PURM
Perspectives on Undergraduate Research & Mentoring

Caution for Mentors: Evidence of Confirmation Bias in Measurements Taken by Undergraduate Students in Course-Based Research

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Introduction

Course-based undergraduate research experiences have attracted a lot of interest from instructors recently because of their association with higher completion rates of Science, Technology, Engineering, and Mathematics (STEM) degrees (Rodenbusch et al., 2016) and evidence that these experiences can encourage interest in higher education, especially for students in underrepresented groups in STEM (Bangera & Brownell, 2014). Students that participate are exposed to many important aspects of scientific research: generation of new knowledge, with several of its associated tasks, such as replication, verification, communication, summarizing, graphing, interpreting, and making conclusions (Dolan, 2016). Course-based research allows an instructor to include a greater number of students in authentic research than they would be able to accommodate in their research lab (Bopegedera, 2021; Shortlidge et al., 2017). In addition, students take pride in being part of a collaborative research effort (Jones & Lerner, 2019), or being engaged in research that is relevant to their own communities (Adkins-Jablonsky et al., 2020). The data collected from these course-based research activities are sometimes published in scientific journals (Dubansky et al., 2013; Porter et al., 2017), or used as pilot data for grant applications (Bakshi et al., 2016; Shortlidge et al., 2016), which is an added benefit for both the students and instructors.

However, if data collected by students as part of course-based research are to be published, the data must be reliable. Students involved in evaluating a hypothesis may be motivated to find the "correct" answer that supports the hypothesis they are testing, which is an example of "confirmation bias" (Nickerson, 1998), rather than finding the answer that supports the data. It has been suggested that hypothesis testing would be less likely to result in confirmation bias than interpretations of behavior from observational studies, but Balph & Balph (1983) provided several counterexamples from the literature and concluded that hypothesis testing does not by itself provide protection against confirmation bias. Inexperienced undergraduates were found to exhibit confirmation bias more frequently than more experienced researchers (Beattie & Baron, 1988), although this was not evaluated for course-based research. Confirmation bias has been evaluated in a number of scholarly disciplines (Hergovich et al., 2010; van Wilgenburg & Elgar, 2013), but to our knowledge has rarely been evaluated in the context of course-based student research (for an example see Marsh & Hanlon, 2007).

We evaluated whether students tend to collect data that support a hypothesis, whether consciously or subconsciously, by developing a simple course-based research project in which we provided the students with different hypotheses for testing. If the collected data show such a bias, this suggests that mentorship of students should include a discussion of confirmation bias and how bias can be minimized. The course was an online laboratory on image analysis in biological research. Early in the course, students had learned about the challenges of interpretation of sizes of three-dimensional objects from two-dimensional image representations. They learned that the apparent length of an object would be affected by its orientation with respect to the camera/sensor collecting the image. For example, a pole would appear longer when viewed at a right angle than when tilted with respect to the camera. For the research project, the students needed to use their skill of making measurements on digital images and their conceptual understanding of geometric projections.

