

The impact of COVID-19 on the perception of mentorship quality among undergraduates
engaged in life sciences research : Evidence from a survey

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Abstract: The COVID-19 pandemic has disrupted higher-education, the training ground of young scientists. A critical aspect of science education is mentorship, yet it is poorly understood and is seldom measured for quality by higher education institutions. The pandemic has the potential to disrupt mentorship relationships and existing literature suggest under-represented minorities are likely to be particularly vulnerable. This study reports the findings of a survey on how senior thesis writers in a life sciences concentration at Harvard perceive their relationships to their faculty mentors during the ongoing COVID19 pandemic. In brief, this study finds that self-reported attitudes towards PIs did not change at a population level relative to recalled perceptions but draws attention to the presence of outliers. This study was not powered to ascertain changes in the perception of mentorship across subpopulations of students. This study also aimed to use theoretical frameworks of mentorship to propose and validate metrics of PI mentorship quality. This study recommends 4 of 5 survey questions used for future validation studies.

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Introduction

The COVID19 Pandemic has Disrupted Higher Education and highlighted the need of a productive scientific workforce

The COVID-19 pandemic has disrupted how higher education is experienced, delivered, and managed. While the media was quick to document the mass exodus from college campuses that students faced (Douglas-Gabriel n.d.; Belkin 2020), research on the effects of the pandemic on student experiences is in its infancy. Understanding student experiences is essential to informing how universities address the need of their students in light of the COVID-19 pandemic but also to plan for future pandemics that scientists say are increasingly likely (Dodds 2019; Tollefson 2020). Over a year after US universities abruptly closed for on campus learning in March of 2019, there is emerging evidence that lower-income and first-generation students are disproportionately impacted by campus closures and the financial downturn caused by the COVID-19 pandemic (Aucejo et al. 2020). The experiences of lower-income and first-generation students carry salience not only because they are more likely to have barriers to online learning during this pandemic but because also because their experiences in higher education can have a real impact on their career choices and therefore contributions to society (Aucejo et al. 2020).

The importance of a productive scientific workforce is on the national consciousness as the countries looked to their scientists to develop vaccines to combat the COVID19 pandemic. While much attention is being paid to scientists, not much is paid to scientific training. What factors impact a student's desire to become a scientist, succeed in their undergraduate education, and pursue graduate studies in the sciences? Research has found that at the heart of these questions is mentorship at levels of STEMM education, yet little attention is paid to the quality and efficacy of mentorship at all levels of career development (Committee on Effective Mentoring in STEMM et al. 2019). Less than 50 % of faculty report mentorship being evaluated while being considered them for promotions, and as little as 7% report engagement in mentorship training (Stolzenberg 2019; Gallup 2018). In this current pandemic, it is unclear how distance has affected STEMM education. In the absence of institutional tracking of the quality of mentorship, there is no telling how the pandemic has affected the relationships that mold the next generation of scientists. Promoting mentorship is particularly valuable to under-represented students. In an environment where mentorship is left to form ad hoc, underrepresented students are typically more vulnerable to receive bad mentorship, lacking the social capital to connect and

leverage their relationships with their mentors (Committee on Effective Mentoring in STEMM et al. 2019). Tracking and improving mentorship is therefore not only important to improving the quality of STEMM education but to equity inclusion, a professed core value of many higher education institutions.

This study seeks to illuminate the current state of mentorship among science undergraduates by using Harvard University as a case study. In particular, this study seeks to answer how the COVID-19 pandemic has affected how Harvard undergraduates engaged in life sciences research perceive their relationship with research mentors. This study focuses on the perception of mentorship as it speaks to, in part, how effectively mentorship is being delivered since “negative mentoring experiences have been linked to attrition, especially for [underrepresented] students” (Committee on Effective Mentoring in STEMM et al. 2019, p.6). A survey was used to investigate how students perceive the quality of their mentorship. To attempt to understand how perceptions have changed, the survey asked students to rate various measures of the quality of mentorship before and after the pandemic. This study must be forthcoming about the difficulty to define let alone measure the quality of mentorship, but it relied on existing literature to generate a list of key quality measures that were probed.

Given that students were forced off of campus and the salience of lab-based research in the life sciences, this study anticipates the perception of the quality of mentorship will be impacted in a non-uniform manner. This study anticipates the variation in quality caused by ad hoc mentorship will be intensified. Students with mentors who have risen to the challenge of mentoring in a pandemic will be viewed with higher favorability while students with absent mentors will be viewed poorly in particular as expectations of mentors are higher during these uncertain times. Before getting into the research design, we will first define mentorship and outline key conceptual frameworks that guided this project.

A Working Definition of Mentorship Rooted in an Integration of 5 Conceptual Framework

This study sought to understand the current state of mentorship between undergraduates engaged in life sciences research at Harvard and their mentors. In order to robustly interrogate mentorship, we used the following working relationship of mentorship outlined by the Committee on Effective Mentoring in STEMM: “Mentorship refers to a collaborative learning relationship and working alliance based on intentionality, trust, and shared responsibility for the interactions in that relationship and the effectiveness of those interactions” (Committee on

Effective Mentoring in STEMM et al. 2019, 4). This definition of mentorship relies on 6 conceptual frameworks, of which we choose 5 frameworks we find most relevant to our study (summarized in Table 1 of the appendix). This study used the ecological systems to situate mentorship, social cognitive career theory, social capital theory, and the tripartite integration model of social influence to explain why mentorship is important for mentees pursuit of science and social exchange theory to explain why mentors and mentees may be impacted by the pandemic.

