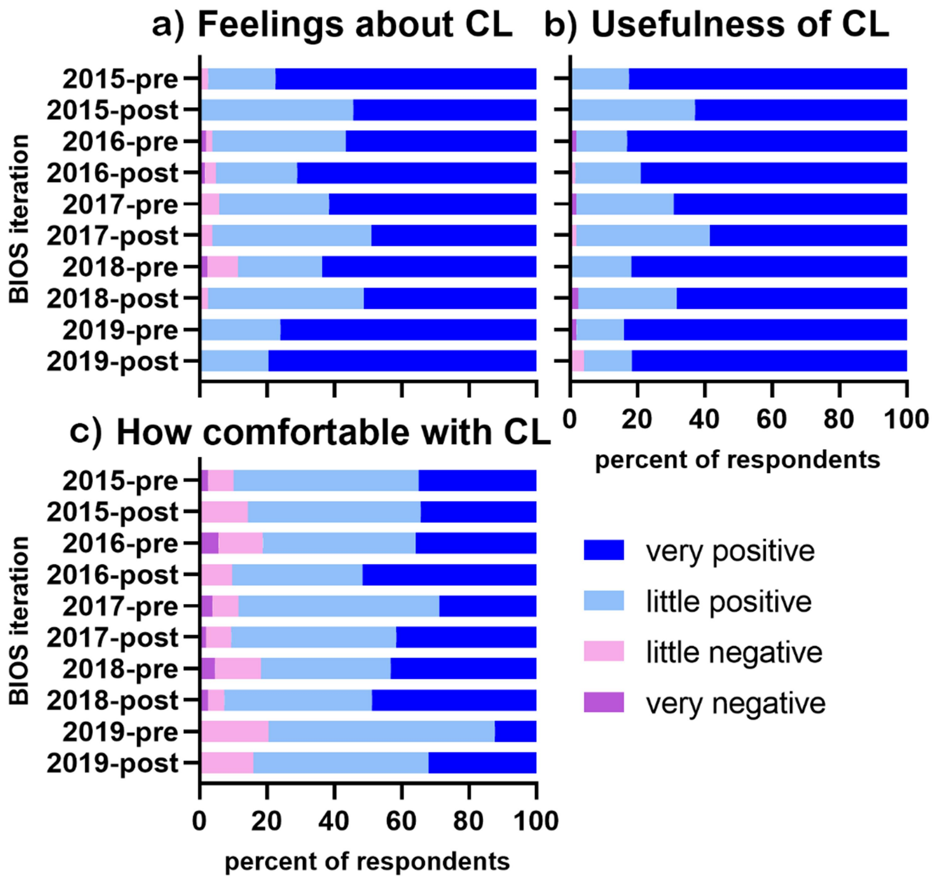
[1]differences between post- and pre- responses for each cohort are reported in Figure 5 with row order corresponding to that figure

STable 11. Pre-and post- exit survey response distributions when BIOS learners were asked to describe science using three words[1].

	2015		2016		2017		2018		2019		All	
	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post
challenging nature ("arduous", "expensive", "difficult")	47.6%	66.7%	33.3%	42.5%	47.5%	80.4%	24.0%	63.5%	45.0%	71.7%	39.5%	65.0%
intellectual appeal ("interesting", "fascinating", "puzzle")	76.8%	66.7%	69.4%	78.0%	60.0%	74.2%	69.0%	91.8%	51.0%	68.5%	65.3%	75.8%
truth-generating potential ("accurate", "precise", "rational")	40.2%	41.7%	44.4%	54.3%	57.5%	30.9%	36.0%	42.4%	51.0%	58.7%	45.8%	45.6%
emotional appeal ("beautiful", "colorful", "free")	43.9%	62.5%	55.6%	61.4%	62.5%	52.6%	84.0%	56.5%	66.0%	48.9%	62.4%	56.4%
practical value ("useful", "necessary", "innovative")	54.9%	45.8%	55.6%	33.1%	40.0%	46.4%	30.0%	17.6%	45.0%	19.6%	45.1%	32.5%
potential for discovery ("mystery", "explore", "discover")	36.6%	16.7%	41.7%	30.7%	32.5%	15.5%	57.0%	28.2%	42.0%	32.6%	42.0%	24.7%

[1]differences between post- and pre- responses are reported in Figure 6, with row order corresponding; parentheses give examples of words falling into each category

SFigure 4. Pre-and post- exit survey response distributions (corresponding to Figure 7) when BIOS learners were asked to comment on perceptions of cooperative learning (CL).



