Response to Associate Editor: “How Environmental Science Graduate Students Acquire Statistical Computing Skills”

Thank you for your careful review of our paper. Following an itemization of how we have addressed your comments, we provide point-by-point responses to each reviewer.

*Improving the lead-in and definitions of terms*

*Review:*

*At present, the manuscript does not clearly define a number of key terms for the study. Reviewers were confused at times about the precise meanings of “computational thinking,” “statistical computing,” and “environmental science.” Reviewer 1 asked why Weintrop was referenced on lines 206-212 in regard to computational thinking, but then aspects of this definition are not drawn upon again in any other part of the paper. Reviewer 2 asked for a description of what is meant by statistical computing, since the authors seem to include primarily mathematical packages (e.g., MATLAB) in their discussion of statistical computing. Providing a clearer definition would allow the authors to explain, for example, how creating an Access database (lines 347-348) is part of statistical computing. Reviewer 2 also asked for clarification on what constitutes an “environmental science” student and what fields might be included in that category.*

Response:

In the revised manuscript, the definition and relation of the statistical computing problems to computational thinking have been removed. The definition of “statistical computing” previously referenced on lines 204-206 have instead been included in the Introduction (lines 84-86), so readers are provided with a more immediate definition of the term. This earlier definition of “statistical computing” is then further contextualized in sections 2.3 and 2.3 of the literature review. Additions made to section 2.2 outline the prevalence of the use of R in the environmental sciences (lines 145-149), as well as the role other scripted programming languages (e.g., SAS, MATLAB, SQL) play in the discussion of statistical computing skills (lines 149-158). Lastly, the definition of “environmental science” previously referenced on lines 70-72 has been modified to directly reference the fields that the definition includes and the nature of the research in these fields (lines 80-82).

*Review:*

*As the authors provide sharpened definitions for key terms, they should also seek to exemplify them in a manner suitable for an audience of statistics education researchers; at present, there are very few examples in the manuscript that bring out the statistical aspects of the participants’ work. The authors need to look for opportunities in the introduction and in the results section to bring such examples to the forefront, since SERJ is a statistics education research journal and not just a journal on general STEM topics.*

Response:

The sharpened definition for “statistical computing” has been tied directly to research from the Statistics Education community on the lack of computational preparation students experience in Statistics courses (section 2.3). Additionally, the Introduction explicitly outlines the connections between the computational preparation of environmental science graduate students and the Statistics courses required for their degree completion (lines 45-52). The Introduction then situates the influence and the importance of the Applied Statistics course sequence, taken by the study participants and the majority of environmental science graduate students, on the statistical computing skills students acquire prior to their research (lines 58-79). On lines 286 to 302, descriptions of the Statistics courses taken to satisfy a Graduate Certificate in Applied Statistics have been included, in addition to statistics from the last five years on the number of graduate students who completed the Applied Statistics course sequence and the Graduate Certificate.

In the Implications section, the importance of the computational training necessary to implement statistics is brought to the forefront. These implications for Statistics Educators are outlined in section 6.2, emphasizing the importance of the inclusion of computing in the Statistics classroom and the need for further research on how to bridge the gap between statistical computing preparation in the classroom and the computing skills required for data-intensive scientific research.

*Matching the research question to the data gathered*

*Review:*

*There is a mismatch between the research question and the data gathered. Reviewer 1 captured this problem well by writing, “The research question (stated on Lines 49–51), refers to knowledge acquisition of statistical computing skills. The questions listed in the interview protocol seem more focused on troubleshooting issues when problems arise.” Reviewer 2 also questioned if the manuscript effectively explores how individual participant learning occurs. The key difficulty here is that the authors present no evidence that the participants have actually “acquired” skills. Instead, they present a collection of anecdotes about how participants pushed through difficulties they had in carrying out particular projects by getting help from others or drawing on other resources. The mismatch between the research question and data carries through to minimize the impact of the concluding parts of the paper; Reviewer 1 wrote, “the Discussion and Implications sections mostly detail the student experiences troubleshooting and debugging, and the reader is left somewhat unsatisfied as to how students acquire statistical computing skills.”*