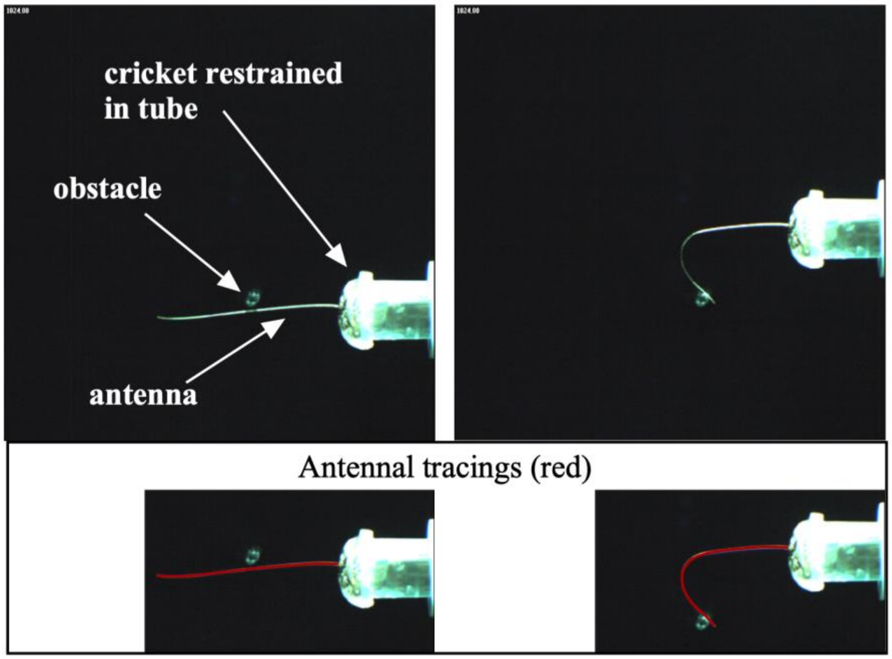
The research project involved measurement from images of a sensory structure responding to a mechanical stimulus. If a long sensory structure such as an insect antenna or mammalian whisker bends in three dimensions during tactile sensing, this changes the way in which information is collected by that sensory structure (e.g., Yu et al., 2019). The task for the students involved in this research project was to trace a long insect antenna before and during bending (a set of static images). Students were randomly divided into small groups; half of the groups were told that they were evaluating whether an antenna appeared to change in length during bending (unspecified whether the change in length was to shorten or lengthen), and half of the groups were told that they were evaluating whether an antenna appeared shorter during bending. To evaluate accuracy, we compared the student measurements of length with our measurements. In order to estimate possible bias caused by expectations, we compared the student measurements of length between the two sets of groups (given the two different hypotheses to test). This research project included many of the components expected in course-based research experiences, such as analyzing data, making interpretations, communicating results, and collaborating (Auchincloss et al., 2014; Dolan, 2016) but did not include opportunities for students to generate their own hypotheses or design the project. Giving the students that option in this project would have prevented us from evaluating confirmation bias, which we hoped would provide useful knowledge in informing mentorship practices.

Methods and Materials

The course-based research project was one set of assignments given over a couple of weeks within one course. A total of 113 students in three different sections of the same course (i.e., "Image Analysis in Biological Research Laboratory") participated in this study. The three different sections were offered during three different quarters, all during the time of the pandemic (Winter 2020 -- Winter 2021). The course had already been developed and approved as an online course prior to the pandemic, and therefore the mode of instructional delivery of this course was not impacted by the pandemic. Most of the students were seniors, and the most common major was biology.

Students were randomly assigned to groups of three or four. There were 10–12 groups in a section of the course. Each group of students within a course section was given a different set of eight images depicting the same insect with its antenna in different configurations (straight or bent) (Figure 1). The same sets of images were used in each of the three sections, so each image set was measured by a total of 9–12 students (combining the three sections). Prior to taking the measurements, half of the groups were given the hypothesis to test that the antenna would be shorter when bent, and the other half were given the hypothesis to test that the antenna may appear to change length when bent without specifying whether shorter or longer). The instructions and background information given to the two sets of groups were otherwise identical, including a null hypothesis of no change in length during bending. Each student independently measured the length of the antenna for each of the eight images using the segmented line selection tool in ImageJ/Fiji and reported the lengths by uploading their data in their own table (template supplied to students) using units of pixels (1 mm real world unit = 11.67 pixels for these images). Students had prior training in the use of this ImageJ tool for taking measurements in images during the course as part of previous assignments. After all the students in a group had taken their measurements, their data were summarized and graphed by the instructor and the students had an opportunity to compare their data with their peers.

Figure 1. *Example of images provided to students (left: straight antenna; right: bent antenna; bottom: examples of tracings done by students for determination of antennal length)*



During the final section (Winter 2021), a survey was conducted to evaluate student expectations. The survey was conducted after students had read the instructions but prior to viewing the image sets or taking any data. The survey had a single free response question, in which students were asked to briefly describe their expected outcome with regard to the hypothesis they were given. The question prompt assured students that they would receive full credit for completion of the survey, regardless of whether the results matched their expectations. Responses were categorized into three expected outcomes: 1) shorter when bending, 2) no change in length, or 3) unspecified change in length (e.g., "the antenna will appear to change length"). For analysis, the responses were grouped into "shorter when bending" and "other response."

