PARTICIPATORY SCIENCE IMPROVES SCIENTIFIC LITERACY IN PRE-SERVICE ELEMENTARY TEACHERS

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Introduction

Scientific literacy describes the ability of people to use scientific information and thinking in their daily lives (American Association for the Advancement of Science [AAAS], 1990). A scientifically literate individual is interested in and able to practice scientific thinking to make sense of the world. Research indicates that the majority of American students do not understand scientific methods, are not experienced in gathering or interpreting empirical evidence, and tend to view the world subjectively. Such scientific novices have minimal experience performing scientific tasks and studies and most likely will not have an opportunity to gain such experience professionally. The question then, is how to help build scientific literacy in science novices, and what kinds of experiences can help build literacy in people who do not have a background nor a long-term professional interest in science?

One way that novices can become engaged in scientific practice is through participatory science programs. Participatory science (often called citizen science) programs allow for the collection of data at a much faster pace and over a much broader range by incorporating more people in the collection aspect of a study while also providing opportunities for science novices to engage with authentic scientific endeavors (Bonney et al., 2009). There are indications that citizen-scientists gain scientific literacy (Trumbull, Bonney, Bascom, & Cabral, 1999), especially with training and experience. Several studies have found scientific ability and accuracy in species identification is correlated with experience (Delaney, Sperling, Adams, & Leung, 2008; Trumbull et. al. 1999). Cox, Philippoff, Baumgartner, and Smith (2012) found that young volunteers could, following training, collect data that did not vary statistically from that collected by expert researchers. Oldekop et al. (2011) found that moderate training led to significant increases in scientific ability. When Crall et al. (2010) assessed participatory science programs by surveying organizations associated with such scientific research, the consensus was that participatory science programs should include extended training and experience to establish gains in scientific literacy.

One group of scientific novices who may benefit from participation in the scientific training and experience provided by citizen science programs are pre-service elementary teachers. Research shows that elementary teachers who have had minimal experience with science are uncomfortable teaching science, and tend not to put as much time and effort into science teaching (Riggs, 1989). Even elementary teachers with a strong conceptual science background tend to lack pedagogical content knowledge in the field of science (Zembel-Saul, Munford, Crawford, Friedrichsen, & Land, 2002). Surveys of pre-service elementary teachers indicate that one of their greatest concerns is teaching science (Howitt, 2007). Hatton (2008) found that teachers were able to overcome these concerns, gaining confidence along with scientific pedagogical content knowledge through inquiry-based instruction. Practical experience with inquiry-based science has a strong influence on the likelihood that elementary teachers will spend time on scientific inquiry in their own classrooms (Moore, 2003). Participation in scientific practice, field and lab experimentation, and scientific reflection are experiences gained by pre-service teachers from authentic scientific experiences like citizen science programs (Bhattacharyya, Volk, & Lumpe, 2009). Given the alignment of participatory science to inquiry-based teaching strategies, we hypothesize that pre-service teachers taking part in authentic science investigations and associated training will increase their scientific knowledge and confidence.

This study examines the impact of authentic scientific experience and inquiry-based instruction as part of an experience aligned to participatory science models among two groups of undergraduate students. The less experienced novice group was a class of elementary education majors class and the more experienced novice group was a class of upper division biology majors at Western Oregon University. Both groups of students were participating in a research project involving study of the invertebrate communities in recovering marshes in the Salmon River Estuary (Oregon Sea Grant). We attempted to gauge students' understanding of material and confidence about scientific activities through the use of concept inventories and self-efficacy surveys, which we developed and aligned to specific research activities.

We wanted to examine the impact of participatory science- both training and research experience- on the knowledge, confidence, and skills of on pre-service teachers contrasted to students in a scientific course of study. We wanted to determine if such a program could impact the ability and likelihood of future elementary teachers to teach science. Bonney et al. (2009) offered several recommended measures of scientific literacy amongst participants in citizen science projects, including "improved participant understanding of science content, enhanced participant understanding of science process, better participant attitudes toward science, and improved participant skills for conducting science" (Bonney et al., 2009, pg. 983). The metrics we used in this study focused on those aspects of program impact by asking participating students to reflect on both their understanding of specific concepts and their ability to conduct scientific tasks. The surveys were administered prior to citizen science experience, after initial training, and after scientific research experience. We compared responses both within and between groups over time to examine how elements of participatory science build science content and skills in these novice groups. We also examined participant behaviors during scientific tasks to compare how different groups of students approached their research experience.