Ecological systems theory defines mentorship at occurring at different levels, all of which impact each other (Chandler et al. 2011). In brief, mentorship occurs in microsystem that are comprised of one on one interactions between mentors and mentees. Many microsystems exist and the different microsystems an individual mentee engages in affects the others. The interaction between microsystems comprises the mesosystem. The exosystem is comprised of all phenomena that impacts the microsystems and mesosystems that exist outside the mentors and mentees such as the institution they reside in or the relationship of their home institution to their home communities. Macrosystems are the culture influences that may impact the microsystems and mesosystems such as systemic racism. The chronosystem is comprised of the temporal dynamics of the other systems. Ecological system theory tells us that mentorship between the mentor and mentee, the microsystem, will be impacted by how relationships held by mentors and mentees to others in light of the pandemic. For example, mentees may have higher time commitments to their family during the pandemic that may impact their ability to sustain their relationships to mentors. Meanwhile, the pandemic has certainly impacted the exosystem and macrosystem as Harvard shifts to online learning, sends students off campus, and de-densified research labs while the pandemic has disproportionately impacted people of color in the United States. Ecological systems theory motivated this study conceptually, as well as helped to articulate the site of mentorship I am interested in, the microsystem. I hope to engage in inductive investigation. By analyzing the state of the microsystem, I hope to get clues on how the ecosystem and macrosystem in particular are impacting mentorship

Meanwhile social capital theory concerns itself with the reproduction of social and power inequities through the gatekeeping and transfer of knowledge that comprises social capital (Bourdieu 1977; 1978). Social capital theory therefore posits that a key function of mentorship is the production and transfer of social capital between mentors and mentees. Mentees need to

accrue social capital to get past key gate-keeping milestone by performing science culture, such as understanding and reinforcing power structures within science. Social capital theory helps to articulate the impacts of declining mentorship as the decline in the transfer of social capital as it concerned with science.

Tripartite Integration Model of Social Influence is similar to social capital theory in that it concerns itself with the reproduction of knowledge but distinguishes itself with its emphasis on its impact on socialization into a community (Estrada et al. 2011). Social exchange theory nominates another key function and outcome of mentorship: fostering and developing a scientific identity. This conceptual framework therefore helps motivate the study, suggesting the COVID19 pandemic could decrease the sense of scientific identity if mentorship quality drops. Decline in scientific identity could in turn lead to attrition in the science as it has been linked to post-secondary pursuit of science (Estrada et al. 2011).

In a similar vein, social cognitive career theory holds that four sources of learning develop a sense of self-efficacy and in turn impact individual's motivation, goal setting, and persistence in achieving these outcomes (Lent, Brown, and Hackett 1994). These four sources are previous experiences, vicarious learning, affective/emotional arousal and social persuasion. The mentor-mentee relationship has the largest potential to affect vicarious learning by providing a model to emulate and providing psychosocial support that in turn effects emotional arousal for science.

Last in the list of conceptual frameworks we apply to mentorship is social exchange theory. The basic tenant of social exchange theory is that individuals are selfish actors that engage in transactional relationships associated with costs and benefits (Blau 1964). Willingness to initiate, sustain, and develop relationships will be impacted by the perceived cost and benefits of a relationship (Blau 1964). Social exchange theory would predict that mentorship must benefit both the mentor and mentee for it to be successful. Alterations in the cost of engaging in the relationship by either individual will cause shifts in the quality of the relationship. This theory in particular helps to probe potential mechanisms of changes in mentorship quality.

Methods

The theoretical frameworks that define the process and outcomes of mentorship inform a survey to probe perceptions of the quality of mentorship

This study aims to characterize the current state of mentorship in light of the COVID19 pandemic. To begin to attempt this question, this study concerned itself with the perceptions of the relationship between mentees and mentors. To measure the perceptions of the quality of their relationship to their mentors, data was gathered from students engage in life sciences research. Though this study was interested in the state of mentorship in the life sciences at large, it used the Department of Stem Cell and Regenerative Biology (SCRB) at Harvard as a case study. It used a single department to minimize variation in the target sample to increase the detectability of the effects of the COVID-19 pandemic. To further homogenize the sampling population, this study surveyed specifically seniors who turned in thesis in the 2020-2021 academic year. This study focused on senior thesis writers because they have a conception of research mentorship before and after the pandemic. Because SCRБ theses require direct supervision by the head of a lab known as a principal investigator (PI), this study asked questions about the perceived relationship between mentees and PIs. Though other mentor-mentee relationships exist among undergraduates engaged in science, these relationships vary across undergraduates. For example, some mentees are paired with direct supervisors in addition to their PIs who could be either graduate or post-doctorate fellows in the same lab. Because all undergraduates in the SCRБ department who submitted senior thesis have associated PIs, this study interrogated the relationship between PIs and undergraduate mentees.

Study Design-Participants were asked about their relationship to their PIs before and after the Pandemic in a random order

This study embarked on a primarily quantitative approach to understand the effects of the pandemic on the perception of mentorship and inquired if the effects of the pandemic are felt equally across demographic groups by collecting survey data. After confirming informed consent, the survey asked respondents about the perceptions of their relationship to their PIs before and after the pandemic. Participants were randomly given either the pre-COVID19 questions or post-COVID19 questions first to control for possible effects of asking about their perception of the relationship at two different time points. Survey questions asked students to rank their perception of various features of their relationship to their PI on a sliding scale of 1 to

5. The survey then collected demographic data concerning socioeconomic status, racial and ethnic backgrounds, and so called first-generation student status, as well as collect other potential variables of interest summarized in Appendix Table 2

For the sake of minimizing the time it would take to fill out the survey, the survey asked only 5 slider questions, all of which were rooted in the aforementioned conceptual frameworks. These questions are listed and justified in Table 2 in the appendix. I aimed to use inductive reasoning to extract general quantitative trends that were associated with changes the perceived mentorship quality between mentees and PIs. I used inductive reasoning instead of a pre-formulated hypothesis to minimize the risk potential research bias as we highlight that the author of this study is deeply embedded in undergraduate research and is a member of the SCRB department.