STable 12. Follow-up interview, focus group excerpts.

Discussion theme	*Selected excerpts (B = ex-BIOS undergraduate; N = non-BIOS undergraduate; P = postgraduate mentor; F = faculty mentor)*
1) differences in timing of first MR experience	(a) **B**: "When I compare my friends who are from BIOS with my friends who are not, the difference is very obvious… Most of my BIOS friends [started an MR experience] within the first semester after BIOS… Even for those who didn't, they would often talk about it and be actively looking for opportunities… For my [non-BIOS] friends, the atmosphere is very different. Most of them say they feel unready… Even when I try to encourage them, they are often unsure… I feel my explanations of what real research is like just can't replace the actual experience, so my words are not very effective." (b) **N**: "Some of my friends who were in BIOS [started their first MR experience] very early... Because I did not participate [in BIOS], I think it is easy for me to notice the differences between BIOS and non-BIOS students. BIOS students definitely are more likely to start research earlier. In fact, when we are having lunch together, BIOS students are also much more likely to want to talk about research… Sometimes, they will talk amongst themselves about their different projects… and that can be annoying sometimes… but, other times, I feel left out and wish I had been able to participate in BIOS too." (c) **P**: "I don't know how it is in other labs but all three of the second-year students who joined our lab in the last two years are from BIOS… I know of another lab that has two second-year students and one third-year student, all from BIOS… Given what I have seen, I think it is pretty clear that BIOS students are more likely to [start an MR experience] earlier than [non-BIOS peers]… I think it is also generally true that BIOS students know more about science than [non-BIOS peers]… This probably helps a lot when they are seeking an [MR opportunity]." (d) **F**: "Before BIOS [was offered], no second-year students had ever applied to my lab. Since then, I have had three in three years, all from BIOS… One of the things I really like about BIOS students is that they are good in interviews. They actually seem to understand what our research is about and even ask good questions sometimes. That difference in attitude was definitely a reason why I agreed to mentor them."
2) differences in perception about barriers to first MR experience	(a) **B**: "I think BIOS had a huge impact on my confidence and ability to do real research. Because I already had the chance to work in a real lab and interact with professors and graduate students, I felt very comfortable in that environment. I know this helped me a lot in making the decision to start my first [MR experience] right after BIOS… Even though I joined a lab that was not a part of BIOS, the BIOS experience was essential in helping me feel confident enough to start my first [experience]… Without BIOS, I am sure I would have waited until my third or fourth year, like many of my other [non-BIOS] classmates." (b) **B:** "Compared to my [non-BIOS] friends, I think most BIOS students feel ready to [start an MR experience] immediately after BIOS. I think we feel like we understand what real research is like and we also have some experience doing it so I think that makes us feel very prepared… When I talk to some of my [non-BIOS] friends, I notice they are often very worried about making mistakes or making a good first impression so they often say that they feel like they need to take more classes first… I think one of the important things BIOS students learn is