All statistical analyses were performed in SAS 9.4. Mixed models were performed using Proc Mixed, with the hypothesis as the fixed effect. A single student measured multiple images, and therefore a student identifier was included in a random statement as a term to be included in the mixed model. Although individual student had a significant random effect ($p < 0.05$), its removal from the model had a negligible effect on the significance of the model. A single outlier was removed from the analyses because it was an error (i.e., the number recorded for length was off by a factor of 2 for a single image by a single student). Normally the complete range in values measured was ±3% of the mean. Outliers were identified in Proc Boxplot using the default criterion: being more than 1.5 times the interquartile range below the lower quartile or above the upper quartile. Fisher's Exact test was performed using Proc Freq (with option chisq).

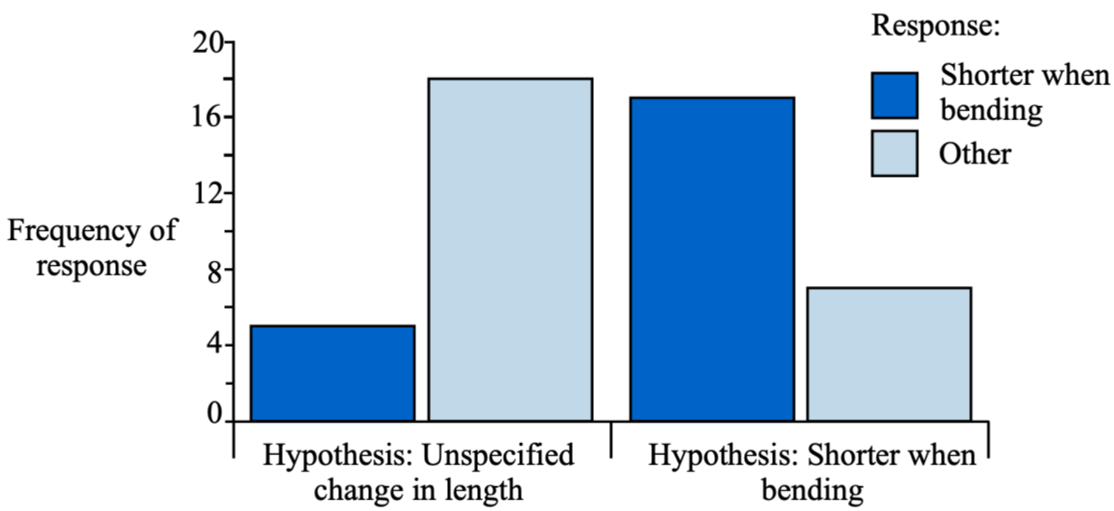
This study was performed with approval from the University of California, Irvine Institutional Review Board (HS#2018-4211). As this was treated as exempt research, all students were automatically enrolled in the study, and no written consent was obtained. A study information sheet describing the purpose of the research in broad terms without identifying the research question was provided to all students and posted on the course website. All students were given the option to have their data removed from analysis. No students chose to opt out of the study.

Results

Survey Responses

Students' responses were affected by the hypothesis that they were given to test. When students were given the hypothesis that the antennae would be shorter when bent, students were more likely to respond that they expected the antenna to be shorter than the students given the alternative hypothesis (p = 0.008, Fisher's exact test, n = 47) (Figure 2). This result by itself is not an indication of confirmation bias, because it demonstrates expectations prior to taking data. But it does show that the students are primed for possible confirmation bias, simply by the wording of the hypothesis being tested.

Figure 2. *Student responses to a survey asking for their expected outcome (n = 47)*



Notes: Students took this survey after reading the instructions which included the hypothesis that was being tested, but before taking data. "Other" responses include expectations other than shortening, such as not changing or lengthening.