In addition to the sliding scale questions included in the survey, a free response question asking respondents about their experiences with their PIs or if they have any recommendations for improvement was included. This question was provided to help contextualize respondent's survey results as well as inform potential institutional recommendations that may have risen from this study.

Data Ethics

Careful attention was paid to anonymizing and securing data as this study was engaged in human research. The raw data made no reference to individuals and not even the author is aware of the identity of respondents. Informed consent was confirmed prior to participants filling out the survey and participants were made aware that at no point will their data be shared outside of the classroom and especially to their department. The study author also withheld the department's name when relaying the results of this study to GenEd1039 students. As a thank you to study participants, the author of this study also shared the results of this study with participants in the form of presentation slides. No identifiable metrics were included in the shared slides.

Data Analysis

Validating survey questions with a heatmap of correlation coefficients and multiple linear regression models

As no consensus exist as to what the best methods are to study mentorship quality, this study aimed to quantitatively validate the survey questions used. An ideal survey question would measure distinct phenomenon to reduce redundancy and should be associated with outcomes of interest, that is increase the success of students in pursuing science. To quantitatively check for measurement of distinct phenomenon and correlation to outcomes, the Pearson correlation coefficient—which measures how associated two metrics are—between each pair of questions was determined using the Corrplot R package (Taiyun Wei and Viliam Simko 2017). To further validate questions as meaningful to predicting PI quality, I created multiple linear regression models to predict how respondents rated their PIs desire to pursue a senior thesis or a science career after graduation as measures of desires to pursue science.

Statistical Tests were used to determine if there were population changes in mean change and spread in PI relationship metrics

All survey responses were recorded as 1-5 as reported in Appendix Table 2. Paired sample T-tests were used to statistically determine if on average, the sampled population changed in their perception of the quality of their relationship to their PIs at a false discovery cut-off of $\alpha = 0.10$. F-tests were performed comparing the variation of pre-pandemic and post-pandemic survey responses for each question at a false discovery cut-off of $\alpha = 0.10$. The results of T-test and F-test were plotted and visualized using the R package sjPlot (Lüdecke 2021).

Plots

The difference from current and pre-pandemic ratings of PI relationship survey questions was calculated for all individuals. The changes in relationship ratings and the correlation of questions to each other were plotted using the R package ggplot2 (Wickham 2016). Multiple linear regression models were generated using R base functions and visualized using ggfortify R package (Tang, Horikoshi, and Li 2016).

Study Limitations and Statement of Positionality

This study aimed to describe the changes in the perception of mentorship associated with the COVID19 pandemic but could not establish causality in the absence of a randomized trial or more complex study design. Because this study relied on survey data, all data was self-reported, and the wording of the questions may have itself impact how mentees reported their relationships to mentors. Careful attention was paid to avoid priming respondents towards answering positively or negatively including randomizing whether students were asked about pre or post COVID19 perceptions first. Still, the possibility of introducing bias within the survey question itself was difficult to eliminate all together. Perhaps the biggest limitation in this study was relying on recalled data, that is asking respondents to recall how they felt about their PI before the pandemic. Because individuals recall emotionally salient memories more vividly, we likely systematically get more accurate recall data of individuals with more emotionally salient experiences than those without. This recall bias must be kept in mind while analyzing survey responses.

In addition to the limitations of this study, this study also discloses the positionality of the author of this study. I, Andrew Castillo, am an undergraduate researcher who wrote a senior thesis in the department being sampled. I am a first generation, low-income, Latinx student. I have my own opinions about my own PI as well as the importance of mentorship in STEMM education. I however conducted this research paying careful awareness and attention as to avoid biasing respondents.

Results

All survey questions are correlated with each other, but PI positivity is least correlated with PI's impact on the desire to pursue science

To understand how the pandemic impacted the relationship between PIs and undergraduate researchers, this study distributed a survey to senior thesis writers in a life sciences department at Harvard. In the Spring of 2021, there were 28 senior thesis writers, of which the author of this study is one. The author excluded himself from the target population to avoid introduction of researcher bias. Individuals in the target population were emailed a unique, anonymous link to the survey 3 times over the span of a week. Of the 27 individuals in the target