*It seems there may be two different ways to deal with the mismatch between the research question and the data. One way might be to present evidence the participants actually have acquired statistical computing skills by discussing their work on the problem-solving tasks (lines 261-269) that are not currently included in the analysis. Another way, suggested by Reviewer 1, might be to re-focus the manuscript on de-bugging rather than knowledge acquisition. Reviewer 1 provides some helpful references that might be incorporated in re-framing the paper and developing a more robust literature review if the authors decide to go this route. If the focus is shifted to de-bugging, the authors can cut the information about computational tasks on lines 261-269 rather than putting greater emphasis on it.*

Response:

The interview protocol included in the previous version was the questions asked of each participant after they had reasoned through the suite of statistical computing tasks. As noticed by Reviewer 1, the final question, detailing where participants had learned the computing skills necessary to implement statistics in their research, was the sole interview question asked at the end of the interview which explored the phenomenon of statistical computing knowledge acquisition. The data presented in this manuscript were acquired through follow-up interview questions during the statistical computing tasks. Lines 330 to 346 outline how these interview questions were facilitated during computing tasks, what questions were asked, and examples of follow-up questions that allowed for the interviewer to probe deeper into participants’ experiences. The full set of interview questions asked of participants following each computing task is included in the updated Appendix, and the statistical computing tasks are included as Supplementary Materials.

The intention of this study is to understand and describe how these participants experienced the phenomenon of acquiring the statistical computing skills necessary for their research. By focusing on these shared experiences, it is not the ambition of this research to outline how individual learning occurs or to present evidence the participants acquired each statistical computing skill. Themes of peers, singular consultant, and independent research speak to the pathways these students attribute to learning the skills they used while reasoning through the statistical computing tasks. These themes exemplify the experience of statistical computing knowledge acquisition when the curriculum in place does not adequately prepare students with these statistical computing skills. Due to the lack of preparation from their coursework, many excerpts from these participants focus on how these pathways were used when they were faced with statistical computing problems they did not have the skills necessary to accomplish. As highlighted in lines 562 to 570, the statistical computing knowledge these participants attributed to the Statistics classroom were low-level concepts, often insufficient for the statistical computing tasks required in their research. Hence, problem solving is a necessary aspect to these participants’ experiences acquiring statistical computing skills.

*Improving the qualitative methodology section*

*Review:*

*The sections describing the qualitative methodology employed need improvement. The purpose for framing the study as having a “pragmatic phenomenological approach” is not clear. It may make more sense to talk about how the study is an instance of case study research, what sort of case study research was done, and why that sort of case study research was selected. In any case, the authors need to more clearly explain their research paradigm and their reasons for operating from it.*

Response:

Revisions made to the qualitative methodology section (1) provide a definition of what a phenomenology is, (2) justify the use of a phenomenology as compared to a case study, and (3) situate how the data collected inform research on the phenomenon of acquiring the statistical computing skills necessary for graduate environmental science research.

*Review:*

*The descriptions of the qualitative data analysis techniques employed are too vague and general. “Reading data numerous times” is not really a method for identifying themes and doing qualitative data analysis. It is a necessary, but not sufficient, part of doing such analyses. The section on qualitative*

*data analysis leaves many questions unanswered, such as: What role did each author play in the analysis of data? Were there any independent analyses? What constituted a “segment” of data? How was the codebook developed? What strategies were used for identifying themes other than reading the data*

*numerous times?*

Response:

The Data Analysis section had undergone substantial revisions to (1) provide readers with the sequence of how the data were processed and condensed, (2) justify how the emergent themes detailing the phenomenon were determined, (3) the role of each author in the data analysis process, and (4) the use of member checking and the researcher’s role in the data collection.

