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Zoos and aquariums as educational resources

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ZOOS AND AQUARIUMS AS EDUCATIONAL RESOURCES

by

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ABSTRACT

As zoos and aquariums have become increasingly focused on conservation education, their menageries of unique and diverse learning opportunities have been underutilized. Through a new postsecondary-level animal behavior laboratory experience at an aquarium (“ZooU”), this study demonstrates that active learning pedagogy aligned with the Next Generation Science Standards (NGSS) could facilitate expansion of education at zoos and aquariums beyond their conservation education niche. Generally, students indicated that ZooU provided new opportunities for them to explore their own interests, demonstrate their learning, and augment their previous laboratory and aquarium experiences. Following both self- and researcher assessments of the students’ work, integrated analyses revealed that students who engaged in more active learning activities at the aquarium demonstrated a greater increase in skills aligned with the NGSS. Additionally, a novel intra-individual analysis was utilized to embrace the variation between learners that typically confounds the results of education studies with repeated measures design. Common challenges for education at zoos and aquariums are discussed through the context of ZooU as a foundation for future investigations. A practical NGSS-aligned guide to field trips at zoos and aquariums—written specifically for science teachers—is also included to support broader utilization of zoos and aquariums as educational resources.

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CHAPTER ONE

ZooU: A New Laboratory Experience Connecting Boston University Students to Active Learning Opportunities at the New England Aquarium

Introduction

Accreditation from the Association of Zoos and Aquariums (AZA) requires a mission guided by both conservation and education (Patrick *et al.* 2018); aptly, conservation education has become a prominent and well-researched focus of AZA zoos and aquariums (Mellish *et al.* 2019). While there is so far little evidence that conservation education inspires sustainable conservation behaviors (e.g. recycling, carpooling, buying local, etc.), there is substantial evidence that conservation education positively impacts both affective (i.e. emotional) and cognitive (i.e. acquisition of knowledge and skills) learning outcomes (Schilbert *et al.* 2023). Since zoos and aquariums have focused their efforts on conservation education, their menageries of other learning opportunities in biology, science more generally, and even non-scientific fields have been underutilized and under-researched. This study begins to explore broader utilization of these unique and diverse learning opportunities to highlight the potential for zoos and aquariums to expand beyond their current conservation education niche.

Due in part to the inherently observational nature of visits to zoos and aquariums and their deep history as recreational entertainment (Miranda *et al.* 2023), the majority of learning opportunities at zoos and aquariums are fundamentally passive (e.g. viewing exhibits, reading signs, listening to presentations). In contrast, active learning is becoming standard pedagogy for formal education as evidence accumulates that greater learning occurs through active (versus passive) engagement (Olimpo *et al.* 2020). In K-12 science education, the creation and utilization of active learning activities has been facilitated by the Next Generation Science Standards (NGSS), a revolutionary framework that pairs central science concepts (Disciplinary Core Ideas, DCIs) with transferrable science skills (Science and Engineering Practices, SEPs) (National Research Council 2013). The resulting active learning pedagogy has been well-researched and widely utilized for formal science education (Olimpo *et al.* 2020)—yet not for education at zoos and aquariums. Through the creation, implementation, and evaluation of active learning activities at an aquarium, this study aimed to demonstrate the benefits of applying formal NGSS-aligned active learning pedagogy to education at zoos and aquariums.

Education research studies, including those from zoos and aquariums, are routinely designed without control groups in an effort to offer equitable learning opportunities (Mellish *et al.* 2019, Spooner *et al.* 2023). Consequently, education studies with repeated measures design often identify a change from pre- to post-assessment but rarely produce direct causal evidence that the change was due to the learning opportunity being studied. Additionally, the sample sizes of education studies are often too small to experimentally control or statistically address normal variation between learners. In an effort to embrace learning variation, this study introduces a novel intra-individual analysis facilitated by the NGSS framework. Instead of relying on each individual’s overall change between assessments and comparing between individuals, separate changes were calculated for each SEP and compared within individuals. Intra-individual comparison mitigates the multitude of confounding factors that vary between learners, and therefore could be a powerful analytical strategy for advancing science education research—especially at zoos and aquariums where control groups are rarely feasible.

Guided by the question—Could NGSS-aligned active learning pedagogy facilitate increased utilization of the unique and diverse learning opportunities at zoos and aquariums?—it was hypothesized that students who engage more with SEP-aligned active learning activities at the aquarium will demonstrate a greater increase in scientific skills aligned with the SEPs they practiced. To better characterize and contextualize the results, additional analyses investigated student feedback about their learning experience, utility of self-assessments, bias in both the activities and assessments, and student selection of learning activities.

Methods

A new laboratory experience ("ZooU") was created to give Boston University (BU) students a unique opportunity to explore aquatic animal behavior and practice their scientific skills at the New England Aquarium (BU Institutional Review Board #6585X). Following a pilot study in the summer of 2022 (Appendix VII), all students enrolled in BU's fall 2022 animal behavior course (CAS/MET BI407/607) completed the ZooU lab as part of the curriculum. Each student could choose individually whether to contribute their ZooU lab work to this study (without anticipated benefits or costs), and only data from consenting students were analyzed and reported.

To focus the students' exploration, ZooU introduced four aquarium-related animal behavior challenges, each aligned with one of Nikolaas Tinbergen's four ethological questions (Tinbergen 1963) and one of the NGSS DCIs for Life Science (LS) (National Research Council 2013). Table 1 summarizes alignment of the challenges with the frameworks, and Appendix II includes full descriptions of the challenges. For each challenge, students were tasked with designing two solutions and proposing an investigation to test their effectiveness.

Table 1.1: Alignment of the ZooU Challenges with Tinbergen's Ethological Framework and the Next Generation Science Standards Disciplinary Core Ideas (DCIs)

	Static	**Dynamic**
Proximate	*Mechanism* **DCI** LS1- From Molecules to Organisms: Structures and Processes **Challenge 1** Penguin Nesting Season Aggression	*Ontogeny* **DCI** LS3- Heredity: Inheritance and Variation of Traits **Challenge 3** Shark Behavioral Plasticity
Ultimate	*Adaptation* **DCI** LS2- Ecosystems: Interactions, Energy, and Dynamics **Challenge 2** Sea Turtle Rescue, Rehabilitation, and Release	*Phylogeny* **DCI** LS4- Biological Evolution: Unity and Diversity **Challenge 4** Pinniped Environmental Enrichment

To maximize modularity and portability, ZooU was created as three Google Forms: Prelab, Lab, and Postlab. For the Prelab, students preliminarily brainstormed ideas for both their designs and investigation using six guiding prompts aligned with the NGSS SEPs (National Research Council 2013) (Table 2). SEPs 4 and 5 as well as 6 and 7 were grouped together to facilitate analyzing data through thinking mathematically and creating explanations through arguing claims. After responding to each guiding prompt, students binarily (yes/no) self-assessed whether their response demonstrated any of three skills aligned with that prompt's SEP (Appendix V). Each skill was synthesized from multiple NGSS SEP goals for students graduating 12th grade. Then, students used their self-assessments to identify the SEPs for which they demonstrated the fewest skills, so they could focus on practicing those SEPs specifically during their Lab at the aquarium.

Table 1.2: Alignment of the ZooU Guiding Prompts with the Next Generation Science Standards Science and Engineering Practices (SEPs)

Science and Engineering Practice(s) (SEPs)	**Aligned Guiding Prompt for the Challenges**
SEP 1: Asking questions and defining problems	What research question do you propose to focus your investigation and why?
SEP 2: Developing and using models	How do you propose to model your investigation (diagram, flowchart, etc.) and how might your investigation change your model?
SEP 3: Planning and carrying out investigations	What are your proposed hypotheses/predictions and data collection methods?
SEP 4: Analyzing and interpreting data **SEP 5:** Using mathematics and computational thinking	How do you propose to analyze your data mathematically/statistically and represent your data tabularly/graphically?
SEP 6: Constructing explanations and designing solutions **SEP 7:** Engaging in argument from evidence	How do you propose to interpret your results regarding your hypotheses/predictions and explain your findings in the context of animal behavior?
SEP 8: Obtaining, evaluating, and communicating information	How do you propose to communicate your findings and recommendations to the aquarium (an audience with varied scientific backgrounds) while incorporating scientific literature?