Length Measurements

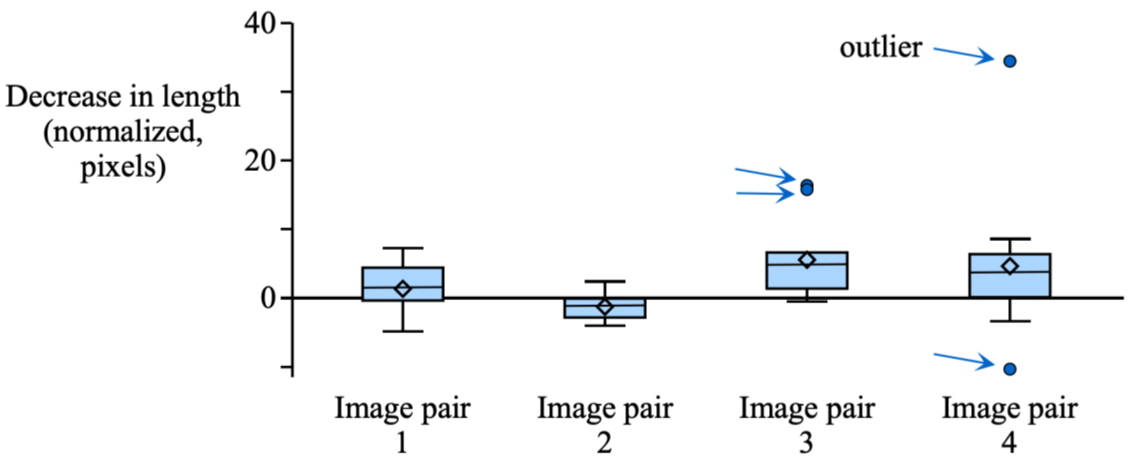
Student length measurements showed good precision. The average range in the length measurements for a single image was 22 pixels (n = 80 images), which is about 6% of the corresponding length. Any single image was measured independently by 9–12 students (3–4 students in each of three course sections). These numbers do not include the one extreme outlier discussed in Methods and Materials. Student data were more variable than length measurements made by the two instructors. The average difference in the two length measurements made by the instructors for a single image was 1 pixel (with a maximum difference of 10 pixels).

Confirmation bias in measurements would result in an inflated (i.e., more positive) value for the decrease in length at bending (i.e., length before–length bent) for the students testing the hypothesis that the antennae shorten during bending. The data were consistent with a hypothesis-driven confirmation bias. The decrease in length measured by the students, normalized to the instructors' measurements for the same images, was 4 pixels larger on average for the students testing the hypothesis that antennae shorten during bending. This small difference between groups was significant in the mixed model with hypothesis as fixed effect ($p = 0.029$ including student as a significant random effect; $p = 0.001$ without student as a random effect).

Outliers

Some of the lengths reported by students were sufficiently different from the average or expected values for that same image that they could be considered outliers (Figure 3). Forty-one outliers were identified out of the 451 measurements (see Methods and Materials section for details of outlier identification). We reasoned that outliers might provide the strongest evidence of bias, and therefore did not remove them from analysis except for one extreme outlier that appeared to be a mistake that is discussed earlier in this manuscript.

Figure 3. *Box plots of the length differences measured by one example group of students*



Notes: Each group measured length differences for one set of four image pairs. The decrease in length when bending was calculated by subtracting the bent length from the straight length, and then normalized by subtracting the average of the instructors' measurements. Therefore, a normalized decrease in length of zero would indicate a match between the student's and instructors' measurements. A normalized decrease in length greater than zero indicates a larger decrease in length than measured by the instructors. Outliers are indicated by blue arrows.

However, the outliers were not significantly different in the two hypothesis groups (mixed model $p = 0.94$). In fact, the trend in the outliers was not in the direction that would support bias and was very trivial in magnitude, given that the average difference in the change in length was smaller than 1 pixel between the two groups. Therefore, the outliers by themselves are not evidence of bias between the two hypothesis groups.

Discussion

The data collected and reported by the students were influenced by the hypothesis that they were testing and therefore provide direct evidence of bias during data collection. This result suggests that educating students about confirmation bias should be part of the mentoring that occurs in the classroom, and that instructors should be very cautious about using course-based research data in publications. While statistically significant, the magnitude of the bias was fairly small, which is consistent with results reported by Marsh & Hanlon (2007).