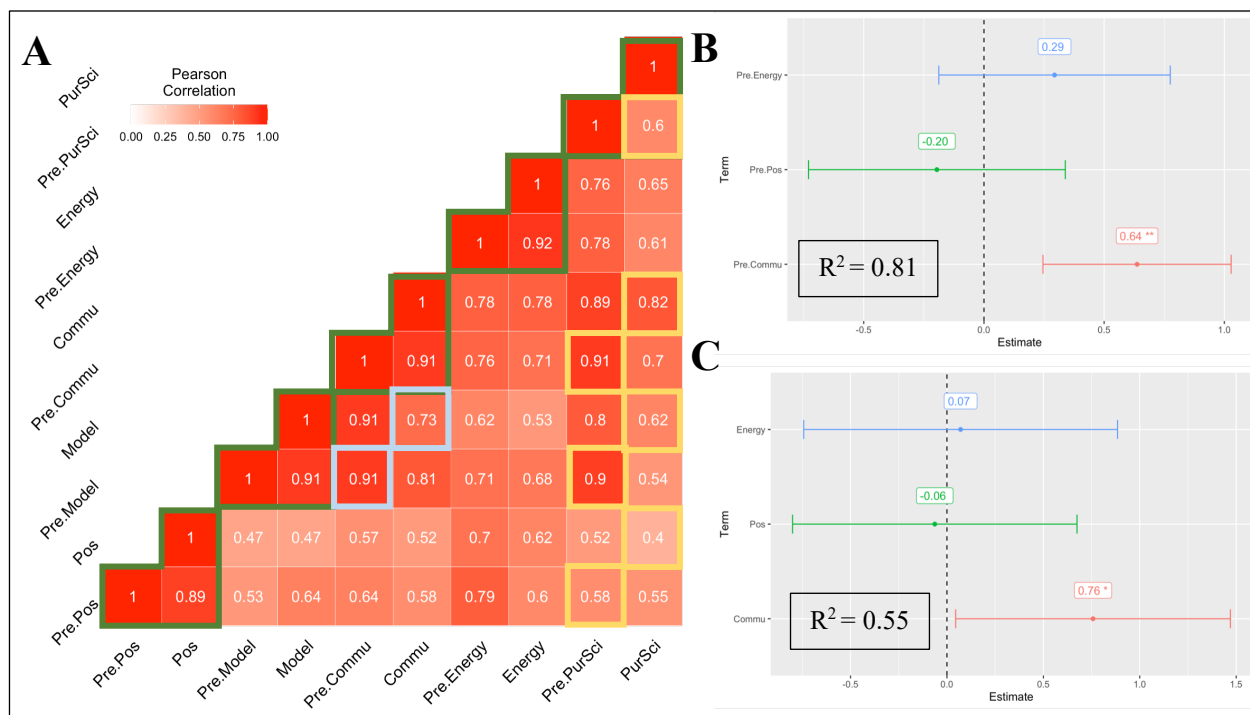


Figure 1 All questions were correlated with each other and community was the strongest predictor of desire to pursue science as impacted by a respondent's PI

A) A heatmap of the Pearson Correlation Coefficient of the responses to each survey question to all other questions. Boxed in green are paired questions, that is they measure the same metric at the time the survey was conducted and as recalled before the pandemic. Boxed in blue are correlations between PI role modelling and PI impact on community. Boxed in yellow are the lowest and highest correlates to PI impact on desire to pursue science. Deeper shades of red represent higher correlation. **B** and **C)** Plots representing multiple linear regression models where correlation coefficients are visualized as dots and 95% confidence intervals as bars. Adjusted R^2 are overlaid on the plots. Pre = Pre-pandemic. ** $p < 0.01$ * $p < 0.05$

population, 26 were contacted, 15 started the survey, and 12 completed the survey. 44% of the target population was sampled in this study.

As there is no consensus as to how to measure the quality of science mentorship systematically, this study aimed to validate the survey questions used to measure mentorship quality. Survey questions were designed to probe some of key assertions of the theoretical frameworks of mentorship (summarized in Table 1). Questions asking about how energized and how positively respondents felt about their PI were administered to approximate the perceived cost and benefits of the relationship. Questions about how respondent's PIs impacted their sense of being in a scientific community, role modelled how to interact with other scientists, and impacted their desire to pursue science were administered to test some of the predicted outcomes of mentorship as proposed by the literature. The full survey is available in the Appendix Table 2.

Asking if these 5 types of questions were measuring distinct phenomenon, a heatmap of the correlation each question to all other questions was made. All questions were at a minimum correlated with each other a 0.4 and at max 0.9 (Figure 1 A). All pre-pandemic questions were highly correlated with their matched questions (Figure 1 A). For example, how positively a respondent felt about their PI pre-pandemic was .89 correlated with how positively they felt about their PI currently. Interestingly, among these matched questions (outlined in green), the desire to pursue science pre-pandemic and currently was least correlated with each other (Figure 1A). Another interesting trend was that all variables were correlated with how respondent's felt their PI impacted their desire to pursue a senior thesis (Pre.PurSci) or to pursue a career in science after graduation (PurSci) at a correlation coefficient greater than 0.5 with the exception of how positively they felt about their PI (Figure 1A). How respondents felt their PI role modelled how to interact with other scientist and impacted their sense of being in a scientific community were the most correlated with their desire to pursue a senior thesis (0.90 and 0.91) and a scientific career after graduation (0.62 and 0.82).

Finding that all metrics were correlated with the desire to pursue science, I asked which metric was a significant predictor of how PIs impacted respondent's desire to pursue a thesis before the pandemic and a scientific career after graduation. I created a multiple linear regression model using all metrics (positivity of relationship, energy after conversations with PI, sense of scientific community, and role modelling by PI) as predictors of how PIs impacted respondent's desire to conduct a thesis pre-pandemic or pursue a scientific career. Because a PIs role modelling of interacting with other scientist and impact on respondent's sense of being in a scientific community were strongly correlated with each other (boxed in blue in Figure 1A), regression models including both would occlude their relationship to a PI's impact on the desire to pursue science. I therefore made two separate sets of models, one excluding metrics of community and the other excluding role modelling how to interact with scientists. The models excluding role modelling and including impact on sense of scientific community explained the most variation in the pre-pandemic (adjusted $R^2 = 0.81$) and at the time of the survey (adjusted $R^2 = 0.55$), so this was chosen as the final model.

In these models, how a PI impacted a respondent's desire to pursue a senior thesis or career in science was significantly associated by how they impacted respondent's sense of being in a scientific community (Figure 2 B and C). PI impact on sense of scientific community was

associated with a .61 increase in the desire to pursue a senior thesis and .76 on pursuing a science career at a p-value of 0.00598 and 0.0398 respective (all survey responses are on scales of 1-5) (Figure 2 B and C). All other metrics measured were not significant at a false discovery rate of 0.10.