*Review:*

*The discussion of member checking was somewhat confusing, as member checking is ordinarily done to confirm the researcher’s interpretations rather than just to check the accuracy of transcriptions.*

Response:

The usage of member checking to verify the accuracy of researcher’s interpretations has been clarified on lines 394 to 396.

*Review:*

*Additionally, Reviewer 1 noted that “Only one final interview question inquires where students learned computational skills more generally.” What sort of limitations does that put on conclusions that can be drawn about the participants’ knowledge and experiences? Both reviewers expressed concern about framing the generalizability of the findings. Reviewer 1 noted that lines 442-444 seemed to imply*

*generalizability in unwarranted ways. Reviewer 2 asked if the information in the manuscript was limited to the particular institution or if it had broader implications. Lines 70-80 at times make it sound as if the researchers are speaking of all graduate students in general rather than just the five in the study. The authors take up the issue of generalizability in lines 562-571, but it seems disconnected from these other portions of the manuscript. In framing a qualitative study, it is essential to maintain a middle ground between not overstating or understating the generalizability of the findings.*

Response:

As previously discussed, the data collected on these participants regarding their experiences acquiring statistical computing skills go beyond the final interview question included in the previous Appendix. The limitations of asking participants for descriptions of their experiences acquiring statistical computing knowledge is addressed in section 6.3 on lines 699-701.

The Implications section, situated alongside the literature on computational preparation of environmental science graduate students and the absence of computing in the Statistics classroom in sections 2.2 and 2.3, provide a backdrop of the potential generalizations of these findings. Indeed, a sample of five graduate environmental science students from one institution does not paint a vast picture of the phenomenon of acquiring the computational skills necessary to implement statistics in the context of environmental science research. However, as evidenced in the Environmental Science and Statistics Education literature, the experiences of computational ill preparation of these five graduate environmental science students is not out of the ordinary, but potentially widespread in these fields. Thus, lines 625-637 detail how the implications of this study may reflect how many other environmental science graduate students in similar programs experience the phenomenon of acquiring the computing skills necessary to implement statistics in the context of environmental science research.

*Providing more details about participants’ content backgrounds*

*Review:*

*In order for readers to have a better understanding of how the findings of the study might apply to their own settings, more description of the participants’ content backgrounds is needed. Reviewer 1 wrote, “a brief description of each of the four courses would provide the readers with more background on what topic areas were covered by the students. This gives insight into the knowledge acquisition of the students and gives more context for the discussion.” Reviewer 2 wrote, “All these students have computer science training in their past in SQL, Python and Java. Are they typical students in environmental science?... Can there be a discussion about how computer literate these students were before they began?” Moreover, it is difficult to interpret statements and observations like those on lines 331-335 and 450-459 without knowing more about the coursework the participants experienced. Providing more details about the participants’ backgrounds should also clarify the significance of the study, as it may enable the authors to*

*make conjectures about specific changes to coursework that may have helped these participants in specific ways.*

Response:

Brief descriptions of the four “typical” courses taken for the Graduate Certificate in Applied Statistics are now provided on lines 58-69 and 284-295. The statistics provided on lines 296-301 contextualize the number of graduate students in these fields that have completed the first graduate-level Applied Statistics course, the second semester Applied Statistics course, and the Graduate Certificate in Applied Statistics over the last five years. Table 1 has been revised to separate the programming languages participants had encountered in their coursework and the programming languages they made use of during their research. This separation along with the clarification on lines 302 to 305, better orient why students from the Ecology and Land Resources Environmental Science departments had exposure to SQL while others did not. Additionally, Table 1 now explicitly states which Statistics courses each participant had completed before the study. These details more firmly establish the importance of Statistical training these fields, emphasizing how few courses these students typically complete during their coursework.

It should be noted that the descriptions of these individuals are not intended to highlight different aspects of the experience of acquiring the computational skills necessary to implement statistics in environmental science research. These participants were selected as a cohort to illuminate and understand this phenomenon. While elements of each of these participants could be distilled into a “typical” graduate environmental science student, that is not the intention of this study. Instead, the focus of this research is on how the lived experiences of these participants help us to understand the phenomenon of acquiring the statistical computing skills necessary for environmental science research.