For the Lab, students individually visited the New England Aquarium as regular aquarium guests once within a 9-day period (two weekends and the weekdays in between). To guide their visit, the students were given 18 active learning activities—three aligned with each SEP (Appendix III). Each activity was designed to transform a traditionally passive learning opportunity at the aquarium (e.g. reading a sign, watching an animal) into an active learning opportunity by incorporating at least one scientific skill. For example, while reading a sign is passive, subsequently asking three empirically testable scientific questions about the content of the sign transforms this passive learning opportunity into an active one. Students also took photos as evidence of each skill they practiced (e.g. of a sign, animal observed, aquarist, student-made graph). Each activity included an opportunity to practice one, two, or three SEP-aligned skills. To earn full credit for the Lab, students were required to complete at least one activity aligned with each SEP (at least 6 total) and practice their scientific skills at least 12 times. Therefore, students could have chosen all of the 2-skill activities from all six SEPs, three 1-skill and three 3-skill activities from different SEPs, or any other combination. Additionally, students were encouraged to choose activities aligned with the SEPs for which they had initially demonstrated the fewest skills. All students were invited to proactively complete extra activities to supplement any potentially incomplete practice and earn up to full (not extra) credit for the Lab. After the Lab, the students also completed a brief free-response learning reflection (Appendix III).

For the Postlab, students revised their six Prelab responses to refine their designs and investigations. Just as for the Prelab, the students self-assessed each Postlab response for three aligned skills. Lastly, the students responded to six survey questions about their ZooU experience (possible responses: ‘Strongly Agree’, ‘Agree’, ‘Neither Agree nor

Disagree', 'Disagree', or 'Strongly Disagree') and completed the informed consent process to contribute their ZooU lab work to this study (Appendix IV).

All data collected from non-consenting students was deleted to retain only the data from students who consented to contributing their ZooU lab work to this study. Consenting students' responses to the guiding prompts were blinded by hiding both student names and Prelab/Postlab labels. The responses were then randomized and assessed by a researcher for the same SEP-aligned skills that the students had self-assessed. This initial assessment by the researcher facilitated creation of additional assessment criteria, which permitted scoring each skill with greater detail and objectivity (Appendix V). To increase assessment consistency, the responses were blinded by a second researcher using unique codes to identify each response before being re-assessed by the first researcher. Occasional embedded identifiers—such as within file names or responses (e.g. "At the aquarium I learned…" identifies a Postlab)—were not removed, so these identifiers were disregarded during re-assessment. The subjectively similar results of the first and second assessments were taken as an indication of consistent assessment methods; only the scores from the second assessment were used for the following methods. To quantify the consistency of the assessment methods, duplicate responses (identical pairs of Prelab and Postlab responses from the same student) were identified. Duplicate responses should have been given the same scores (valid pairs), but some were given different scores (invalid pairs), so the responses with different scores were reassessed to correct one score to match the other. The consistency of the assessment methods was calculated as the number of initially valid scores (two from valid pairs plus one from invalid pairs) divided by the total number of duplicate scores.

To identify significant differences in survey responses, chi-squared analyses were performed using pooled data; ‘Strongly Agree’ and ‘Agree’ were pooled as ‘Positive’, and ‘Disagree’ and ‘Strongly Disagree’ were pooled as ‘Negative’. Appendix VI includes tests and explanations of statistical conditions for all analyses.

For both the self- and researcher-assessed data, the number of skills a student demonstrated in the Prelab was subtracted from the number of skills they demonstrated in the Postlab to calculate their change in skills both by SEP and overall. T-tests and Cohen’s D analyses were performed to identify significant changes in skills both by SEP and overall. To identify potential differences in students’ mean change in skills across the four different challenges, an ANOVA was performed. Each student’s change in skills was divided by their possible change in skills (i.e. 18 total skills minus their initial (Prelab) skills demonstrated) to calculate the student’s relative change in skills both by SEP and overall. Pearson’s correlations were calculated for both initial skills demonstrated and total skills practiced versus both absolute and relative change in skills. T-tests were also used to compare both the change in skills of students who practiced their skills 12 or fewer times with those who practiced their skills greater than 12 times.

Within each SEP, students were grouped by the number of times they practiced skills aligned with that SEP (i.e. 1, 2, or 3 times), and each group’s mean change in skills for that SEP was calculated. Mann-Whitney tests were used to quantify the effect of practicing an SEP once versus three times on the mean change in skills for that SEP and overall. To relativize each student's practice for each SEP, the number of times the student practiced each SEP was divided by their total practice across all SEPs. Then, the mean of all students' relative practice was calculated by SEP. Similarly, to relativize each student's change in skills for each SEP, the student's change in skills for each SEP was divided by their total change in skills across all SEPs. Then, the mean of all students' relative change in skills was calculated by SEP. Finally, to relativize each student's initial skill deficit for each SEP, initial SEP deficit (3 possible SEP skills minus their initial (Prelab) skills demonstrated for the SEP) was divided by initial total deficit (18 possible total skills minus their initial (Prelab) total skills demonstrated). Then, the mean of all students' relative initial deficit was calculated by SEP.

Results

Students enrolled in BU's fall 2022 animal behavior course (CAS/MET BI 407/607) were primarily upper-level undergraduate biology students, and of the 102 students enrolled, 72 students (71%) consented to contributing their ZooU lab work to this study. From the consenting students' work, the researcher assessed 864 responses to the guiding prompts (72 students responded to six prompts for both the Prelab and Postlab), of which 33 pairs were duplicate responses. Since three skills were assessed per response, there were 99 pairs of duplicate skill assessments, of which 82 received the same score (valid pairs) and 17 received different scores (invalid pairs). Of each invalid pair, only one score required correction, so 181 scores were initially valid (two scores from 82 valid pairs plus one score from 17 invalid pairs) and 17 scores were initially invalid, which resulted in an assessment consistency of 91%.

Through significantly positive responses to the ZooU experience survey (Q1-5, 57-79% positive, p<0.001), students indicated that ZooU provided new opportunities for them to explore their own interests, demonstrate their learning, and benefit from unique and diverse educational resources at the aquarium in ways that augmented regular labs and aquarium visits (Q1-5, p<0.001) (Figure 1.1). While a majority of students reported enjoying the ZooU activities (Q6, 49% positive compared to 33% negative), responses varied and were less significantly positive (p<0.10). Appendix VI describes the statistical results from these and all subsequent analyses in greater detail.

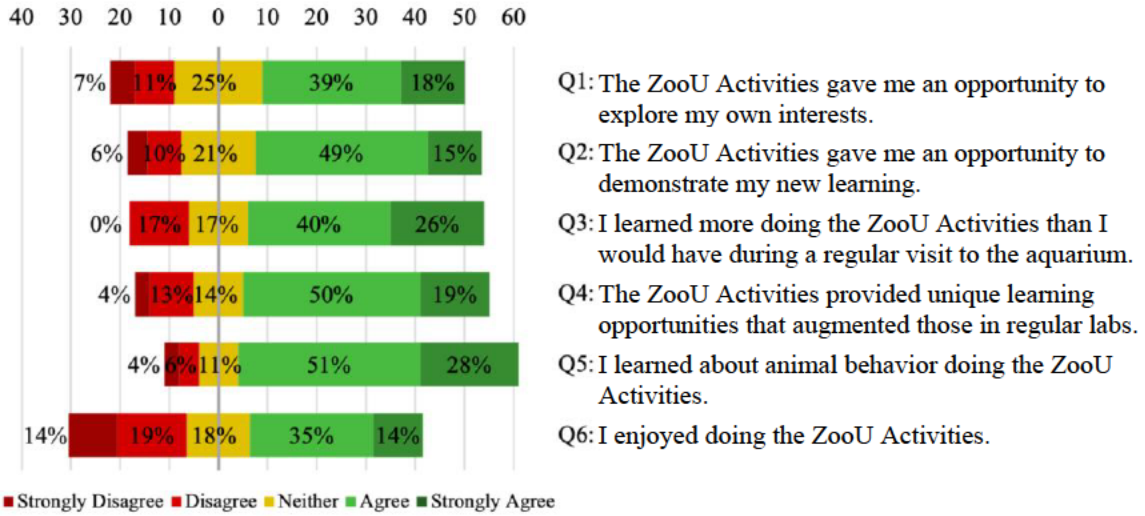


Figure 1.1: Summary of Experience Survey Responses. Summary of student responses to six survey questions about their ZooU experience with absolute student numbers (x-axis) and percents for each bar. All six questions had significantly positive responses (p<0.001 for Q1-5 and p<0.10 for Q6). N=72 responses per question.

The students' responses to the ZooU challenges were both self-assessed and researcher assessed. Since, there was no significant difference in the students' mean change in skills across the four challenges (p<0.44), the data from all four challenges were analyzed together. In the self-assessments, students reported demonstrating a mean of 11.15 skills for the Prelab and 16.22 skills for the Postlab—a significant increase in each SEP and overall (p<0.001) (Figure 1.2). According to the researcher assessment, students demonstrated fewer skills with a mean of 5.10 skills for the Prelab and 7.88 skills for the Postlab—but still a significant increase in each SEP and overall (p<0.001) (Figure 1.2). Additionally, the increases were characterized by effect sizes small (SEP 4/5), medium (SEPs 2, 3, and 6/7), and large (SEPs 1 and 8, and overall).