Methods

We surveyed two groups of students participating in a citizen science project to monitor invertebrates in the Salmon River Estuary. These two groups of novices varied in experience: Education majors with no expertise in biology and Biology majors with at least two years of laboratory-based biology coursework. We wanted to determine if teaching strategies aligned to participatory science could increase both groups' understanding of biology content and science practice. We also wanted to determine if these activities could help future teachers gain confidence about doing science.

Our two groups of students were all enrolled full-time at Western Oregon University during Spring 2011. We surveyed a total of 29 students, 14 Education majors and 15 Biology majors.

The Education majors were all enrolled in the General Science 311 (GS 311) Science for Educators course in Spring 2011 at Western Oregon University. Students take GS 311 prior to admission into an education cohort, and the only prerequisite for this course is a non-majors general biology or earth science course. Our comparator group of more experienced science students were enrolled in Marine Ecology, Biology 361 (BI 361). This course is an elective for biology majors, and students must complete an introductory biology sequence as well as General Ecology as prerequisites. Both groups of students were comprised primarily of sophomores and juniors, and had been engaged in college-level coursework for similar periods of time. We did not gather data on overall GPAs, but the course grade averages for the two groups were similar. Both courses had a higher proportion of female students, although GS 311 was much more female-skewed. The primary difference between the two groups was their level of experience with laboratory science; BI 361 students all had an average of six terms of experience with majors level laboratory science and GS 311 students had an average of one term of experience with non-majors level lab science. Both classes worked together on the Salmon River Estuary project during the Spring 2011 quarter, taking part in both field and laboratory activities.

We used two instruments. The first was a self-efficacy survey in which students used a 5-point Likert scale to respond to statements designed to gauge how students felt about their ability to perform tasks associated with sorting and identifying macroinvertebrates. We developed the statements in this survey to target the critical skills needed to accurately and confidently perform the scientific tasks essential to macroinvertebrate collection and identification. Statements also targeted those skills that were also considered to be fairly challenging For example, identifying nematode worms was one target skill as opposed to identifying bivalves as bivalves are much easier to identify than nematodes. The students were asked to rate their confidence and understanding related to these statements by indicating their agreement or disagreement with the statement.

The second instrument was a concept inventory in which students rated their understanding of concepts related to biological terminology and process skills using a 5-point Likert scale. We developed this instrument to focus on specific terms that we knew both groups of students were going to be exposed to during the course of the project. These included biological terminology, process skills, or pedagogical content knowledge. These terms consisted of concepts such as taxonomic names of certain organisms that could be found in the substrate samples, terms associated with the sorting procedures, and specific terms used to describe diagnostic body features associated with macroinvertebrates. As this concept inventory relied on participants to self-report their perceived level of knowledge, we included several concepts not taught in either course nor connected in any way to the research project as a validation method.

We administered both instruments on the first day of class prior to any instruction (pre-surveys). We then administered the second set of surveys (mid-surveys) after students took part in direct lecture instruction about the project goals and procedures. We administered the third set of surveys (post-surveys) after students took part in field experience to collect benthic core samples and completed a two-hour laboratory activity focused on sorting and identifying benthic invertebrates. Both student groups worked together in the field, but due to limited microscope availability were separated during the laboratory session. Both classes were offered the same researcher assistance and tools in the laboratory. During the laboratory exercise, we used an observation instrument to record the types and numbers of procedural and identification errors made by both groups as well as the types and numbers of questions asked.

We collected and averaged the self-efficacy and concept inventory results for each group in each of the three survey periods. For the survey questions that were phrased negatively (e.g. "Using a dissection microscope takes skills I do not possess") we reversed the scoring axis so that all statements used the same positive 1-5 scale. Although the survey results were anonymous, each student selected a code name to allow us to align participant surveys. These code names allowed us to identify which survey corresponded to a previous survey to determine individual changes in knowledge and skills. Following a review of normal probability plots and standard deviation, we determined that ANOVA was an appropriate analytical tool to compare the variation in each individual concept or statement as well as average responses between the two groups at each phase of instruction and within the same group during different phases of instruction.