At a population level, measured metrics of PI quality did not significantly change

Having interrogated the validity of the metrics measured through this study's survey, I then asked if there were population level changes in these metrics as reported by respondents. How each respondent felt about their PI by measured metrics currently was subtracted from how they recalled feeling pre-pandemic. I found that most people did not feel differently about how their PI impacted their desire to pursue science, how energized they felt after talking to their PI, how they felt their PI role modelled how to interact with other scientist or their sense, of being in a scientific community, or how positively they felt about their PI (83.3, 66.7, 75.0, 83.3, and 75.0 percent respectively reporting no change) (Figure 2 A). Also appreciable in the data is that some individuals reported positive and negative changes in metrics measured (Figure 2) and that the most variation reported change was in individuals desire to pursue science (Figure 2 B-F). Noting that there were changes in the positive and negative directions, I asked if the pre-pandemic and current reported means and standard deviations in these metrics were statically different. I ran paired T-test which tests for differences in means and F-Tests which tests for differences in spread for all matched current and pre-pandemic metrics. I found all metrics did not exhibit significant changes in mean or spread with the exception in the sense of scientific community which was significantly increased at a false discovery rate of 0.10 (Supplemental Figure 1; F-test were not significant, data not shown). Having found no population changes in mean or spread in the metrics of PI mentorship of interest, I sought to stratify the data with the collected demographic information. However, there was not enough variation by subgroup to statistically ask questions. For example, there was only 2 individuals who identify as men in this sample and there were only 3 SEF eligible individuals in these sample. I was not statically powered to make stratified comparisons. To maximize anonymity of respondents and because no conclusions can be drawn from this data, I do include this data in the study.

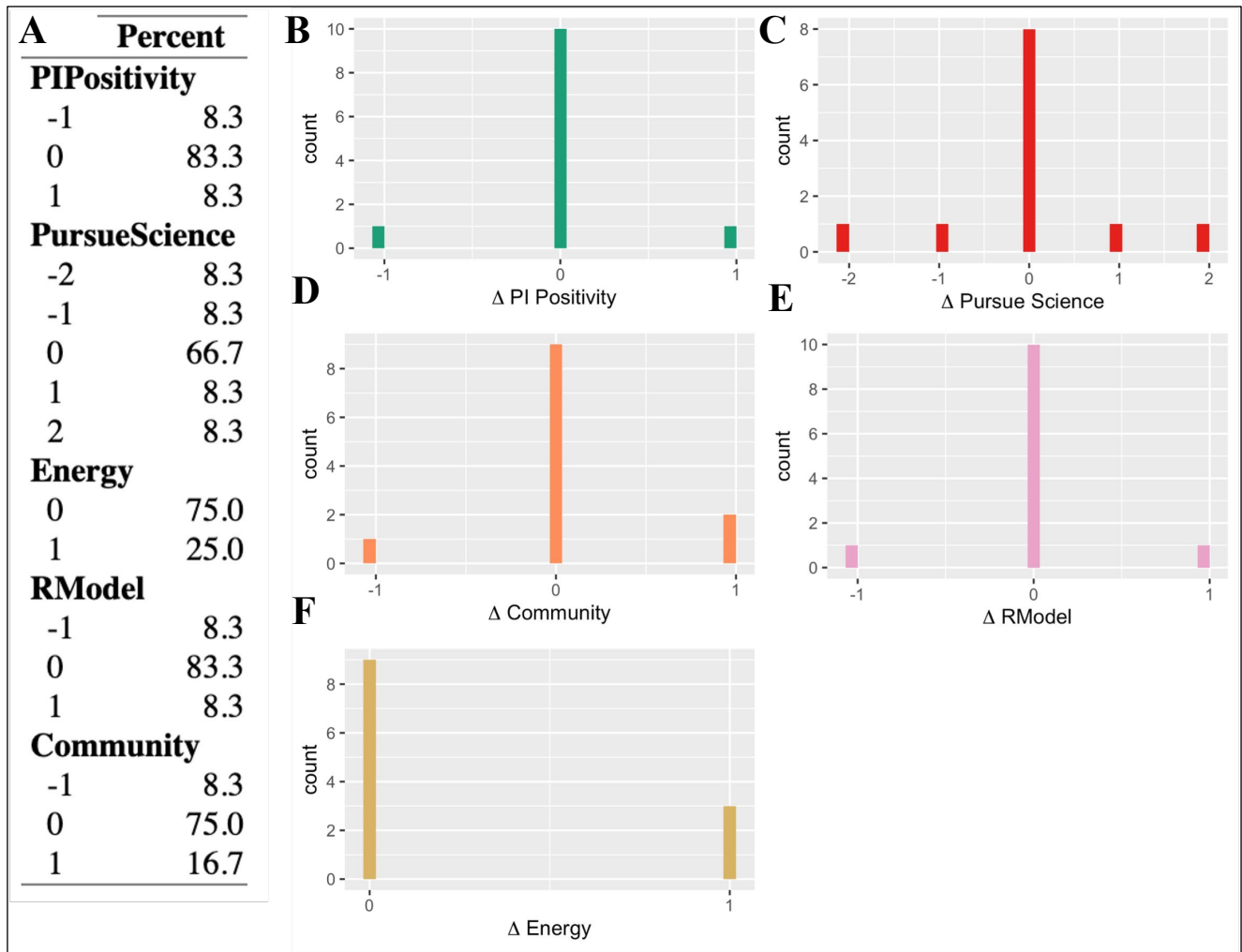


Figure 2 Most quality of mentorship metrics did not change between pre-pandemic and time of survey
 A) A table the changes in respondent’s perception of their PIs relative to pre-pandemic. B-E) Histograms of the changes in respondents’ perceptions of their PIs relative to the pre-pandemic perceptions. PI Positivity = Positivity towards PI; Pursue Science = PI’s impact on respondents’ desire to pursue science; Community = PI’s impact on respondents’ sense of being in a scientific community; RModel = PI role modeling of how to interact with other scientist; Energy = How energized respondents felt after talking to their PI.

Open Response Question

In addition to the being administered PI mentorship quality questions, respondents were also given the option to respond to the following free response question:

This study aims to understand the effects of the pandemic on mentorship between PIs and undergraduates engaged in science research. Is there anything you would like to add about your experiences with your PI or any recommendations you would have for improvements?