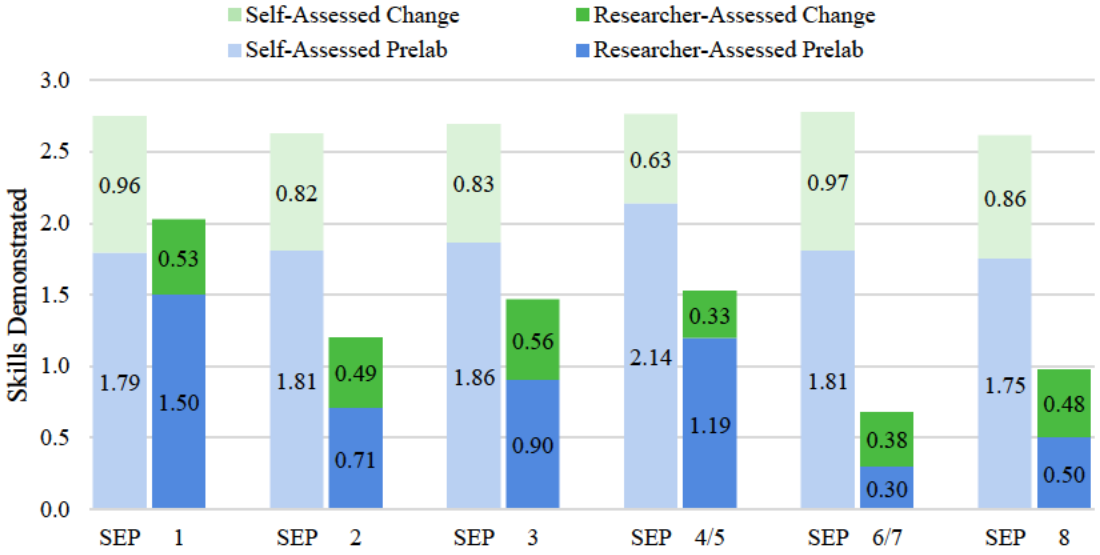


Figure 1.2: Skills Demonstrated in Prelab and Postlab Responses by SEP. Mean number of skills demonstrated in the students' Prelab and Postlab responses according to self-assessments (faded left-side columns) and researcher assessment (non-faded right-side columns). Each SEP was assessed for three skills, as represented by the y-axis maximum. For each SEP, the students' mean Prelab skills (blue) was plotted with mean change in skills (green) stacked on top, which was calculated using mean Postlab skills (i.e. Postlab minus Prelab equals change). According to both assessments, the students demonstrated significantly more skills in their Postlab compared to their Prelab responses for each SEP and overall (p<0.001). N=72 students for both assessment types for each SEP.

In general, the students' initial skills demonstrated had little effect on their change in skills (Figure 1.3). The Pearson's correlation of initial skills demonstrated versus *absolute* change in skills was slightly negative (-0.14), whereas initial skills demonstrated versus *relative* change in skills was slightly positive (0.17). Yet, students who practiced their skills more times at the aquarium tended to demonstrate a greater increase in skills (Figure 1.4). Both the Pearson's correlations of total skills practiced versus *absolute* and *relative* change in skills were moderately positive (0.33 and 0.40 respectively). Similarly, students who practiced their skills more than 12 times demonstrated a significantly greater increase in skills (mean: 3.22 skills, N=34) compared to students who practiced their skills 12 times or fewer (mean: 2.28 skills, N=38) ($p<0.05$).

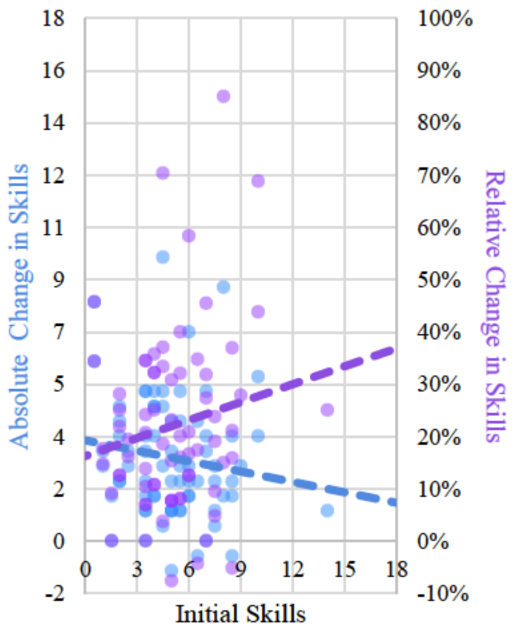


Figure 1.3: Initial Skills vs (Relative) Change in Skills. Each student's initial skills demonstrated (Prelab) was plotted versus both their absolute (blue) and relative (purple) change in skills—with a linear trendline for both the absolute (Pearson's r = -0.14) and relative (Pearson's r = 0.17) dataset. The maximum number of skills students could demonstrate was 18, as represented by the axes' maximums. N=72 students.

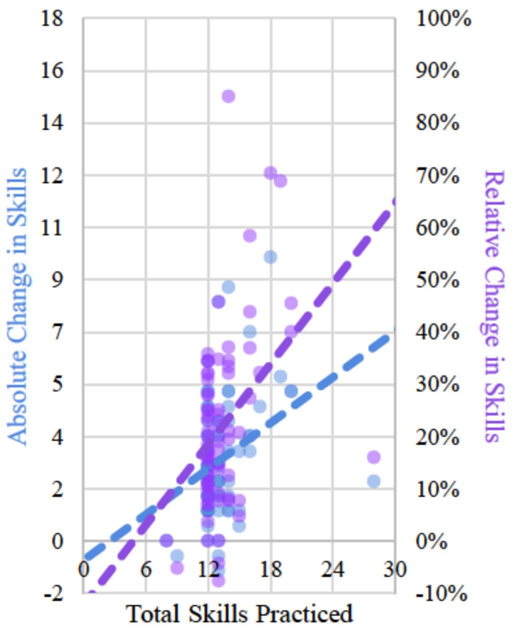


Figure 1.4: Total Skills Practiced vs (Relative) Change in Skills. Each student's total skills practiced (Lab) was plotted versus both their absolute (blue) and relative (purple) change in skills—with a linear trendline for both the absolute (Pearson's r = 0.33) and relative (Pearson's r = 0.40) dataset. Students who practiced skills more than 12 times (N=38) demonstrated a significantly greater increase in skills ($p<0.05$). N=72 students.

Also, students who practiced an SEP three times tended to demonstrate a greater increase in skills for that SEP when compared to students who only practiced that SEP once (Figure 1.5)—significantly so for SEP 3 ($p<0.1$), SEPs 6/7 and 8 ($p<0.05$), and overall ($p<0.01$).

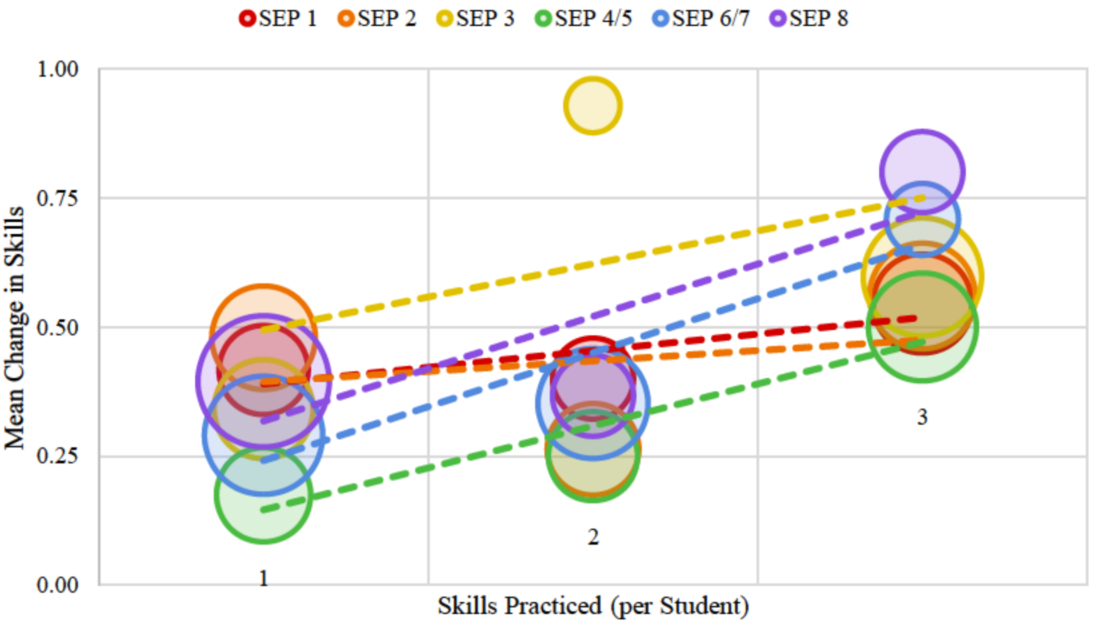


Figure 1.5: Skills Practiced vs Change in Skills by SEP. Within each SEP, students were grouped by the number of times they practiced skills aligned with that SEP (i.e. 1, 2, or 3 times, x-axis), and each group's mean change in skills for that SEP was calculated (y-axis). The area of each group's bubble is proportional to the number of students in that group (N=7-38). The linear trendline for each SEP is positive, and there was a significant difference in the mean increase in skills between groups that practiced skills aligned with those SEPs once versus three times significantly so for SEP 3 ($p<0.1$), SEPs 6/7 and 8 ($p<0.05$), and overall ($p<0.01$). N=55-70 students for each SEP (color) and N=101-153 students for each amount of practice (column).