Variability and Reliability of Student Data

The student data were somewhat variable, with 10% of the measurements identified as outliers, notwithstanding the simplicity of the measurements. However, despite this sizable number of outliers, the overall average coefficient of variation in length measurements was only 2% (averaging the coefficients of variation for 80 different images, each of which had 10–12 student replicates), which suggests a high degree of precision. The outliers did not appear to be examples of confirmation bias, because the direction of the outlier deviations was not in concordance with the hypothesis-driven expectations. Therefore, the outliers appeared to result from ordinary error: inaccuracy or imprecision, either at the level of tracing or reporting.

The most obvious way in which a biased length could be generated consciously or subconsciously when tracing length in an image is by selection of the starting and ending points of the trace while using the tracing tool. While measuring length might seem unambiguous and unlikely to be susceptible to bias, Kozlov and Zvereva (2015) documented confirmation bias in measuring lengths of leaves (i.e., half-widths on either side of the midrib to estimate asymmetry) by experienced scientists. They attributed the source of the length bias to the positioning of the line segment used for the length measurement (e.g., not completely perpendicular to the midrib), or to subconsciously rounding the measurements in the expected direction. Rounding direction as a source of bias is discussed by Craig (1992).

While there are relatively few publications evaluating the reliability of student data, one published study found that the data taken by high school students were quite close to measurements made by the instructor. For example, the means for measured water temperature differed by no more than 0.7 °C (Fogleman & Curran, 2008). In this latter case, confirmation bias is less likely to be an issue because these students were collecting data in the absence of prior expectations, although other sources of error could still occur.

The focus of much of the literature on course-based research experiences is on best practices for developing course-based research or evidence for how course-based research can benefit students (e.g., Bell et al., 2017), leaving the accuracy in student data largely undiscussed. However, Dolan (2016) does recommend that course-based research experiences should include checks for data quality. Price et al. (2020) provided training for the students to ensure that they were taking data accurately. And Wiley & Stover (2014) found that students engaged in course-based research were more motivated to spend more time and did a better job on their reports if they had the opportunity to publish their data online, although they did not assess the accuracy of the student-collected data. We suggest that accuracy in data collection should be a central topic covered in mentoring of students as part of course-based research.

Using Student Data in Publications

One of the main motivating factors for faculty developing course-based research experiences for their courses is the ability to publish or use the data as pilot data for grants (Shortlidge et al., 2016). However, if the students' data collection is biased, then the data would not be suitable for publication, or sharing outside the classroom. Students typically do not have a stake in the publication of the data, so they are unlikely to be motivated to knowingly alter data for purposes of publication. However, they may feel there is one "correct" answer and subconsciously take or include measurements that fit that answer. This concern is supported by the results of our survey, which demonstrated that students' expectations for their data were significantly affected by the hypothesis that they were given to test. In addition, students' data were significantly more likely to support their given hypothesis. If students have a preconceived idea of what the outcome should be, they are likely to assume their data collection is accurate if it meets their expectations without doing any critical assessment of their result (Alaimo et al., 2014). For this reason, particular caution should be taken for course-based research activities in which the student is asked to collect data for a hypothesis or question with an implied expectation (e.g., "Are antennae shorter when bending?") which are likely to be more susceptible to confirmation bias than projects in which the question addressed does not imply an expected outcome (e.g., “How long are these antennae?”). Null results are generally harder to publish (Fanelli, 2012; Merrill, 2014), which provides additional incentive to collect data that reject the null hypothesis if publication is an intended goal. Instructors are aware of this publication bias which may subconsciously influence what they imply about the study outcome to the students.

How to Minimize Confirmation Bias

While confirmation bias has rarely been addressed explicitly in the context of course-based research, the topic of confirmation bias and its causes has been discussed in many scientific and social science studies (e.g., Hergovich et al., 2010; Marsh & Hanlon, 2007; van Wilgenburg & Elgar, 2013). Factors that contribute to confirmation bias include non-blind experimental design, prior expectations formed by the researcher, or reluctance to contradict previous studies (Marsh & Hanlon, 2007). In course-based research, the studies are typically not blind, and while the students may not have formed their own prior expectations, the instructor’s experimental design, grading method, or how the hypothesis is presented may bias the student.

With respect to course-based research activities, bias may be avoided or minimized by several approaches, although not all approaches are suitable for all projects.