Results

Tables 1 and 2 provide an overview of how BI 361 and GS 311 concept inventories and self-efficacy surveys compare at different stages of the project. Significant variations in both the overall self-efficacy and concept scores between the more experienced biology students and the less experienced education students persisted throughout the survey, but there is a decreasing of the gap between groups at each stage.

The self-efficacy surveys reveal changes in both groups of students over the course of the project (Figure 1). Although significant variations in both the overall self-efficacy and concept scores between the two classes persisted throughout the survey, we can see a decreasing of range between the BI 361 class and the GS 311 class at each stage. In the pre-survey both the BI 361 and the GS 311 students had a high number of students who fell in the "Unsure" range. The less experienced GS 311 students had a lower average score of 3.3, while BI 361 had an average score of 4, demonstrating that these less experienced novices felt less confident than their more experienced counterparts. Both groups increased their self-efficacy by about the same amount following direct instruction, with mid-survey scores of 3.6 for GS 311 and 4.2 for BI 361. Inquiry-based instruction further increased self-efficacy, and had a greater increase for GS 311 students (average score 4.1) than for BI 361 (4.45). The GS 311 novice group also increased their self-efficacy after both direct instruction and inquiry-based instruction. BI 360 did not significantly increase self-efficacy during each phase, but did significantly increase their self-efficacy from the beginning to the end of the project.

A closer examination of self-efficacy survey questions (Figure 2) reveals that the most significant gains were made by GS 311 students following inquiry-based instruction. This group reported significantly lower self-efficacy regarding general identification of invertebrates, identification of specific invertebrate groups (nematodes) both before instruction and following direct instruction. After the inquiry-based session, they no longer showed significant differences on these topics. The area where these students still questioned their self-efficacy compared to BI 361 students was in their command of microscopy. While a statement about possessing microscope skills became similar to the biology group, a similar statement about confidence using those skills remained significantly lower even after inquiry-based instruction.

Observational data aligns to these self-reports. Students in GS 311 requested procedural assistance in about 50% more instances in a two-hour laboratory period than did students in BI

361 and the majority of these questions were about microscope use. Students in the two courses asked approximately the same number of questions about how to identify specific invertebrates, particularly oligochaete worms.

The concept inventory results (Figure 3) also demonstrate changes over time in both groups. While both groups were initially generally unsure of what most terms meant, reported understanding of the topics was lower for the GS 311 students (2.8) than it was for the BI 361 students (3.5). This trend remained throughout, but both groups significantly increased their conceptual knowledge after direct instruction in techniques, and significantly increased this knowledge again after inquiry-based instruction, although this average increase in conceptual knowledge was smaller. The results from the concept inventory mid-survey indicate a higher average score for both classes as well, with a much greater increase for the GS 311 group (increase of .5 to 3.3) than for BI 361 (increase of .3 to 3.8). Following inquiry-based instruction, GS 311 had narrowed the gap between the two groups with a score of 3.8 compared to the post-survey score of 3.9 for BI 361. There were also fewer concepts for which the two groups showed significant understanding in their concept understanding by the end of the project (Figure 4). In the pre- and mid- surveys 22 concepts showed significant variation between the two groups; in the post-survey 13 concepts showed significant variation. While the self-reported understanding of most of the concepts on the inventory increased for both groups, the self-reported understanding of the validation concepts (those concepts included on the inventory that were not taught as part of the project) either remained the same or decreased.

Conclusions & Implications for Practice

While participatory science is not a new phenomenon, the model is gaining popularity as scientists recognize this mechanism for quickly and efficiently collecting large amounts of data. The majority of recent education research studies on citizen science programs have focused primarily on the validity of data collected by novices (Cox et al., 2012; Oldekop et al., 2011) and we are unaware of any research into the impact of citizen science experiences *specifically* on pre-service teachers. We wanted to examine the impact of a citizen science program on the knowledge, confidence, and skills of participants to consider how such a program could impact the ability and likelihood of future elementary teachers to teach science.

The results of both the concept inventory and self-efficacy survey demonstrate that participation in a citizen science program positively impacted scientific novices, both those that have expressed an interest in and embarked in the study of biology and those who are truly novices and do not intend a career in science. In general, concept knowledge gains were similar between experienced biology students and education majors, although the biology students started with and maintained a slightly higher conceptual knowledge level throughout. This seems to indicate that engaging in activities that align to participatory science, both direct training to prepare for data collection and the actual participation in research activities, can increase the biological content of novices. We do acknowledge that the self-reported concept knowledge may be subject to some bias. However, we interpret the inclusion of validation concepts that decreased or remained stable in reported understanding to mean that such bias was negligible in measuring concept knowledge increases.