Finally, students tended to demonstrate a greater relative increase in skills for the SEPs that they practiced relatively more (Figure 1.6). SEP 4/5 was notably below the trendline with the lowest mean relative change in skills. Interestingly, students also tended to practice relatively more skills aligned with the SEPs for which they had initially demonstrated relatively more skills (Figure 1.7).

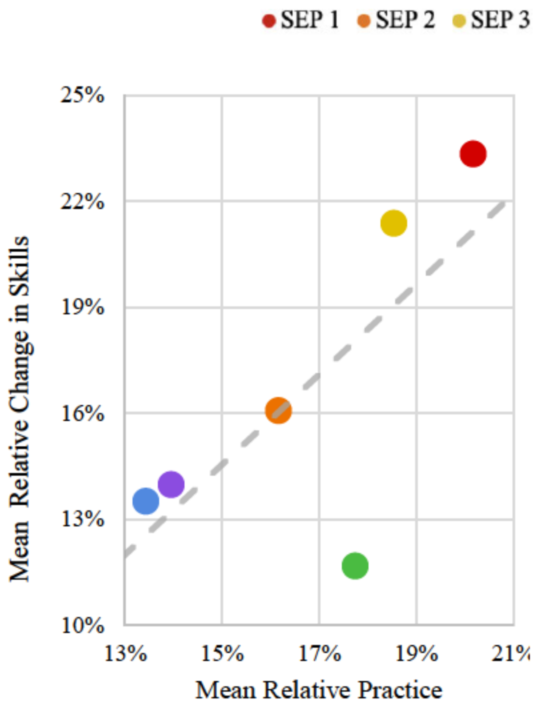


Figure 1.6: Relative Practice vs Relative Change in Skills by SEP. Mean relative practice (x-axis) and mean relative change in skills (y-axis) were plotted for each SEP with a generally positive linear trendline. Notably, SEP 4/5 was below the trendline. N=72 students for each SEP.

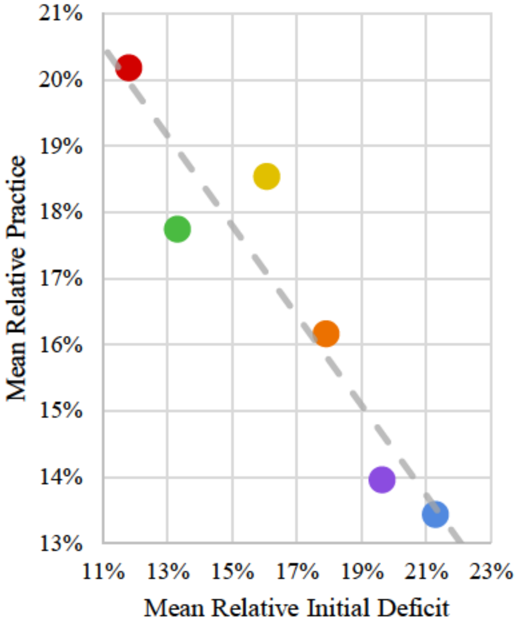


Figure 1.7: Relative Initial Deficit vs Relative Practice by SEP. Mean relative initial deficit in skills (x-axis) and mean relative practice (y-axis) were plotted for each SEP with a generally negative linear trendline. N=72 students for each SEP.

Discussion

The overall feedback for ZooU was quite positive. Specifically, the students indicated that ZooU provided new opportunities for them to explore their own interests, demonstrate their learning, and benefit from the unique and diverse educational resources at the aquarium (Q1-5, Figure 1.1). Students had a more mixed response regarding enjoyment of the ZooU activities (Q6, Figure 1.1); however, several logistical challenges were likely contributing factors (e.g. transportation and technology). Interestingly, students accustomed to traditional passive learning pedagogy (e.g. in typical postsecondary courses) tend to initially respond negatively to modern active learning pedagogy—despite ultimately learning more (Deslauriers *et al.* 2019). While a similar phenomenon might have influenced student enjoyment, the overall feedback was much more positive than predicted. Perhaps these students were more receptive to the active learning pedagogy incorporated into ZooU because the aquarium environment was also novel. The overall positive feedback from these students for ZooU encourages continued efforts to explore broader utilization of learning opportunities at zoos and aquariums.

Since the ZooU assessments were based on SEP goals for 12th grade, the participating postsecondary students were theoretically expected to demonstrate complete mastery of all skills assessed; yet according to the researcher assessment, the students demonstrated a mean of 7.88 of 18 skills. While these results may stem from incomplete science education, perhaps due to the COVID-19 pandemic (Gao *et al.* 2022), the full explanation is likely multirooted. Importantly, the ZooU assessment could not have been—and was not intended to be—a comprehensive evaluation of these students' scientific skills. Even when successfully implementing the NGSS, accurately and practically measuring learning remains a major challenge for science education (Pellegrino 2013). In general, the findings of this study corroborate growing understanding that the NGSS framework has established lofty goals for science education as a whole (Hoeg *et al.* 2017), and further efforts to expand (and research) education at zoos and aquariums could help achieve these goals.

While the students' self-assessments reported greater initial skills demonstrated and less variability between SEPs than the researcher assessment, both assessments reported a significant increase in skills for all SEPs (Figure 1.2). These results suggest that while students did not self-assess their initial skills accurately, they did recognize their increase in skills—also see survey questions 2 and 5 (Figure 1.1). Collectively, these findings align with the well-studied Dunning-Kruger effect: learners are generally unaware of their (lack of) initial skills, yet they are aware of their skills increasing (Dunning 2011). As a result, response-shift bias is a common challenge for education studies with repeated measures design because self-assessors unconsciously update their internal learning assessment scales as they become aware of knowledge they previously lacked (Mellish *et al.* 2019, Spooner *et al.* 2023). Since there is both evidence that students are aware of their learning progress (even at a zoo or aquarium) and evidence that instructors are needed to calibrate learning scales, two-way instructor-student conversations are likely more beneficial than either self- or instructor assessment alone. Implementing two-way learning progress assessments at zoos and aquariums, where formal instructor-student relationships are rare, is an important area for future research.

For education to be equitable, all students must have opportunities to learn, and since learners vary substantially (e.g. styles, abilities, backgrounds), creating equitable learning opportunities requires differentiation (Smith *et al.* 2021). The ZooU Lab was highly differentiated by giving students choice in the activities they explored both according to their self-assessment-driven focus on practicing certain SEPs and their innate interest in exploring certain behaviors of specific animals. The effectiveness of this differentiation strategy was evaluated through the relationship between initial skills demonstrated and change in skills (Figure 1.3); theoretically, a horizontal trendline would indicate that all students increased their skills regardless of their initial skills demonstrated. In reality, the slightly negative trend indicates that students who demonstrated fewer skills initially had a slightly greater absolute increase in skills; however, the trend reverses when considering this relationship relative to initial skills demonstrated. These insignificantly slight trends suggest that the ZooU lab experience had little bias and was well-differentiated to support all students' learning regardless of their initial skills demonstrated. Creating unbiased and highly differentiated learning opportunities is especially important at zoos and aquariums because of their historic role as a gateway into science for people whose identities remain broadly underrepresented in science fields (Williams 2021). Further research is needed to identify (and expand) components of education at zoos and aquariums that are disproportionately responsible for welcoming diverse perspectives into science.

While the ZooU assessments reported that students demonstrated a significant increase in skills from Prelab to Postlab, further analyses were performed to gather evidence that the increase was due to the NGSS SEP-aligned active learning activities at the aquarium. Initial evidence included the moderately positive relationships between the students' total skills practiced (Lab) and both their absolute and relative change in skills, which suggested that students who practiced their skills more also tended to demonstrate a greater increase in skills (Figure 1.4). Additionally, students who practiced their skills more than 12 times demonstrated a significantly greater increase in skills than those who practiced their skills 12 times or fewer. Finally, students who practiced an SEP three times demonstrated a significantly greater increase in skills aligned with that SEP compared to students who practiced that SEP once (Figure 1.5). Unfortunately, inevitable variation between learners propagates confounding variables that likely skewed the results of these inter-individual comparisons. For example, some students may have allocated more effort to both the graded Lab and Postlab compared to the ungraded Prelab, which would have artificially decreased their Prelab skills and confoundingly inflated both the number of times they practiced their skills and their change in skills.