*Smaller issues*

*Review:*

*In revising the manuscript, also attend to the helpful discussions of smaller issues given by Reviewers 1 and 2. In section 6, there should be no Section 6.1 if there is no Section 6.2.*

Response:

Section 6 now has three subsections: 6.1 Implications for Statistics Educators, 6.2 Implications for Environmental Science Educators, and 6.3 Limitations and Future Research.

*Review:*

*The word “authenticity” seems to be used in strange ways at various points in the manuscript; consider using a different word, for example, on lines 286 and 312.*

Response:

Different terms have been substituted for “authenticity” on lines 397 and 424.

Response to Reviewer #1: “How Environmental Science Graduate Students Acquire Statistical Computing Skills”

*Review:*

*The primary issue faced in the is the alignment of the research questions and interview protocol used to collect the data. The research question (stated on Lines 49–51), refers to knowledge acquisition of statistical computing skills. The questions listed in the interview protocol seem more focused on*

*troubleshooting issues when problems arise. Only one final interview question inquires where students learned computational skills more generally. Subsequently, the Discussion and Implications sections mostly detail the student experiences troubleshooting and debugging, and the reader is left somewhat unsatisfied as to how students acquire statistical computing skills.*

*To alleviate this, the authors might re-focus the stated RQ to understand students’ help seeking patterns when troubleshooting computational issues. This is a more nuanced part of the broader question of knowledge acquisition and also relates to ideas of metacognition in computational reasoning. If the*

*authors decide to go this route, it would also necessitate additional emphasis on debugging and troubleshooting in both the literature review and in the results and discussion. For example, it might be fitting for the literature review to incorporate some research on debugging in order to frame why this is*

*a useful skill in itself for students to learn metacognitive skills like debugging and decomposition.*

Response:

See previous response to Associate Editor on lines 84-114.

*Review:*

*In Section 3, Lines 202–212 could be revised to better align with the research questions addressed in the discussion of the paper.*

Response:

The research questions included on lines 55-57 now align with the data collected, as described in section 3.2.

*Review:*

*The first two sentences in Lines 202–206 might be better situated at the beginning of the Methodology section.*

Response:

This revision has been made, as seen on lines 239-244.

*Review:*

*Lines 206–212 contain a Weintrop reference to computational thinking that is not addressed again in the manuscript. If the aspects of computational thinking in this framework are important for the analysis of the data, perhaps the discussion or implications section should revisit these concepts. Revisiting these concepts in light of the data analysis will help tie this framework into the study.*

Response:

The reference to computational thinking has been removed from the revised manuscript. The intention of this study was to understand and describe the phenomenon of acquiring the statistical computing skills necessary for research in the environmental sciences, not to outline how participants reasoned through statistical computing tasks.

*Review:*

*Figure 1 could be removed or revised as it does not appear to add much to the Discussion section. If the authors chose to include it, they should amend the text in Lines 442–444 to sound less generalizable to students outside of their sample.*

Response:

Figure 1 has been removed from the revised manuscript and lines 556-563 confine the discussion of the study’s results to the five environmental science graduate students.

*Review:*

*The first sentence in Line 229 could be revised to improve readability. The author(s) could consider splitting it into multiple sentences for clarity.*

Response:

This revision has been made, as seen on lines 282-288.

*Review:*

*Additionally, a brief description of each of the four courses would provide the readers with more background on what topic areas were covered by the students. This gives insight into the knowledge acquisition of the students and gives more context for the discussion.*

Response:

This revision has been made, as seen on lines 286-296.