There was greater variation in perceived scientific skills gains between the two groups. Although both groups increased their self-efficacy values significantly between the beginning and the end of their participation, only the GS 311 novice group also showed significant increases following both direct instruction and again following inquiry-based instruction. These gains were nearly sufficient to close the initial gap between the two groups. Moreover, the larger gains in self-efficacy were made by GS 311 students following inquiry-based instruction. Thus, it would appear that the more essential element of participatory science for improving scientific confidence and skills is the opportunity to actually engage in research. Indeed, we saw that research experience actually helped erase the gap in scientific confidence between our less and more experienced students. Even in the case of microscopy, where their confidence levels were significantly lower than that of the more experienced biology students, the education students still indicated an increase in their perceived microscope skill levels. These results are supported by the observations made of participant behavior during the inquiry-based sessions in which less experienced and more experienced novices asked similar types of questions, although the less experienced GS 311 students asked a greater number of questions.

The observations made of the number and types of questions asked by students demonstrate that even having already had direct instruction in identification and scientific techniques, novices still can learn much from the opportunity to engage in inquiry-based research. The GS 311 students had many questions about microscope use, which they did not ask during direct instruction about procedures used to identify invertebrates. The questions did not surface until they were fully engaged in attempting to identify invertebrates. Novices being trained in scientific practice may not even know what questions to ask until they are fully engaged in such practice.

We found that both more and less experienced novices benefited by taking part in activities aligned to participatory science and that the greatest benefits were enjoyed by the least experienced novices following inquiry-based instruction, although there were some scientific skills (like microscopy) that were not fully impacted by such instruction. These results also offer the opportunity to consider how the overall sorting and identification process associated with the Salmon River Estuary study can be improved. We found that the biggest difference in skill was in microscope use and that this was also most challenging skill to build in the less experienced novices. More targeted training for novice participants in this type of project might focus on these particular activities to build only skill level, but overall scientific self-efficacy.

In conclusion, participation in authentic research experiences, including participatory science and participatory science-aligned projects (like ours), are certainly a mechanism for students of biology to effectively build their content and skills base. But such experiences are also a way that elementary teachers can build not only their content knowledge about science, but also their own confidence about leading scientific investigations with their own students. One recommendation that we make based on our results is that pre-service (and in-service) educators be offered opportunities to take part in authentic research experiences like those offered by citizen science projects. Given the popularity and wide availability of participatory science programs available today, these are excellent venues for pre-service teachers to gain pedagogical content knowledge and confidence through an authentic scientific experience. Developers and coordinators of such programs should include as much opportunity as possible for these participants to engage in scientific research.

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References

Bhattacharyya S., Volk T., & Lumpe, A. (2009). The influence of an extensive inquiry-based field experience on pre-service elementary student teachers' science teaching beliefs. *Journal of Science Teacher Education, 20,* 199-218.

Bonney, R., Cooper, C.B., Dickinson, J., Kelling, S. Phillips, T., Rosenberg, K., & Shirk, J. (2009). Citizen science: A developing tool for expanding science knowledge and scientific literacy. *Bioscience, 59(11),* 977-984.

Cox, T.E., Philippoff, J., Baumgartner, E., & Smith, C.M. (in press). Expert variability provides perspective on the strengths and weaknesses of citizen driven intertidal monitoring program. *Ecological Applications*. Online at http://www.esajournals.org/doi/pdf/10.1890/11-1614.1

Crall, A.W., Newman, G.J., Jarnevich, C.S., Stohlgren, T.J., Waller, D.M., & Graham, J. (2010). Improving and integrating data on invasive species collected by citizen scientists, *Biological Invasions 12 (10),* 3419-3428.

Delaney, D.G., Sperling, C.D., Adams, C.S., & Leung, B. (2008). Marine invasive species: validation of citizen science and implications for national monitoring networks, *Biological Invasions, 10 (1),* 117-128.

Hatton, M. (2008). Pre-service elementary teachers' concerns about teaching science. 19 p. retrieved 30 April 2012 from http://www.eric.ed.gov/PDFS/ED503450.pdf.