Fortunately, intra-individual comparisons (e.g. one student's change in one SEP compared to another SEP) are not affected by variation between learners because individual variation is distributed across all SEPs. These analyses identified a trend that students who practiced more skills aligned with a certain SEP also demonstrated a greater increase in skills for that specific SEP compared to the other SEPs that they practiced fewer times (Figure 1.6). Intra-individual comparison is a novel use of the NGSS framework that could help circumvent some of the confounding variables and methodological limitations that typically plague science education research. Intra-individual analyses also facilitate identification of especially (in)effective sets of activities. For example, SEP 4/5 was below the trendline—suggesting that the aligned activities were relatively less effective. Understanding the relative effectiveness of activities by SEP helps preferentially focus instructional efforts towards developing activities aligned with SEPs for which students need additional support, thus maximizing the educational benefit of chronically overstretched instructional resources.

The negative trend between relative initial skill deficit and relative practice was an unexpected result (Figure 1.7). If students had chosen to practice activities aligned with SEPs for which they had initially demonstrated fewer skills (as encouraged), the trend would have been positive. However, with the students' self-assessments reporting low variability across the SEPs for initial skills demonstrated (Figure 1.2), the students may not have been able to identify specific SEPs to focus on at the aquarium. Yet in that case, the trend would have been random (i.e. students having randomly chosen activities). The unexpectedly negative trend suggests that students tended to practice SEPs for which they had initially demonstrated more skills—potentially minimizing their learning. Since the Lab activities were graded for quality and completeness, students' may have felt pressure to choose 'safer' activities that they were more likely to successfully accomplish over 'riskier' activities that could have helped them practice their less-mastered SEPs. These results highlight the importance of removing the pressure of irreparable grades, so students can take educational risks and maximize their learning (Pollio *et al.* 2000). For students to maximize the unique and diverse learning opportunities at zoos and aquariums, pedagogy that encourages educational risk-taking must be adapted from formal education or created specifically for education at zoos and aquariums.

While the results of this study are specific to the ZooU laboratory experience, they highlight universal challenges of education at zoos and aquariums: structuring curriculum and assessment to effectively measure and communicate learning progress, differentiating opportunities for all learners, and creating cultures that encourage learning. Continued investigation of these challenges, with a wide variety of learners, is needed to support broader utilization of the unique and diverse learning opportunities at zoos and aquariums.

CHAPTER TWO

Field Trips to Zoos and Aquariums:

Solving Pedagogical Challenges Using the Next Generation Science Standards

Zoos and Aquariums as Educational Resources

Zoos and aquariums are full of unique learning opportunities, and with over 200 zoological institutions accredited by the Association of Zoos and Aquariums (AZA) across the United States, you likely have one of these underutilized educational resources in your backyard (Association of Zoos and Aquariums 2023). In 2022, the AZA reported that "5.5 million individuals were reached through field trips, outreach programs and education resources targeted to K-12 students" (Association of Zoos and Aquariums 2022); despite their popularity, the unique learning opportunities at zoos and aquariums remain underutilized by teachers because of the substantial logistical and pedagogical challenges of field trips. While the logistics are typically situation-specific, the pedagogical challenges are more universal: making meaningful connections to existing curricula, creating active learning opportunities, differentiating and scaffolding instruction, and assessing both student learning and field trip effectiveness. Fortunately, the Next Generation Science Standards (NGSS) (National Research Council 2013) provide an excellent framework for addressing each of these pedagogical challenges.

The following guide for NGSS field trips to zoos and aquariums arose from the development of a new laboratory experience at Boston University (BU), during which students visited The New England Aquarium to explore aquatic animal behavior and practice scientific skills (see Chapter 1). The lab was aligned with 12th grade NGSS because the framework does not extend to postsecondary science education; however, these standards were ultimately appropriate because even the most proficient students did not demonstrate 12th grade mastery of all the scientific skills assessed. While this finding could stem from the disruption in these students' secondary science education during the COVID-19 pandemic (Gao *et al.* 2022), the complete explanation is likely multirooted. However, the students did demonstrate greater mastery of the NGSS after completing the lab—evidence of an effective field trip. While the lab was created for students at a postsecondary level, the lab's NGSS-based strategies for addressing the pedagogical challenges of field trips are adaptable for any grade level, so examples from the lab are used throughout the following guide. Using the NGSS framework to solve the pedagogical challenges that have long plagued zoo and aquarium field trips is a critical step towards utilizing our zoological institutions to their fullest educational potential.

Making Meaningful Connections to Curricula

"For such a large number of problems there will be some animal of choice, or a few such animals, on which it can be most conveniently studied."

~ August Krogh (1929) *The Progress of Physiology*

The vast diversity of organisms at zoos and aquariums supports curricular connections to every subject area and grade level. Most of the curated content at zoos and aquariums is conservation related, but conservation is only one lens through which students can learn science. Of the NGSS domains, life science has the most obvious connections to zoos and aquariums, but connections to the other three NGSS domains abound. For field trips, just as in classrooms, alignment with Disciplinary Core Ideas (DCIs) helps focus lessons for both students and teachers. Without a focused lesson plan, field trips to zoos and aquariums can easily disintegrate into a scramble to see all of the animals, which is both impossible and counterproductive. For example, The Smithsonian National Zoo is home to over 360 species; if students attempted to see every species in one six-hour field trip, they would only see each species for one minute, which is clearly not enough time for any substantial learning to occur. Additionally, unfocussed zoo and aquarium visits only reinforce the misconception that these institutions do not offer substantial learning opportunities. Aligning zoo and aquarium field trips with DCIs helps prioritize their quality over the quantity of learning opportunities packed into them. The following examples of highly focused zoo/aquarium field trips are aligned with DCIs within each of the NGSS domains:

Physical Sciences (PS4.A: Wave Properties)

Physical science students learning about sound waves could explore transmission of animal sounds through different materials (e.g. fish sounds through water, bird sounds through air, burrower sounds through substrate), followed by investigating sound production and amplification adaptations in mammals (e.g. howler monkeys, lions, whales), before finally focusing on unique ways animals use sound (e.g. bats hunting with echolocation, shrimp hunting with cavitation).

Life Sciences (LS1.A: Structure and Function)

Life science students learning about muscular systems could explore the diversity of muscle tissue in invertebrates (e.g. from spiders to octopuses), followed by investigating unique muscular structures in mammals (e.g. elephant trunks, anteater tongues), before finally comparing the biomechanical tradeoff of strength versus speed using lions and cheetahs or strength versus agility using wolves and foxes.

Earth and Space Sciences (ESS2.D: Weather and Climate)

Earth science students learning about climate could explore animal adaptations to specific environments by identifying them in coral reef inhabitants (e.g. specialized feeding appendages, symbiotic relationships), followed by comparing features of related species from different climates (e.g. fur length/color in grizzly versus polar bears, ear surface area in African versus Asian elephants), before finally assessing which characteristics make certain animals especially sensitive to climate change (e.g. island isolation, niche specialties, competition with humans).

Engineering and Technology (ETS1.C: Optimizing the Design Solution)

Engineering students learning about material properties could explore the diversity of structural materials made by animals (e.g. shell, bone, keratin, chitin), followed by identifying scenarios when these materials fail (e.g. predation, molting, aging), before finally comparing how evolution has optimized the same material for the specific biological requirements of different species (e.g. turtle shell versus gibbon humerus).

While the topics of the field trips above might not be appropriate for your students specifically, aligning learning opportunities at zoos and aquariums with the DCIs can facilitate integration with your curriculum. Often even a brief conversation with educators or zoologists at your local zoo or aquarium will yield excitingly novel connections to your curriculum. In fact, many of the BU students were surprised by how much they learned from talking to educators and aquarists at the New England Aquarium.

“I think an unexpected obstacle I overcame was talking to the aquarium staff about their work because I am a little afraid to talk to strangers, especially about topics I do not know about. However, I am so glad that I did because learning about everything they do and how they collect behavioral information is incredibly interesting. Everyone was so kind!”

~ BU Student

“Speaking with the aquarium staff allowed me to learn about and appreciate the behind-the-scenes work they do to ensure the health of the marine animals while making the aquarium an interesting and educational environment for visitors.”

~ BU Student

Similarly, the content level of the field trips above might not be appropriate for your students, but aligning learning opportunities at zoos and aquariums with the DCIs outlined for specific grade bands can facilitate appropriate leveling. Typically, young children are the target audience of zoos and aquariums, so alignment with appropriately advanced DCIs is especially important for older students to address the prevalent misconception that learning opportunities at zoos and aquariums are juvenile. Even at the postsecondary level, many BU students realized the educational value of zoos and aquariums during their lab.