	that mistakes already happen often in real science… so I think we understand that good science is not about how you avoid mistakes but more about how you address them and continue to move your experiments forward in a positive way.” (c) **B:** “I think another thing that is really important is the experience interacting with mentors… In most regular classes, students don’t interact that much with professors or teaching assistants. In BIOS, there is much more interaction… Without it, I think most students feel shy or worried about talking to professors, especially when asking for something, like a position in the lab… I think BIOS helps students feel more comfortable talking to [authority figures], making it easier for them to ask for [MR opportunities].” (d) **P**: “One of the undergraduates who works in our lab now is from BIOS. I remember seeing him during the summer when he was a BIOS student... In the fall, he came into the lab and asked me if our professor was looking for new undergraduates. I, of course, didn’t know but I remember thinking that he was very brave to just walk in here and ask. That was the first time I ever saw an undergraduate do that. Later, I learned he had also walked in and asked people in two other labs so I wonder if his familiarity with the building and his experiences working with other people in this building [during BIOS] might have helped him feel more comfortable to do that.” (e) **P:** “One of the things I have noticed about BIOS students is that they are much better about asking questions and communicating. [Non-BIOS students] often are very shy and quiet when they first get into the lab but BIOS students are usually not… I am not sure if this is because gregarious students are more likely to apply for BIOS or if the BIOS experience makes them more comfortable talking about science… Either way, I feel there is a clear difference between them. I think this desire to communicate more is probably something that professors like, making it more likely for them to agree to mentor a BIOS student.” (f) **F:** “Compared to other faculty, I think I tend to get more requests from undergraduates to join my lab. Most of the requests start as emails… When I compare the emails I get from BIOS students with [non-BIOS] students, I think there is a clear difference. BIOS students are usually able to say something about what they worked on in BIOS when they introduce themselves. Sometimes, they will say things like, ‘I have PCR experience.’ I think things like that are obvious attractions for a [prospective mentor] because they help you decide how useful that student might be. For me, I know that makes it more likely for me to accept a younger student [into the lab]… Probably, [non-BIOS] students don’t have this kind of advantage.” (g) **N**: “Having talked to many of my friends about [MR opportunities], I think BIOS students might have an advantage because they can say they were BIOS students. This helps [prospective mentors] know they already have some experience working in a lab, doing real research. So, when they are contacting professors about possible [opportunities], I think this probably works strongly in their favor… I also know some BIOS students who used one of their BIOS mentors as a reference when asking professors about potential opportunities. This probably helps a lot too, I think, and is another advantage [non-BIOS] students usually don’t have.”
3) differences in	(a) **B**: “After BIOS, I immediately joined the lab of my [BIOS faculty mentor]. I

multiple MR experiences	worked there about a year and a half and made some good progress on my project. Because my project was kind of finished, I then asked if I could look into joining another lab to try something new. Luckily, [my first faculty mentor] was very satisfied with my performance so I was able to join a second lab without much trouble… My first [faculty mentor] even recommended me to my second [faculty mentor]." (b) **B**: "I started [my first MR experience] right after BIOS and worked there for about six months. I soon found, however, that the project was not as fun or as rigorous as I expected so I quit and joined another lab… I don't think I would have had the courage to quit like that unless I had been in BIOS… BIOS helped me understand what good research looks like so I was able to better judge how good the [first] project was… BIOS also helped me feel very confident in my abilities so I was also confident in my ability to join another lab even if I quit. If I wasn't so confident or experienced, I think I would have just stayed in that [first] lab until I graduated because I would be afraid of not being able to find a second chance." (c) **N**: "I think it is true that BIOS students are much more likely to work in two or more labs. I think their earlier starts in research have a lot to do with it… At the same time, I also think sometimes [ex-BIOS students] are just better at working in the lab. I think they are usually better at experiments and also trusted more often [by mentors] to do important tasks... By the time we graduate, our skill levels are probably more similar, but when we first start, I think it is true that BIOS students are a little better at most things. I think this probably gives them more opportunities to join more labs, especially if they say they are from BIOS or have good results from their [first MR project]… I know one student who showed slides of his work from his [first project] to convince his second [faculty mentor] to accept him... That kind of strategy probably works very well since most professors want a productive student." (d) **P**: "On our floor, there are three undergraduates who worked in our lab before and now work in other labs. All are BIOS students. I don't know much about the BIOS program but I do think BIOS students are more aggressive about looking for opportunities. They all started their research a little early, in their second year, so I think that allows them to be more productive. Since they are more productive, I think they get to use their time better and have more chances to finish projects and start extra opportunities." (e) **F**: "I have two [MR mentees] in my lab now who had already been in another lab before. Both participated in BIOS. Most of the BIOS students I have interacted with are very smart and I also hear very good things about them from other faculty. I think these kinds of rumors make many faculty more inclined to take on a BIOS student who has already worked in another lab, even if that [experience] was very short… This is different from other kinds of students. For other students, when you hear they quit from a lab, you are naturally worried about their motivation or their desire to work hard so you might be more hesitant to give them a second chance."
4) differences in performance during MR	(a) **P:** "In our lab, we have one BIOS student and two non-BIOS students. The BIOS student clearly is more productive even though they [matriculated in the same year]. The BIOS student also generally needs less help from me and is better about finding answers to his own questions. I think this helps me a lot because I can leave him alone and let him work independently."