Howitt C. (2007). Pre-service elementary teachers' perceptions of factors in an holistic methods course influencing their confidence in teaching science. *Research in Science Education, 37,* 41-58.

Moore, R. (2003). Reexamining the field experiences of preservice teachers. *Journal of Teacher Education 54 (1),* 31–42.

Oldekop, J.A., Bebbington, A.J., Berdel, F., Truelove, N.K., Wiersberg, T., & Preziosi, R.F. (2011). Testing the accuracy of non-experts in biodiversity monitoring exercises using fern species richness in the Ecuadorian Amazon. *Biodiversity and Conservation, 20,* 2615-2626.

Riggs, I.M., & Enochs, L.G. (1989). Toward the development of an elementary teacher's science teaching efficacy belief instrument. Annual Meeting of the National Association for Research in Science Teaching; Mar. 30, 1989. 31 p.

Trumbull, D.J., Bonney, R., Bascom, D., & Cabral, A. (1999). Thinking scientifically during participation in a citizen-science project, *Informal Science,* 265-275.

Zembel-Saul, C., D. Munford, B. Crawford, P. Friedrichsen, & S. Land. (2002). Scaffolding preservice science teachers’ evidence-based arguments during an investigation of natural selection. *Research in Science Education 32,* 437–463.

Table 1: ANOVA with 2-way interactions and Scheffe post-hoc tests for Average Concept Inventory Scores. n =29.

ANOVA

Source	df	Sums of Squares	Mean Square	F-ratio	p
Const	1	814.340	814.340	7698.3	≤ 0.0001
Survey	2	13.2453	6.62267	62.607	≤ 0.0001
Class	1	11.9628	11.9628	113.09	≤0.0001
Survey*Class	2	0.864310	0.432155	4.0854	0.0211
Error	68	7.19313	0.105781		
Total	73	32.1785			

Scheffe Post Hoc Tests

Comparison	Difference	std. err.	P
GS,Pre - BI,Pre	-0.849003	0.1332	0.000000
GS,Mid - BI,Mid	-1.04894	0.1279	0.000000
GS,Post - BI,Post	-0.524217	0.1332	0.000937
BI,Pre - BI,Post	-0.891738	0.1332	0.000000
BI,Pre - BI,Mid	-0.641738	0.1302	0.000031
BI,Mid - BI,Post	-0.250000	0.1358	0.191180
GS,Mid - GS,Post	-0.774725	0.1253	0.000000
GS,Pre - GS,Post	-1.21652	0.1332	0.000000
GS,Pre - GS,Mid	-0.441799	0.1310	0.005220
GS,Mid - BI,Post	-1.29894	0.1310	0.000000
GS,Mid - BI,Pre	-0.407204	0.1253	0.007367
GS,Post - BI,Mid	-0.274217	0.1302	0.116657
GS,Post - BI,Pre	0.367521	0.1276	0.019930
GS,Pre - BI,Mid	-1.49074	0.1358	0.000000
GS,Pre - BI,Post	-1.74074	0.1387	0.000000

Table 2: ANOVA with 2-way interactions and Scheffe post-hoc tests for Self-Efficacy Survey Scores. n =29.

ANOVA

Source	df	Sums of Squares	Mean Square	F-ratio	p
Const	1	1221.07	1221.07	11515	≤ 0.0001
Survey	2	5.17925	2.58962	24.420	≤ 0.0001
Class	1	6.81662	6.81662	64.280	≤ 0.0001
Survey*Class	2	0.329854	0.164927	1.5552	0.2181
Error	72	7.63529	0.106046		
Total	77	19.1312			

Scheffe Post Hoc Tests

Comparison	Difference	std. err	p
GS,Pre - BI,Pre	-0.706294	0.1312	0.000005
GS,Mid - BI,Mid	-0.408591	0.1312	0.010579
GS,Post - BI,Post	-0.670330	0.1231	0.000004
BI,Pre - BI,Post	-0.496503	0.1312	0.001459
BI,Pre - BI,Mid	-0.252747	0.1231	0.128871
BI,Mid - BI,Post	-0.243756	0.1312	0.185328
GS,Pre - GS,Post	-0.794206	0.1312	0.000000
GS,Pre - GS,Mid	-0.288711	0.1312	0.096037
GS,Mid - GS,Post	-0.505495	0.1231	0.000512
GS,Mid - BI,Post	-0.914086	0.1312	0.000000
GS,Mid - BI,Pre	-0.417582	0.1231	0.004801
GS,Post - BI,Mid	-0.164835	0.1231	0.412396
GS,Post - BI,Pre	0.087912	0.1231	0.775554
GS,Pre - BI,Mid	-0.959041	0.1312	0.000000
GS,Pre - BI,Post	-1.20280	0.1389	0.000000