*Review:*

*Lines 261–269 mention computational tasks the students performed after the interview. These tasks and their analysis are future endeavors that never get more attention in this paper. In order to keep the focus of this research on the interview this section could be shortened or cut.*

Response:

This reference to a future analysis of the statistical computing tasks has been removed from the revised manuscript. The statistical computing tasks are described on lines 323-330 solely to set the stage for the interview questions which were asked following the completion of each task.

Response to Reviewer #2: “How Environmental Science Graduate Students Acquire Statistical Computing Skills”

*Review:*

*It would be useful to see a description of what you mean by statistical computing. I had thought that it referred to the coding required in statistical packages, but I see that you describe a course at Harvard which used MATLAB which is not a statistical package. Could elaborate on this, please?*

Response:

See previous response to Associate Editor on lines 24-28.

*Review:*

*I think the article would benefit from a better description of what constitutes an ‘environmental science’ student. In the last paragraph of the Introduction you point out that ‘environmental science’ in the literature means something quite specific. In this case you say that it refers to ‘large assortment of fields serviced by the graduate level applied statistics course sequence’. I cannot see any information telling me what these fields are which, presumably, may vary depending on the institution. Of the five students in the study, three are listed as being ‘environmental science’ students. Doesn’t this mean something specific here? If so, what? The other two are ‘Animal Range Science’ and ‘Ecology’. Again, information on what these disciplines are would be relevant.*

Response:

See previous response to Associate Editor on lines 28-30.

*Review:*

*How is environmental science any different from any other non-computer science student needing to obtain these skills? Why have you chosen this particular area to consider?*

Response:

The computational preparation of graduate students in other biological fields is provided on lines 165-185 as a comparison to the computational ill preparation of environmental science graduate students see on lines 143-164. Additionally, Statistics preparation is considered vital for the majority of environmental science graduate students, but statistical computing is largely absent from the Statistics classroom (lines 207-227).

*Review:*

*Don’t the themes you list describe how this skill is learned, normally? By anyone? Admittedly, I am a statistician and, also, I did my training a very long time ago and we had limited computer training in our courses. Since then I have needed to learn a variety of different statistics packages – or even refamiliarize myself with packages that I once used and need to remember how to use again. I have had very limited training in those packages. But I would have said that the only way to become fluent is to use the packages for your own work and asking other people for help when you are stuck (especially someone who is an expert in the language) – this is normally how you learn. I am confused as to what this study adds to what everyone who has learned a package already knows. Are the findings particular to fields other than statistics? Could you, perhaps, outline what the ideal is for teaching or learning statistical computing?*

Response:

We appreciate your comment on the distinction between knowledge of statistical packages and computing knowledge necessary to implement statistics. Indeed, often the implementation of statistical packages is necessary to implement statistics in the context of environmental science research, however, learning and implementing statistical packages is a small piece of this picture.

As seen in section 2.3, detailing research in Statistics Education on computing in the Statistics curricula, a lack of computational training in the Statistics classroom is standard. Commonly, these students learn clean statistical analysis, often with statistical packages, on tidy data. Students are often either provided with code and expected to execute the code to obtain the statistical results needed or told they need to learn to program themselves or in a crash-course by a TA. When these students are then faced to write their own R code for tasks such as tidying or reorganizing their data, using simulation-based inference, or visualizing their own data they are in unchartered territory. Certainly, these students may have experienced a variety of R packages in the Statistics classroom, but that does not therefore imply that students have the computational skills necessary to use R extensively throughout their own research.

The themes from this study bridge the gap in understanding how environmental science graduate students acquire the statistical computing skills necessary for their research. As outlined in both the Environmental Science and Statistics Education literature in sections 2.2 and 2.3, there is evidence these students are not acquiring these necessary skills in their graduate curriculum or Statistics coursework. Lines 102 to 105 establish the unique perspective of this study, and how this study adds to the existing literature which thus far has largely itemized the deficiencies of the environmental science curriculum (lines 149-158). The experiences of these students, described in the Results, help to shed light on the importance of statistical computing knowledge, as there may be many graduate environmental science students faced with similar challenges but may not have the perseverance you are fortunate to have.