1. Use blind studies as appropriate (e.g., the students are unaware of which sample is which).
2. Avoid giving students the sense that they will be penalized if they get the “wrong” answer.
3. Verify results by having different students work independently to make the same measurements.
4. Discuss confirmation bias with the students as an important phenomenon that must be avoided to protect the integrity of scientific research.
5. Use a hypothesis that is not “leading,” or otherwise guide the students in data collection without “leading” them to a particular result.

Addressing Confirmation Bias During Mentoring

Professional development is an important part of effective mentoring in undergraduate research (Shanahan et al., 2015). Part of professional development for undergraduate students in research should include discussion of the importance of generating and sharing reliable and accurate data. Students might be unaware of the potential for unexpected biases to creep in. Informing them about bias makes it more likely to avoid. In addition, learning about how different experimental designs may be used to minimize or avoid bias and other forms of error is an important part of scientific education. Including these topics will benefit both the instructor and the student because it encourages the student to think critically about how data are collected and analyzed and makes it more likely that data would meet the standard for publication. In large research universities, undergraduate students may receive more face-to-face instruction during course-based research from their graduate teaching assistants than faculty members (Heim & Holt, 2019). Under these circumstances, it would be helpful to incorporate a plan for addressing confirmation bias directly into the course structure for consistency.

The intent of this study was to evaluate whether confirmation bias occurred in the context of a short research project embedded in an undergraduate course. Now that we have documented confirmation bias, this provides rationale for its inclusion in a mentoring plan. Based on our results, we have specific recommendations for mentoring. There are different approaches that could be used to mentor students about confirmation bias. One approach is to discuss a paper that documents confirmation bias with the students. Possible papers include Kozlov and Zvereva (2015), Marsh and Hanlon (2007), or van Wilgenburg and Elgar (2013). Questions to ask students during discussion could include:

1. Would you be surprised if the data you collected was influenced by the hypothesis that you were testing?
2. How do you decide which data to include and which to discard (e.g., outliers)? Could this bias your results?
3. What are ways to reduce bias?

A second approach is to allow students to experience their own confirmation bias collectively, by explicitly sharing their results after data collection (as was done in our course). A direct experience like this can be particularly impactful, as it is easy to persuade oneself that collecting data is objective and therefore not susceptible to bias, and evidence of confirmation bias is likely to be a surprise to the students. When students share their data, it is important to avoid shaming or embarrassing. Students should be mentored to understand that there is variation in data (e.g., hence the need for replicates), that everybody occasionally makes mistakes, and that confirmation bias can occur, even to experienced scientists. In addition, students should be taught that if their data are very different from that collected by others, this could be a learning opportunity as they examine the possible cause of this difference. For example, perhaps there is nothing wrong with their data and their sample was merely different. Students should not feel that they will be penalized for getting a "wrong" answer (Dolan, 2016). A group discussion with the students along the lines of what was discussed above is very helpful for developing their understanding. How effective these different approaches will be in educating students about confirmation bias needs to be determined rigorously in a classroom setting with proper controls.

It is likely that some kinds of course-based research projects are more susceptible to confirmation bias than others, and those are the projects that are particularly in need of mentoring on this issue. Course-based research projects can consist of a single laboratory exercise or take an entire quarter/semester or more (Auchincloss et al., 2014; Dolan, 2016), but the duration of the activity is probably less likely to matter in terms of confirmation bias than other factors. As discussed earlier, the type of hypothesis is probably the most impactful, because some hypotheses lend themselves to drive an answer in a particular direction. The type of hypothesis is more likely to matter than the source of the hypothesis (e.g., provided by the instructor, or generated by the student). For student-generated hypotheses, part of the mentoring could include a discussion with the student on whether the hypothesis might lend itself to confirmation bias or not. Mentorship in the topic of confirmation bias will also be beneficial to students as it adds to a student's critical thinking skillset, which can be used when interpreting the research done in the literature or in planning their own future experiments.

Conclusion

While course-based research provides many benefits to both students and instructors, we have shown evidence of confirmation bias, in that the student-generated data were affected by the hypothesis being tested. Instructors should be aware of the possibility of bias, design course-based research activities in ways that reduce this risk, and mentor the students about this topic.

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