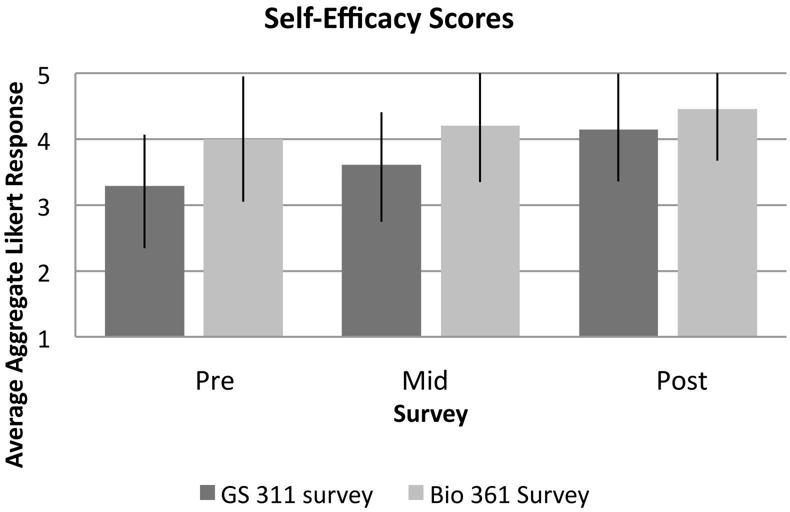

Figure 1. Self-Efficacy Scores aggregated and averaged for each class. Error bars indicate standard deviation. n = 29 Variation between class p<0.00001 pre, mid, and post.