Only 4 individuals responded to this question. I highlight the responses of two individuals in this section, individual 1 and 4 in this section (Table 3). Individual 1 wrote, “What made this year challenging was not conducting my own experiments in lab. My PI was great through it all though”. It is notable that this individual did not report any change in the mentorship metrics and reported the highest score possible for all metrics in the survey. Meanwhile, individual 4 wrote:

[M]y PI seemed very uninterested in getting to understand students; which makes me question as to why my PI accepted undergrads in their lab; there should be more vetting of PIs who truly do not have the capacity to take on undergrads through the department.

Similar to individual 1, individual 4 also reported the most extreme values in the survey, ranking their relationship to their mentor before and after the pandemic 1-3, that is the most negative or neutral values for all metrics.

Discussion of Findings and Conclusions

This study aimed to test the hypothesis that the pandemic increased variation in the quality of mentorship as well as validate the chosen metrics used to evaluate the quality of mentorship. This study also sought to ask if the experienced quality of mentorship was different within subpopulation of students. To address these aims, I conducted a survey, finding all question were correlated with each other, and that no population level changes in PI mentorship metrics were detected with the exception in how respondents felt their PI impacted their sense of being in a scientific community. Due to a lack of representation by subgroup, I was not statistically powered to sub-stratify the data and make statistical comparisons.

I sought to validate the metrics I used to measure the quality of mentorship by asking how each metric correlated to each other. I focus on correlations to how respondents perceived their PI impacted their desire to pursue science. Because all metrics had an appreciable correlation to each other, I conclude that each individual metric is likely not measuring in isolated phenomenon. This is not surprising given that I am measuring the purported benefits, costs, and mechanisms of mentorship as reported by the literature (Supplemental Table 1 and Table 2). Critically, the data meet fundamental predictions of the literature. Social Capital Theory as applied to mentorship would predict that PIs role modelling how to engage with other scientist would be positively associated with success in science (Committee on Effective Mentoring in STEMM et al. 2019; Bourdieu 1978). We found that how a student perceived their

PIs role modelling was amongst the most highly correlated with their desire to pursue a senior thesis and a scientific career, meeting this key prediction. Meanwhile, the Tripartite Integration Model of Social Influence posits that one of the key functions of PI mentorship is helping to develop a sense of community which in turn impacts desire to pursue science by Social Cognitive Career Theory (Estrada et al. 2011; Lent, Brown, and Hackett 1994). Respondent's perception of how their PI impacted their sense of belonging to a scientific community was also highly correlated with their desire to pursue a senior thesis and pursue a career in science and was the most significant predictor in linear regression models that were able to explain most of the variation in the data. This data analysis leads me to conclude the data is consistent with the existing body of literature supporting that the survey questions meaningfully capture aspects of mentorship quality. I note that one of the quality metric questions, how positively respondents felt about their PI, was the least correlated with their desire to pursue science. This suggests that either students' desire to pursue science is not that affected by their relationship with their PI, or more likely this question poorly measured mentorship quality. Future studies should refine or remove this survey question.

This study suggests that in the sampled department, the pandemic was not correlated with changes in quality of mentorship in the measured metrics at a population level. The only significant change in the measured metrics was how respondents felt their PI impacted their sense of being in a scientific community. Because other quality metrics assayed did not change, it is unlikely this positive change is attributable to an overall increase in mentorship quality. Perhaps this metric changed because seniors engaged more deeply with science by virtue of engaging in a senior thesis relative to when they were juniors. This means it is possible that they felt more a part of a scientific community because they themselves were engaging more with the scientific community. This increase in engagement coincided with the pandemic, suggesting this positive increase is not directly attributable to the pandemic. Interviewing respondents about their answers with a mixed methods approach could help tease out the mechanisms by which this metric increased in future studies.

While population level changes were not generally observed, I also draw attention to the fact that some degree of negative change was observed in all metrics. Of particular concern is that 16.6% of respondents reported a drop in their perception of their PIs impact on their desire to pursue science. We emphasize that a drop of 1 is a 20% decrease on a scale of 1-5. This means

some outliers fell through the cracks of ad hoc mentorship in the pandemic. While this data suggest that mentorship quality was resilient to the pandemic in this population, it also suggest it is vulnerable to outliers. Universities should be concerned with both the whole student body and individual students. Negative outliers therefore constitute a failure and oversight. This study motivates the monitoring of mentorship quality to prevent outliers from being negatively impacted by their PI mentorship experiences.

Indeed, the free response question suggest some individuals were negatively impacted by their PI. Individual 4 questioned why his/her PI took on undergrad mentees at all. Individual 4 finished the survey with a recommendation to the department:

[T]here should be more vetting of PIs who truly do not have the capacity to take on undergrads [...]; it is difficult for students to communicate these issues to PIs because of an immense power dynamic; so there should be something anonymous or another avenue to communicate with PIs to circumvent this.

The fact that individuals with the most extreme responses in the survey were those who responded to the free response question suggest some degree of sampling bias. They should be read as informative of extreme opinions rather than the general population's opinion. Still, it is outliers that we are interested in, especially considering that negative mentorship experiences were correlated with a drop in the desire to pursue science after graduation in this study.

Individual 3 also offered up suggestions to the department:

The [...] department communicates through students quite a bit, which causes confusion for PIs and can lead to tension in the relationships students have with their PIs. In the future, SCRB should communicate directly with students, PIs and mentors for EVERYTHING. Similarly, more support is needed for Black and Brown students who sometimes are not as easily assured of their scientific capabilities as their white peers.

Overall, students called for increase oversight by the department of mentorship relationships as well as increasing avenues for anonymous airing of complaints. This suggest outliers are particularly vulnerable because the PI-mentee relationship has such huge power differentials that that mentees do not feel comfortable advocating for themselves. I conclude that while the pandemic as a whole did not decrease population level mentorship quality, vulnerable students still exist within the population who do not have the tools to improve their own relationship. This

puts them at risk leaving science all together. It is the responsibility of higher education institutions to monitor this relationship.