> "As a kid who used to go to aquariums, I was always just curious to see the coolest looking creature. Going as an undergraduate, my goals and ambitions were different… I learned a lot about many interesting species that unfortunately get overlooked. Additionally, by spending more time at a certain enclosure, I was able to utilize my phone to do research instantly to learn more about an animal."
>
> ~ BU Student

While aligning a field trip with a single DCI can help maintain the lesson's focus, alignment with multiple DCIs can also be beneficial if the connections between them are clearly articulated. Making connections between DCIs is often easier within an NGSS domain; however, making connections across domains can be especially strategic when planning a field trip for multiple classes working towards mastering different standards (e.g. biology and physics, 5th and 6th grade). As much as scientists hate to admit it, none of them can do science alone, so any opportunity for students to collaborate across science (and non-science!) disciplines is highly valuable and practical experience. Maximizing these interdisciplinary benefits can also help justify efforts to solve the logistical challenges of a zoo/aquarium field trip and inspire support from your colleagues, administrators, and students' families.

Creating Active Learning Opportunities

As any visitor can experience, zoos and aquariums are full of passive learning opportunities. There are animals to watch and signs to read at almost every exhibit, and with a bit of timing, it is usually possible to listen to a few presentations as well. Many zoos and aquariums also offer opportunities for visitors to interact with certain animals (e.g. animal ambassadors, feedings, training sessions, rides). For field trips, these learning opportunities are often structured within guided tours; the pedagogical framework is similar whether the guide is a live person, a scavenger hunt worksheet, or an audio recording. While structured tours can guide students through the overwhelming diversity of passive learning opportunities at zoos and aquariums, they cannot inherently promote active learning. It is well-established that students learn best when actively engaged (Freeman *et al.* 2014); consequently, active learning is now a major goal for educators in formal education settings, and therefore, active learning should also be a major goal for field trips to informal education settings such as zoos and aquariums. The ensuing challenge is transforming the abundant passive learning opportunities at zoos and aquariums into active ones. Again, the NGSS framework provides a solution—the Science and Engineering Practices (SEPs).

> "In the context of the Framework and the NGSS [STEM professionals from science museums and centers] can be invaluable resources for helping teachers understand and engage in the science and engineering practices."
>
> ~National Academies of Sciences, Engineering, and Medicine (2015)
>
> *Guide to Implementing the Next Generation Science Standards*

Each of the eight SEPs has a set of related skills, which are outlined by grade band in NGSS Appendix F (National Research Council 2013). As an example from 12th grade, a skill—identify and originate scientific questions that can be answered empirically— is aligned with SEP 1: Asking questions (for science) and defining problems (for engineering). Practicing these scientific skills naturally stimulates active learning because students are given opportunities to actively engage in scientific processes themselves instead of only passively learning about science performed by others. Therefore, pairing passive learning opportunities at zoos and aquariums with SEP-aligned skills transforms them into active learning activities. For example, just reading the signs near an exhibit would be passive learning, but if students also engage actively by asking questions (SEP 1) that arise from reading the signs, then the signs become an active learning opportunity. The following active learning activity was designed to align with SEP 1 at the 12th grade level:

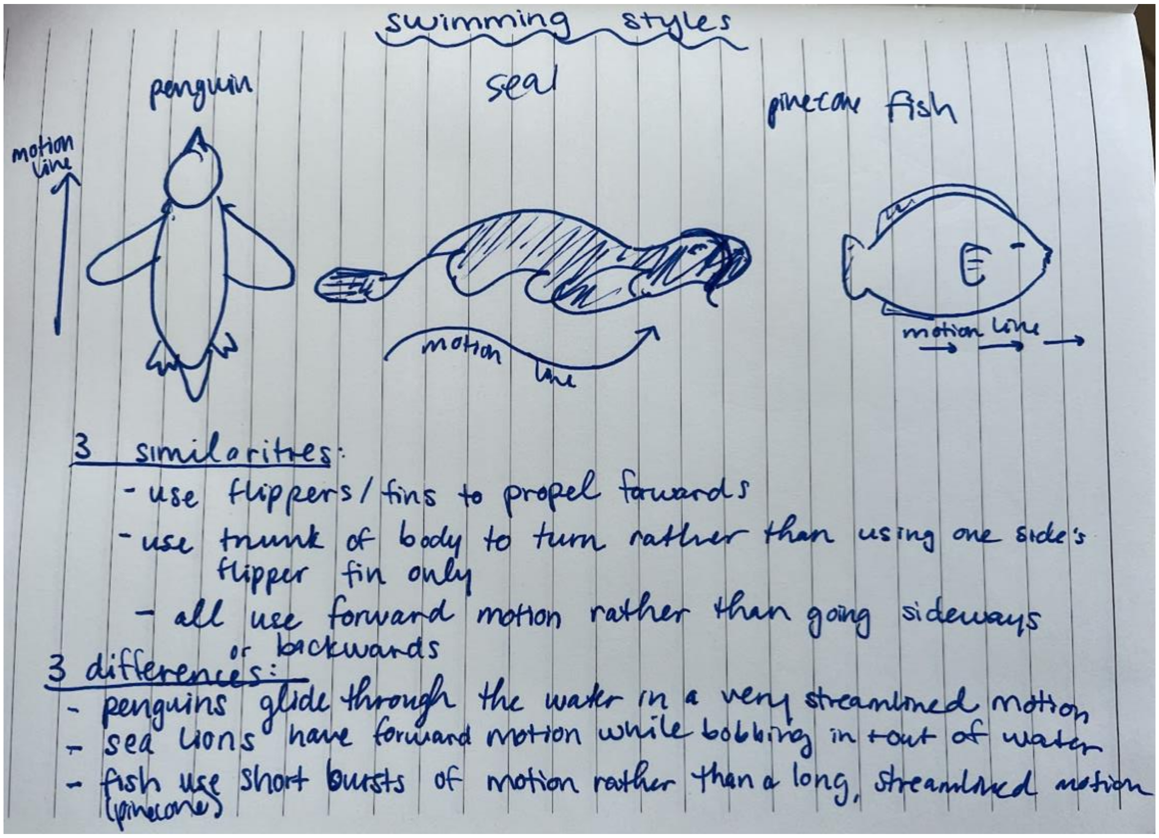
> Active Learning Activity Aligned with SEP 1:
>
> *Choose one species at the aquarium whose behavior you find interesting and read all of the signs around its enclosure. Then, write three questions about its behavior that you cannot find answers to on the signs, but that you could explore with a scientific investigation.*

Due to the observational nature of visiting zoos and aquariums, hands-on activities are usually not available; however, 'hands-on' and 'active learning' are not synonymous. Students can engage actively in scientific skills such as asking questions, collecting data, developing explanations, and communicating science without touching anything—especially dangerous animals. For inspiration, explore STEM Teaching Tool #30 (Vanhorne *et al.* 2016), which contains broadly outlined assessment task templates aligned with each SEP that can be adapted for active learning activities.

Just as field trips can be aligned with multiple DCIs, active learning activities can also be aligned with multiple skills within or between SEPs. For example, the following activity was aligned with two skills within SEP 1—identify and originate scientific questions that can be answered empirically—and—contextualize questions through connections to scientific observations—as well as one skill from SEP 3—determine and implement appropriate investigatory methods for the data qualities needed.

> Active Learning Activity Aligned with SEP 1 (two skills) and 3 (one skill):
> *Find a food source in an exhibit and identify which exhibited species might forage there. Observe one individual from one of those species for 5 minutes and record all behaviors you observe. Based on your observations, write three questions about the species' foraging behavior that could be explored scientifically through additional observation sessions.*

Aligning one activity with multiple skills gives students multiple ways to both practice their skills and demonstrate their learning while developing the ability to use the SEPs cohesively and dynamically (Figure 2.1).



3 similarites:
- use flippers/fins to propel forwards
- use trunk of body to turn rather than using one side's flipper fin only
- all use forward motion rather than going sideways or backwards

3 differences:
- penguins glide through the water in a very streamlined motion
- sea lions have forward motion while bobbing in + out of water
- fish (pinecone) use short bursts of motion rather than a long, streamlined motion

Figure 2.1: Example Student Lab Model. A student's model from the following activity, which was aligned with three scientific skills within SEP 2 (Developing and Using Models): *Find three species from different animal classes (e.g. mammals, birds, reptiles, amphibians, bony fish, cartilaginous fish). Take three photos: one of each species doing the same behavior. Create a model (e.g. diagram, drawing, flowchart, etc.) highlighting at least three similarities and three differences in the behavior across the three species as evidence either for or against these species' common ancestry. Describe one limitation of your model and something you could do to address it.*

Importantly, the success of a field trip does not need to rely on any special arrangements with the zoo/aquarium; all of the resources students need to practice their scientific skills are accessible to regular visitors. Instead of moonlighting as a travel agent to coordinate special arrangements, you can instead focus on creating active learning opportunities curated for your students' specific learning goals. Appendix III includes the 18 active learning activities created for the BU Animal Behavior Lab at the New England Aquarium, about which this student wrote:

> "Usually at an aquarium, I would just walk around aimlessly. I feel that actively thinking through questions and formulating my own responses to well-thought-out prompts allowed me to really learn a lot from my time at the aquarium."
>
> ~ BU Student

Pairing SEP-aligned skills with zoo and aquarium resources within the context of a field trip's focusing DCI(s) results in almost limitless combinations of active learning activities (Figure 2.2).