(b) **B:** "I sometimes think BIOS students might be more self-sufficient than [non-BIOS peers]… In our lab, we have two BIOS students and two [non-BIOS]. We all joined the lab at about the same time but I feel the BIOS students have been more productive and have needed less help [from mentors]... I can not prove this point but I feel it is generally true for other labs too… In those labs, I know of situations where BIOS and non-BIOS students joined at similar times but BIOS students are further along in their projects… Sometimes, [ex-BIOS students] also act like leaders by [mentoring] other [undergraduates]… I hope [non-BIOS students] don't feel bad about me saying this… I know five BIOS classmates who have experimental results that are going to be published… I don't know a single [non-BIOS student] who has these kinds of results."

(c) **N:** "I also think BIOS students might be more self-sufficient during [MR]. In our lab, we only have one graduate student… We have five undergraduates so the graduate student can not always take care of [everyone]… In this group, there is one BIOS student and he has kind of become the leader and teacher, helping us learn our experiments and troubleshoot them… I think his added experience from BIOS helps a lot in his ability to help us. I also know of another lab where another BIOS student is being like a mentor or teacher for other [non-BIOS students]."

(d) **P:** "I am mentoring both a BIOS student and a non-BIOS student. I do think maybe the BIOS student knew a little more when they first started [working in our lab], but now, I feel their abilities are very similar… So, if there is an advantage from BIOS, I don't think it lasts very long…"

(e) **F:** "I do feel BIOS students can be more self-sufficient, but I also think that might have something to do with how long they have been in the lab and how much prior experience they have working on things [related to their MR project]… If you compare a BIOS student with biochemistry experience and a non-BIOS student with no biochemistry experience, the first will do better [conducting MR] in a biochemistry lab. But, if you compare a BIOS student with no biochemistry experience and a non-BIOS student with biochemistry experience, I think the latter will probably do better. So, I feel there is nothing magical about BIOS necessarily, it matters whether BIOS gives them experience relevant to what they do later…"

(f) **P**: "I think a key aspect of improved performance [during MR] is having high interest in the research topic. I think BIOS students have a much better understanding of what they are interested in doing so they can arrive in the lab and start working much more quickly… non-BIOS students, on the other hand, I think are still trying to [figure out] what they like so when they come into the lab, it is more of an exploration for them, rather than a focused [apprenticeship] that tries to get [publishable] results… Because of this difference, I think BIOS students are much more likely to be focused and engaged."

(g) **B**: "I agree [ex-BIOS students] likely have more confidence and better lab skills when they [start their first MR experience]… At the same time, I also think they have a better idea of what they are interested in working on so they are more likely to join a lab where they will be productive and [engaged]… I think this difference in interest can be really important in giving students high motivation."

STable 13. Comparison of BIOS and non-BIOS student GPA, at time of BIOS enrollment and at graduation.

	Average GPA at BIOS enrollment			*Average GPA at graduation*		
Matriculated	BIOS	Non-BIOS	Difference[1]	BIOS	Non-BIOS	Difference[1]
2014	3.11	2.75	0.36**	3.22	2.93	0.29*
2015	3.24	2.84	0.40**	3.36	3.04	0.32**
2016	3.09	2.85	0.24*	3.35	3.09	0.26**
Combined	3.14	2.80	0.32***	3.29	3.03	0.30***

[1] asterisks indicate statistical significance between BIOS and non-BIOS, determined by Mann Whitney U: * = $p<0.05$; ** = $p<0.01$; *** = $p<0.001$