Future studies should aim to replicate this study across institutions, refining the survey questions by removing PI positivity question. By replicating this study across diverse institutions, the analysis can be stratified to speak to how subpopulations of students were impacted by the pandemic. It is unclear if the lack of population level changes in this life sciences department at Harvard is generalizable across higher education institutions. Given the large financial resources Harvard had and its success in preserving research continuity during the pandemic, it is plausible other less resourced institutions may have been more impacted by the pandemic and therefore PI-mentee relationships may be more prone to change. Future studies should continue to use quantitative methods to validate the study of PI mentorship, but they might also consider a mixed method approach to especially better understand the experiences of both positive and negative outliers. Negative outliers are of special concern since negative experiences are associated with attrition in science. This study overall endorses institutional tracking of PI mentorship at the undergraduate level that have been historically untracked relative to the graduate level. More research is needed to both understand the importance of mentorship in STEMM but also how define, measure, and improve the quality of mentorship.

Appendix

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Table 1 Theoretical Frameworks of Mentorship

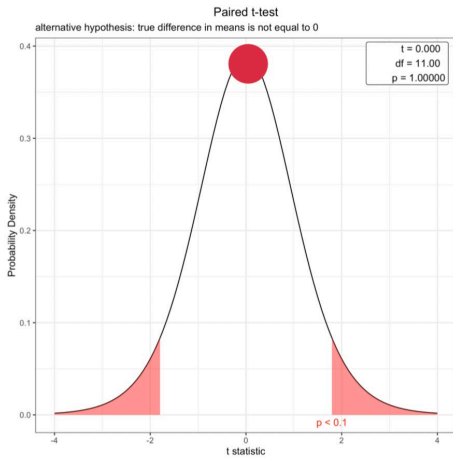
Framework	Components	Implication on Study	Citation
Ecological Systems Theory	Mentorships occur at 5 levels: 1. Microsystem-between two individual 2. Mesosystems-between microsystems 3. Exosystems-linkages that exist outside the individuals such as to institutions 4. Macrosystems-cultural influences micro and mesosystems 5. Chronosystem-Changes over time	Changes in macrosystem and exosystem caused by the COVID19 pandemic expects changes to the microsystem.	(Committee on Effective Mentoring in STEMM et al. 2019; Chandler et al. 2011)
Social Cognitive Career Theory	Previous performance, vicarious learning, affective/emotional arousal, and social persuasion affect development of self-efficacy	Changes in mentorship can affect development of self-efficacy and therefore rates of attrition in the sciences	(Lent, Brown, and Hackett 1994)
Social Exchange Theory	People engage in relationships as self-interested actors and relationships carry both costs and benefits	Help to conceptualize potential mechanisms for how the pandemic may alter the perceive cost-benefit of mentorship that may lead explain observed changes in mentorship	(Blau 1964)
Social Capital Theory	Social capital is comprised of information individuals get from social structures and that information deters access to resources to outsiders	Motivates investigation of mentorship as it a key relationship that generates and reproduces social capital in the sciences	(Bourdieu 1978; 1977)
Tripartite Integration Model of Social Influence	Individuals are socialized into a community by being oriented to the rules, roles, and values of a community	Mentors help mentees develop a science identity by providing a model. Alterations in mentorship can impact science identity.	(Estrada et al. 2011)

Table 2 Survey Questions are informed by research question and theoretical frameworks

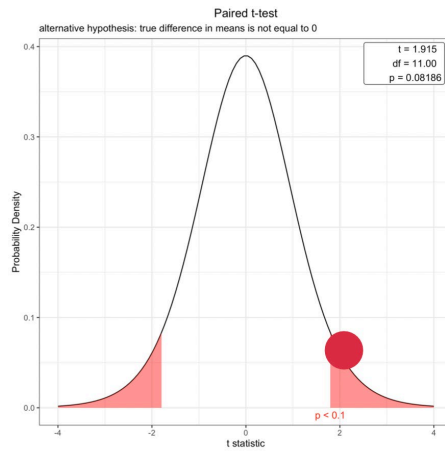
Overall Research Topic: Science Mentorship and the Pandemic		
Research Sub-question	Survey Question	Theoretical Root and purpose
Did the COVID-19 pandemic affect the quality of research?	How positive do you feel your relationship is to your PI? 1=It is not positive 3=Moderately positive 5=Very positive	Ecological Systems Theory says microsystems are the core of mentorship and is comprised of the mentor and mentee. The strength of this relationship is impacted by all other levels. We ask directly what the perceived strength of this relationship is to see if it has changed pre and post pandemic.
	On a scale of 1-5, how much do you agree with the following statement: My PI has positively impacted my desire to pursue science after graduation whether through graduate school, industry, or any other science career? 1=My PI has strongly decreased my desire to pursue science after graduation. 3=My PI has not affected my desire to pursue a science career after graduation. 5=My PI has strongly increased my desire to pursue science after graduation.	Social Cognitive Career Theory- This question aims to test if one of the key predicted positive impacts of mentorship is occurring, increasing participation in science post-graduation.
	Rank how energized you feel after having a conversation with you PI. 1 = Very low energy. I need to take a mental break after meetings with my PI. 3 = Neutral. I feel like my energy levels are like they always are after talking to my PI. 4 = My energy levels are very high and I am ready to get on to my next research task.	Social Exchange Theory- This question aims to uncover the perceived cost of the mentor-mentee relationship from the mentee's perspective. By asking about energy levels, we hope to avoid biasing responses toward positive or negative perceptions of relationship.
	Rank whether you feel like your PI has provided positive model on how to interact with other scientist? 1=My PI has not provided a model on how to interact with other scientist that I wish to emulate 3=I do not have a strong opinion as to whether my PI has provided a model for how to interact with other scientist. 5=My PI has provided a strong model of how to interact with other scientist that I wish to emulate.	Social Capital Theory-This question aims to probe whether social capital is being passed down through interactions with their PI.
	On a scale of 1-5, how much do you agree with the following statement: My PI has helped me feel welcomed in the scientific community? 1=My PI has strongly hindered my sense of belonging in the scientific community 3= My PI has neither hindered nor helped my sense of belonging in the scientific community 5=My PI has strongly helped my sense of belonging in the scientific community	Tripartite Integration Model of Social Influence-This question aims to understand whether the mentorship that is occurring between the mentee and PI is delivering a key predicted outcome of this model: developing a sense of belonging in a community.
Have different	Are you SEF eligible?	I ask this question as a proxy for low income status