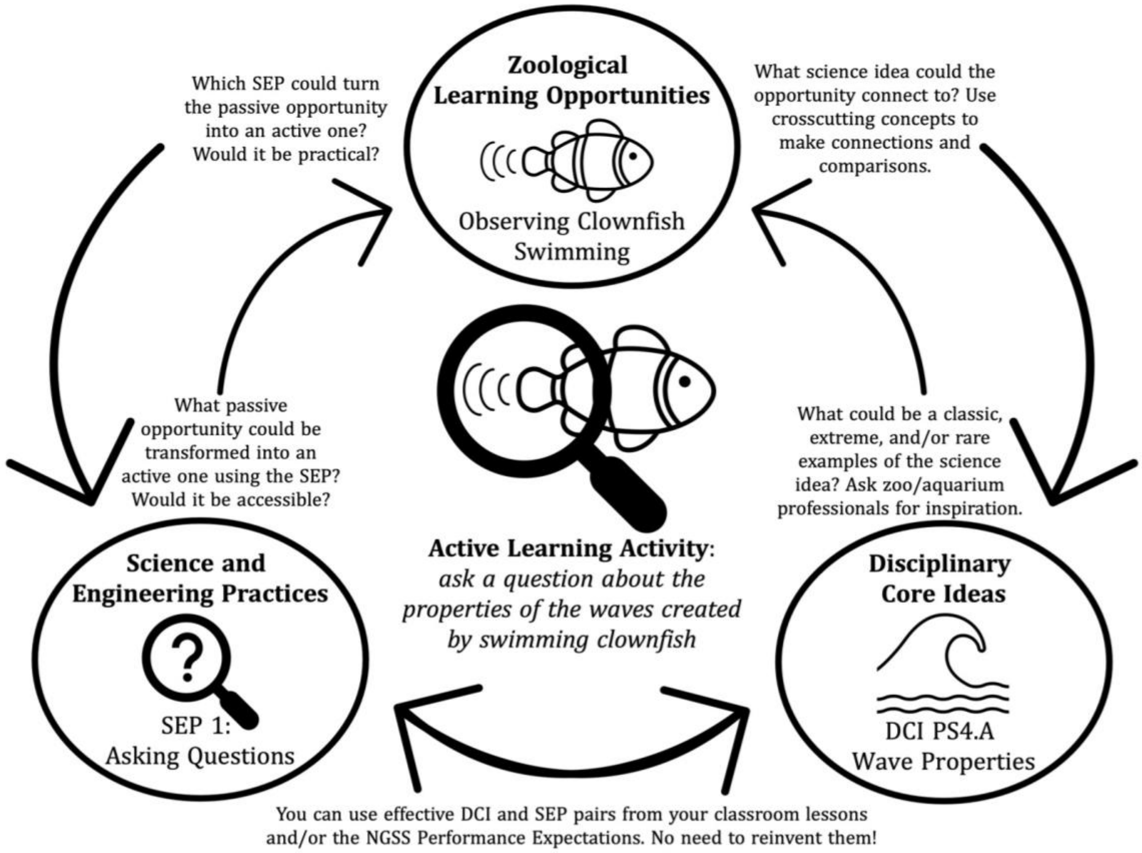


Figure 2.2: The Process of Creating Zoo and Aquarium Active Learning Activities. Start by identifying a zoological learning opportunity of interest, or a Science and Engineering Practice or Disciplinary Core Idea from your standards. Then, make connections by following the arrows and using the corresponding questions to create active learning activities with all three interconnected components. For activity inspiration, refer to STEM Teaching Tool #30 and the Active Learning Activities section of Appendix III.

Differentiation and Scaffolding Strategies

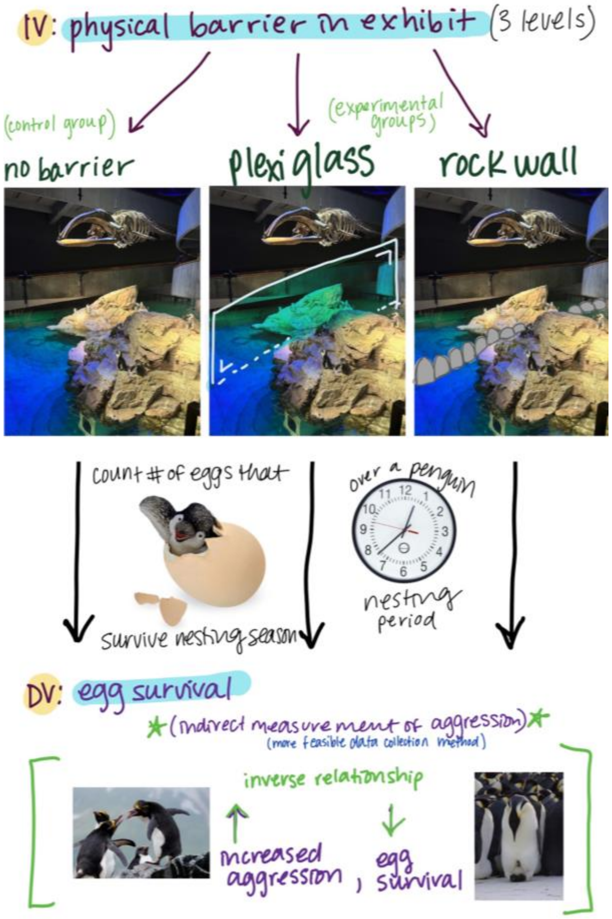
Differentiating instruction is challenging both in and out of the classroom. In the context of NGSS field trips to zoos and aquariums, differentiation can be as simple as providing a variety of activities aligned with different standards that match your students' learning goals. For example, a 6th grade class might include students practicing scientific skills at the 5th, 6th, and 7th grade levels, so creating activities aligned with each of those grade's standards provides appropriate learning opportunities for all of these students. Differentiating instruction might also include providing scaffolding for students who need support to practice scientific skills. STEM Teaching Tool #41 (Penuel *et al.* 2018) contains sentence starters with embedded SEP language that provide excellent scaffolding support for students practicing their scientific skills. Using a combination of these differentiation strategies can help you support your students whether they are striving to achieve, maintain, or exceed grade level standards.

Letting students choose their own learning opportunities can increase their learning and motivation (Katz *et al.* 2007); however, not all students have developed the metacognitive skills they need to choose *appropriate* learning opportunities. Additionally, the diversity of learning opportunities at zoos and aquariums provides an overwhelming menagerie of choices for students, so establishing some structure for their choices is beneficial. For example, an activity could task students with observing foraging behaviors of a species they choose. Alternatively, the activity could task students with observing a certain species but let them choose which behavior to observe. An even more structured activity could task students with observing a certain behavior of a certain species, but such highly structured activities can undermine developing learning autonomy. Offering examples is another strategy that provides both choice and structure (e.g. choose any species (e.g. moray eel, tiger shark, clownfish) and any behavior (e.g. foraging, locomotion, dominance) to observe). The amount of structure you provide should reflect your students' metacognitive skills and the specificity with which you want them to focus on certain standards. For students with a solid understanding of their own NGSS proficiency, encouraging them to choose their own learning activities based on goals to increase mastery of certain standards can help them develop the metacognitive skills they need to be successful learners and scientists.

Assessment Strategies for Both Students and Field Trips

Aligning field trips with the NGSS also facilitates assessment of both student learning and field trip effectiveness. Just as in the classroom, teachers can assess field trip learning by determining whether students have demonstrated the SEP-aligned skill(s) in the context of the aligned DCI(s) for each activity. For a more specific assessment, teachers can also determine the grade level at which students demonstrated proficiency. Utilizing the same NGSS assessment strategies in both classroom and field trip settings facilitates consistent expectations and communication around assessment—a great benefit for students, teachers, and anyone reading their report cards.

Additionally, an individual student's increase in skills can be assessed by comparing their proficiency before and after the field trip. Then, all of the students' assessments can be compiled (e.g. averaged) to assess the field trip's effectiveness. For the new BU animal behavior lab, students were assessed using both Prelab and Postlab assignments. Both assignments were a series of six SEP-aligned questions that guided students through developing an investigation to solve an animal behavior challenge at the New England Aquarium (see Appendix II). For the Prelab, students brainstormed ideas and drafted responses to each question that demonstrated as many of the three SEP-aligned skills as possible (Figure 2.3). For the Postlab (after completing the lab), the students revised their Prelab responses to (hopefully) demonstrate additional skills (Figure 2.3).