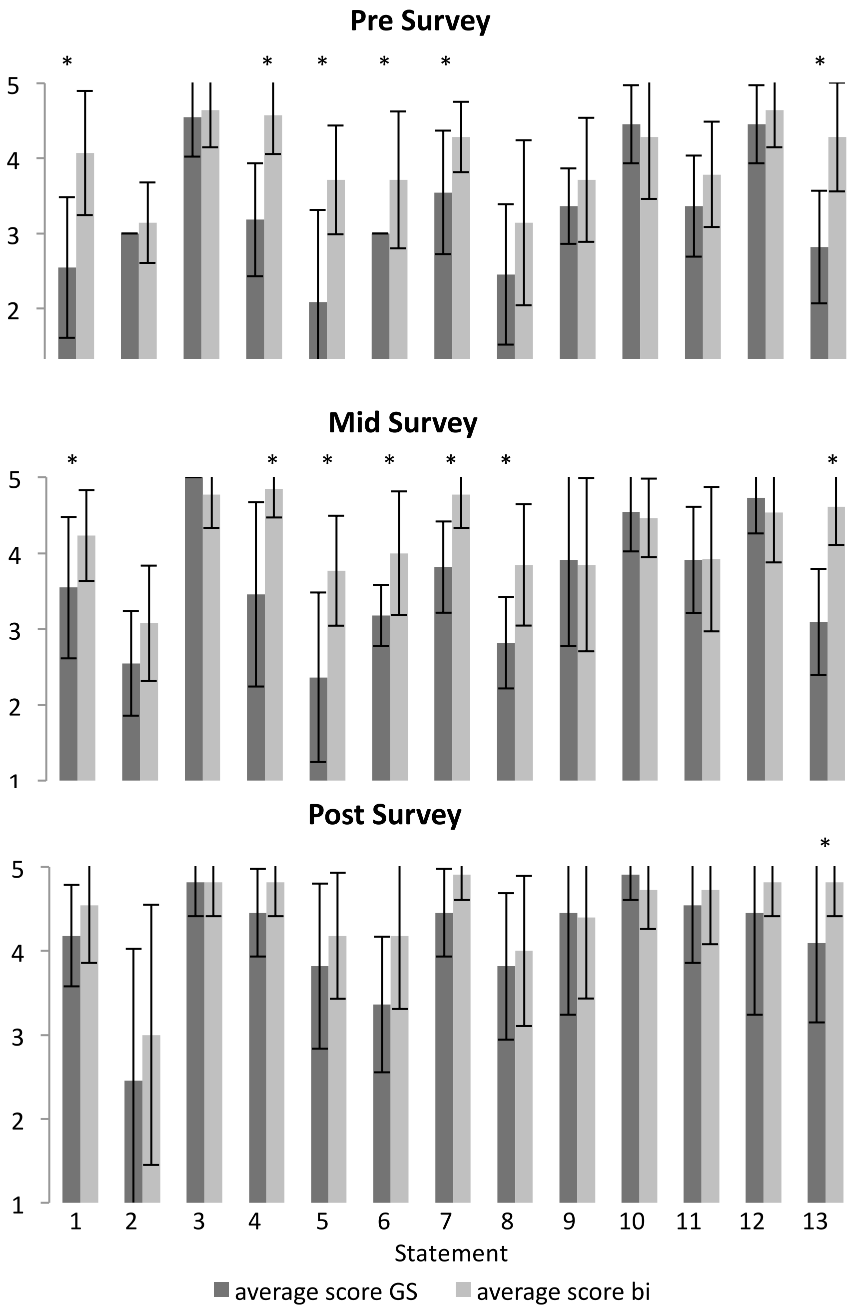

Figure 2: Self Efficacy Survey Questions aggregated for each individual question (Appendix 1A). * indicates statistically significant difference between classes at p <0.05. n = 29.

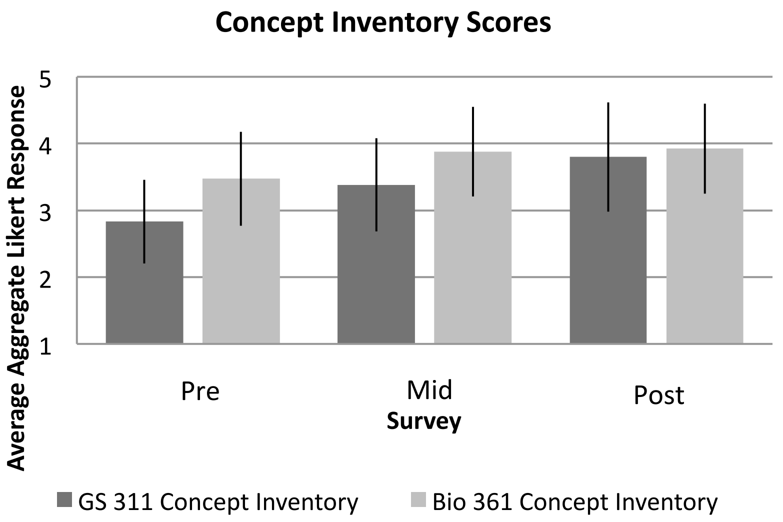

Figure 3. Concept Inventory Scores aggregated and averaged for each class. n = 29. Error bars indicate standard deviation. n = 29 Variation between class p<0.0001 pre and mid; p = 0.0027 post.