groups been affected by the COVID19 pandemic equally in terms of its effects on mentorship?	Do you consider yourself a first generation college student?	We ask this question to see if FGLI students have different responses to subsequent survey questions relative to their peers who are not first generation students.
	Are you living off or on campus?	I ask this because we expect that access to mentorship will be impacted by whether respondents are on campus.
	Are you living with family members, friends, alone, or with others not listed here?	I ask this because ecological systems theory suggest all microsystem relationships impact the relationship between the mentor and mentee and we want to control for this.
	What ethnicity do you consider yourself as? Caucasian, Black, Latino, Asian, mix-race or ethnicity	Given that underrepresented minorities in STEM tend to have worse access to mentorship than their white male peers, we want to control for ethnicity in our data.
	Do you identify as a woman, man, non-binary, or other?	Given that underrepresented minorities in STEM tend to have worse access to mentorship than their white male peers, we want to control for ethnicity in our data.
	To your knowledge, does your PI hold the same racial or ethnic identity as you?	The literature suggest minority students with matched racial identities are more likely to pursue science.
	To your knowledge, does your PI hold the same gender identity as you?	The literature suggest that female PIs engage with their students equally regardless of gender while male PIs rate their female students lower on average.

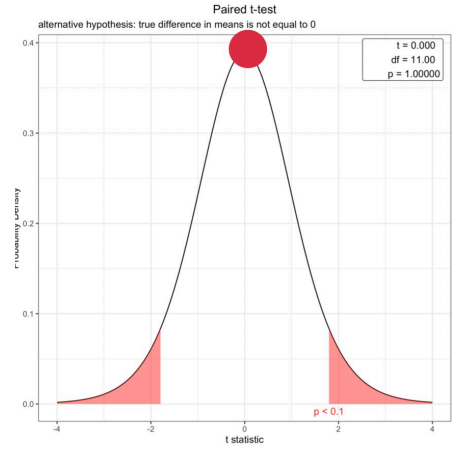
Δ PI Positivity



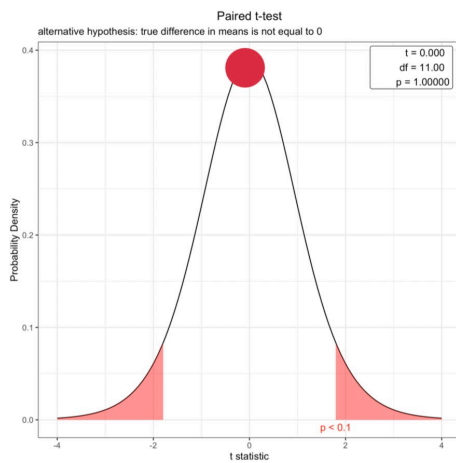
Δ Community



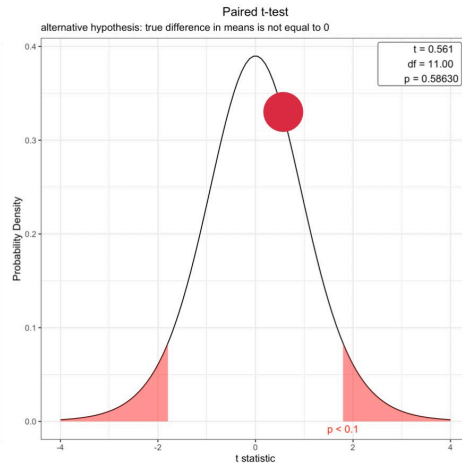
Δ Role Modelling



Δ Pursue Science



Δ Energy



Supplemental Figure 1 Only how energized respondents felt after talking to their PIs was significantly different compared to pre-pandemic recalls

Probability densities of paired T-test comparing mean scores in measured metrics. Red dots are overlaid at the T-statistic arising from paired T-tests. Shared in red are significant t-statistic values at $\alpha = 0.05$.

Table 3 Free response question suggest more institutional surveillance for outliers is necessary

Question: This study aims to understand the effects of the pandemic on mentorship between PIs and undergraduates engaged in science research. Is there anything you would like to add about your experiences with your PI or any recommendations you would have for improvements? This question is not optional so if not proceed to the end of the survey.	
1	What made this year challenging was not conducting my own experiments in lab. My PI was great through it all though!
2	He's a little weird and I did not have as close of a relationship with him as other kids in my lab
3	The SCRB department communicates through students quite a bit, which causes confusion for PIs and can lead to tension in the relationships students have with their PIs. In the future, SCRB should communicate directly with students, PIs and mentors for EVERYTHING. Similarly, more support is needed for Black and Brown students who sometimes are not as easily assured of their scientific capabilities as their white peers.
4	my PI seemed very uninterested in getting to understand students; which makes me question as to why my PI accepted undergrads in their lab; there should be more vetting of PIs who truly do not have the capacity to take on undergrads through the department; it is difficult for students to communicate these issues to PIs because of an immense power dynamic; so there should be something anonymous or another avenue to communicate with PIs to circumvent this

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