Statistical computing skills are data driven and thus differ in nature from the acquisition of other programming/computing skills (lines 115-128). The themes of this study, delineated in the Results, reflect how these participants experienced the phenomenon of acquiring the statistical computing skills necessary for environmental science research. Lines 710-722 detail how the findings of this study should not be generalized to the acquisition of other general programming skills.

Additionally, it was not the intention of this phenomenology to characterize situations in which statistical computing can be learned. An abundance of literature from the Statistics Education community can be referenced on ways in which statistical computing can be infused into the classroom, but no literature currently exists focusing on the student perspective and experience of statistical computing knowledge acquisition.

*Review:*

*All these students have computer science training in their past in SQL, Python and Java. Are they typical students in environmental science? I imagine that this level of computer literacy would be very rare amongst students. Or does it reflect the educational requirements in the United States? I would also have thought that this level of background would make it especially easy (compared to other students) to pick up a statistical programming language. Can there be a discussion about how computer literate these students were before they began?*

Response:

A more thorough description of participants’ computer science training has been included in lines 303-310. Additionally, Table 1 has been revised to separate the programming languages participants encountered in their coursework and the languages they employed in their research. Lines 307-310 identify Stephanie as a participant with far more computing experience than others, due to her work in a laboratory prior to beginning graduate school.

*Review:*

*Learning from their own personal research is one of the themes emerging from the interviews – that doesn’t seem to describe how that learning happens. Table 2 describes taking their course knowledge and transferring it to statistical computing applications. In my own experience I guess it just means using the package to solve their own statistical problems. But do you improve your skills that you picked up in your course when you are not talking to a colleague? Is it through trial and error, using help pages, Googling? I would have thought it would be useful to provide more detail on, specifically, how these skills are learned. I guess reiterating point 1 – what would be the ideal way to learn a statistical package?*

Response:

This research explores the experiences of graduate students in the environmental sciences when acquiring statistical computing skills, focusing on the experiences that fostered or inhibited learning. In section 4.1 each participant emphasized the importance of applying the statistical concepts learned in the classroom to their own research. Through these experiences participants were able to see how messy the implementation of statistics can be (lines 432-434). The resources used by each of these participants when wrangling with statistical computing tasks necessary for their research vary, but every participant reiterated the importance of the experiences from independent research experience on acquiring statistical computing knowledge in the context of environmental science research.

*Review:*

*There are only five students in this study. I understand that with qualitative work you are not necessarily interested in a representative sample. However, you are interested in saturation and do you feel you reached saturation with these five people? I would have thought with only five people you would be interviewing a group of experts who are being interviewed in depth – which is not the case here. I can’t help but feel that any answers you get from this investigation may be quite specific to the institution you are gathering your information from. In which case, this seems more like an exercise in improving teaching practice for an individual at a particular place rather than a way of making a general comment about environmental science students learning statistical computing.*

Response:

See previous response to Associate Editor on lines 182-192.

*Review:*

*Have the respondent’s comments been anonymized? I assume the names used are not the names of the participants – that would be very unusual.*

Response:

Lines 351-353 describe how participants were given pseudonyms after the interviews were transcribed. Table 1 also references participants’ pseudonyms in the first column.

*Review:*

*I can’t find information on the ethics approval for this project or that the participants have given informed consent. This information needs to be provided.*

Response:

The ethics approval from our institution has been provided on lines 273-275. Additional material on the IRB approval can be provided if required by SERJ.

*Review:*

*On lines 280 and 282, the words ‘statistical’ and ‘modifications’ are misspelled.*

Response:

These misspellings have been remedied.

*Review:*

*It isn’t clear to me what the word ‘sequence’ means in this context. For example, line 63, you speak of a ‘terminal statistics sequence’. I think an explanation of this term would be helpful as it is used a lot in this paper.*

Response:

See revisions on lines 60-70, which clarify that this Applied Statistics course “sequence” consists of two one-semester courses.