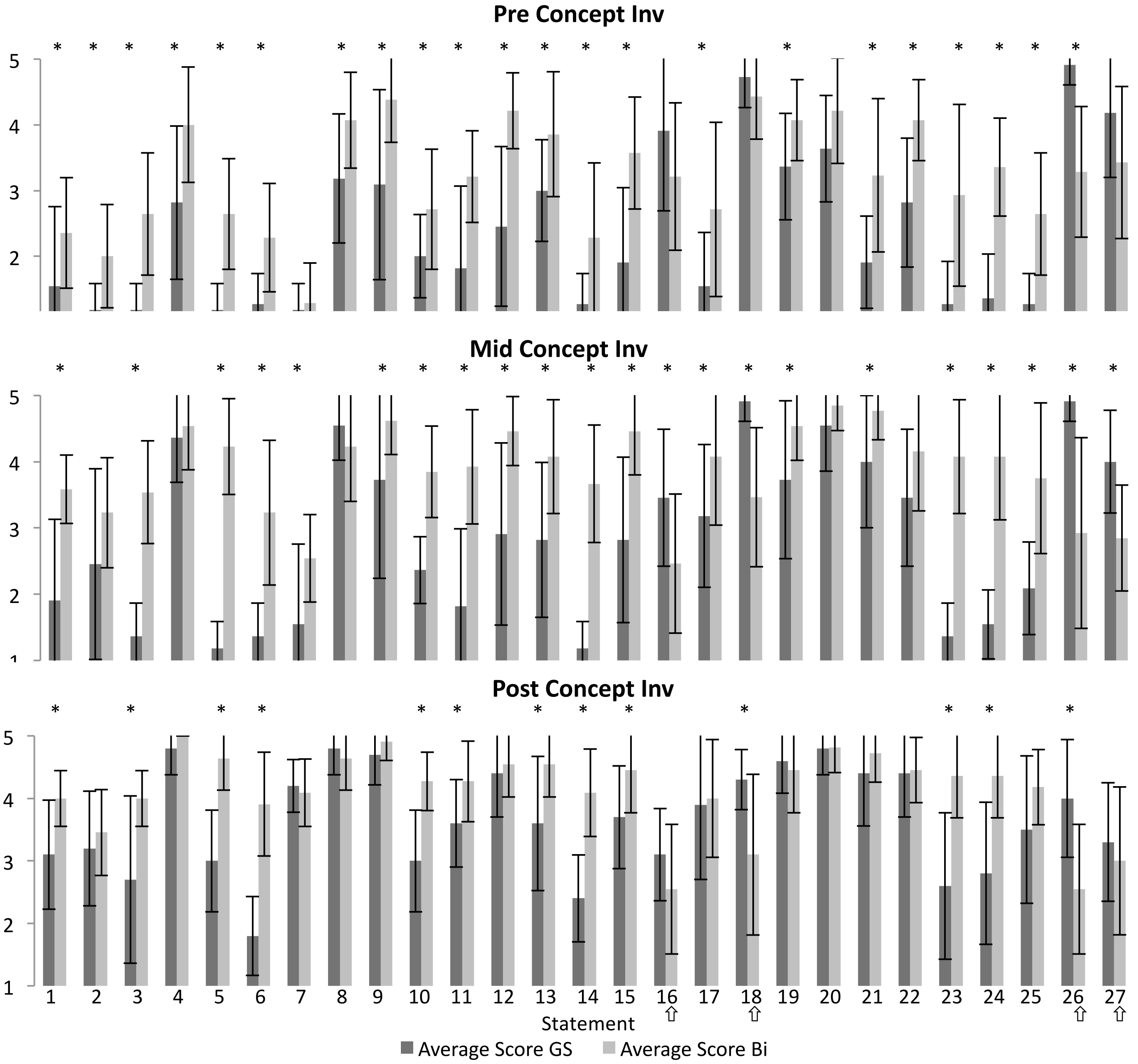

Figure 4: Concept Inventory responses aggregated for each individual question (Appendix 1B). * indicates statistically significant difference between classes at $p < 0.05$. n = 29. Validation questions identified with ⇧.

Appendix 1A: Self-Efficacy Survey Items. + indicates statements with a negative scoring axis, reversed for correction in analysis.

1. I can identify what a macroinvertebrate is
2. Rose Bengal is used as a preservative +
3. In a lab it is important to document any irregularities
4. Using a dissection microscope takes skills I do not possess +
5. I can clearly identify a Nematode
6. If something is marked with dye it will always be a macroinvertebrate +
7. I could show someone else how to use a microscope
8. I don't know how to differentiate between macroinveretebrates +
9. It is ok NOT to collect and document every macroinvertebrate I find +
10. Lab procedures are just as important as lab results
11. Drying out of samples is a major concern in our study
12. If I find something I can not identify it probably is not important +
13. Microscopy is a skill I feel comfortable performing

Appendix 1B: Concept Inventory Items. * indicates validation items not targeted by project instruction, training or research activities.

1. Amphipoda
2. Formalin
3. Annelida
4. Segmentation
5. Parapodia
6. Chaetae
7. Rose Bengal
8. Antennae
9. Forceps
10. Tube dwelling
11. Nematoda
12. Phylum
13. Calcium Carbonate
14. Polychaeta
15. Macroinvertebrate
16. Haemoglobin *
17. Benthic
18. Prostomium *
19. Order
20. Exoskeleton
21. Desiccation
22. Ethanol
23. Bivalvia
24. Gastropoda
25. Decapoda
26. Plecoptera *
27. Phonics *