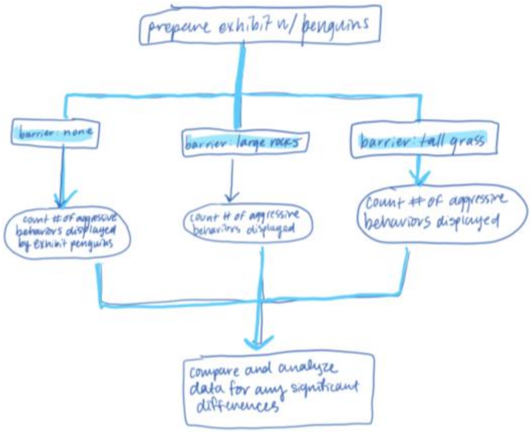


Figure 2.3: Example Student Prelab and Postlab Models. A student's models (above: Prelab, left: Postlab) in response to the guiding question "How do you propose to model your investigation (diagram, flowchart, etc.), and how might your investigation change your model?"—aligned with SEP 2 (Developing and Using Models). Responses to this question (both the models and separate written explanations) were assessed for the following skills: use a model to test the effectiveness of a design or investigation; discuss the limitations of a model to suggest improvements and refinements; construct and annotate representative drawings/diagrams as models.

Each student’s individual increase in skills demonstrated from the Prelab to the Postlab was an indication of their individual progress, whereas the average increase in skills demonstrated across all students was an indication of the lab’s effectiveness. A similar paired pre- and post- assessment strategy could be implemented by any K-12+ teacher using any—ideally preexisting—NGSS-aligned assessment tool both before and after their field trip.

5+ Tips for Successful Zoo and Aquarium Field Trips

1. Be focused and specific.

- Choose highly specific science ideas (DCIs) for students to explore (e.g. ‘color as a communication tool’ instead of ‘animal communication’), and align them with a limited number of skills (SEPs) to practice. Such a narrow scope minimizes the pressure to move on to the next task, which encourages students to engage more deeply.
- Similarly, ask students to engage deeply with only a select few animals. Selecting certain species of interest encourages students to explore those animals in greater depth than during a typical walkthrough zoo/aquarium visit.
- Communicate clear learning goals to students (e.g. complete a certain number of activities, practice/demonstrate a certain number of skills). Ideally, students should create their own learning goals, so they feel responsible for their learning at the zoo/aquarium.

2. Be flexible.

- Anticipate needing to adapt your active learning activities due to weather, animal availability, animal behavior, student interest, etc. Be transparent with students about these challenges, so they understand that successful scientists are adaptable and creative problem solvers that also benefit greatly from thoughtful preparation.
- Create a plethora of active learning activities to provide ample opportunities both for differentiation and to flex with the unpredictable. The more varied your activities are, the more of them will ultimately be successful during the field trip.
- Make the most of unexpected learning opportunities (e.g. new animals, rare behaviors, special events, behind the scenes experiences). Involving students in the process of adjusting plans demonstrates that scientists, especially zoologists, often have to adjust their planned investigations to maximize unique and unexpected opportunities.

3. Think like a zoologist (or ask one!).

- Encourage students to make comparisons between animals (and environments). Making their own observations of similarities and differences can help students better understand and apply complex ideas (e.g. allometry, natural selection, ecological niches).
- Extrapolate scientific ideas beyond the zoo/aquarium. Both the scientific concepts and the actual science projects happening at zoos and aquariums have global relevance. Highlighting these bigger picture connections introduces students to a multitude of mostly unknown scientific careers (e.g. field conservation researcher,

environmental policy advocate, rescue/rehabilitation veterinarian, zoonotic disease epidemiologist).

- Incorporate a little conservation realism (e.g. climate change, pollution, habitat degradation), but sharing too much can feel apocalyptic and demotivating. Share more with students who demonstrate significant passion (and resilience) for conservation work.

4. <u>Celebrate interdisciplinary opportunities.</u>

- Utilize technology and art. Everyone loves photos and videos of animals. Give students opportunities to be creative and incorporate multiple media in their work.
- Highlight people who work at the zoo/aquarium in jobs unrelated to, yet essential for, science (e.g. finance, art, marketing, education). These role models may be especially meaningful for your less enthusiastic science students because they demonstrate that everyone belongs in, and can contribute to, the greater scientific community.
- Incorporate diverse perspectives, cultures, and identities of various scientists. Subsequently, students who share these traits will feel a greater sense of belonging in the scientific community, and all students will better understand the value of diversity in science.

5. <u>Embrace the logistics.</u>

- Give students unstructured time to explore before they start their activities. They will be more focused and efficient if they are familiar with the zoo/aquarium layout and have already run around to see their favorite species.

- Encourage exploration of often-overlooked animals (e.g. waterfowl in an exhibit with a charismatic mammal, hermit crabs in an aquarium with flashy reef fish). Their exhibits will be less crowded, and students will be surprised by how much they can learn about these species.
- Ask students to work together but to also submit their own work. Working together gives students an opportunity to practice collaboration through real-time scientific discussion with peers while exploring safely in groups. Submitting their own work keeps them (and you) accountable for their individual learning progress.

Zoos and aquariums are full of unique learning opportunities that are underutilized by teachers because of the pedagogical challenges surrounding field trips. The NGSS provide an excellent framework for addressing the most troublesome pedagogical challenges: making meaningful connections to existing curricula, creating active learning opportunities, differentiating and scaffolding instruction, and assessing both student learning and field trip effectiveness. Hopefully this guide empowers you to solve these pedagogical challenges by aligning zoo and aquarium field trips with the NGSS, so you can utilize your local zoological institutions to their fullest educational potential. When you do, you and your students might just agree with this BU student:

"I was surprised about just how much there is to learn at the aquarium. It is so much more than just viewing the animals!"

~ BU Student

APPENDICES

Appendix I: ZooU Instructions

Prelab Instructions

The Prelab is your opportunity to brainstorm ideas for your challenge using the following six guiding prompts [Appendix V]. Your responses do not need to be complete thoughts (the Prelab is graded only for completion). After each guiding prompt, there is a self-assessment of a Science and Engineering Practice (SEP) with three related scientific skills [Appendix V]. The Lab activities at the New England Aquarium [Appendix III] are designed to help you learn about aquatic animal behavior while practicing these scientific skills. Afterward, the Postlab will be your opportunity to demonstrate your (hopefully improved) scientific skills by revisiting these six guiding prompts and self-assessing again (for a grade).

Self-assessment: Which of the following skills (related to [insert each SEP]) do you think you demonstrated successfully in your response above? While you do not have to demonstrate these skills in the Prelab, self-assessing critically will help you identify which skills to practice at the aquarium.

Goal Setting: Which Science and Engineering Practices (SEPs) will you focus on practicing while you are at the New England Aquarium? Choose at least two SEPs based on the checkboxes that you left blank in the self-assessments. Use these learning goals when you choose activities to do at the aquarium, so you can practice the skills you will need to demonstrate in your Postlab.

What else do you want/need to learn while you are at the aquarium? This is a good place to note any specific questions you have related to your challenge. Make sure to record any helpful information you find at the aquarium that may not be available online (e.g. how many individuals of a certain species are at the aquarium).

Lab Instructions

To guide your learning at the New England Aquarium (NEAq), each section contains three activities aligned with one of the Science and Engineering Practices (SEPs). Each activity is worth up to one, two, or three points corresponding to the number of scientific skills involved.

To earn full credit for this Lab, complete at least one activity from each section AND earn at least 12 activity points. For example, you might choose to do the 2-point activity in all six sections. Or, you might choose three 1-point activities and three 3-point activities. Or, you might choose to do all three activities from one section, two other 2-point activities and three other 1-point activities from the remaining sections. Refer to your Prelab learning goals to help you choose activities aligned with the specific SEPs you planned to practice.

In consideration of your possible travel time from BU, the Lab is planned to fit within two hours; however, you may stay at the aquarium as long as you want. To finish the Lab within two hours, aim to spend about 10 minutes on 1-point questions, 20 minutes on 2-point questions, and 30 minutes on 3-point questions.

You will earn activity points for demonstrating specific scientific skills (bulleted under each SEP) as you complete activities. If you think you might not earn all of the points from an activity, you may proactively complete additional activities to earn the remaining points; however, any extra activity points (above 12) will NOT count as extra credit.

Collaboration with others and additional research is encouraged; however, you must submit only your own original work. You may complete the sections in any order.

The activities have intentionally broad instructions, so you can investigate the animals and behaviors you find most interesting!

Postlab Instructions

The Postlab questions are identical to the Prelab that you already completed; however, this time your responses must demonstrate your new learning after visiting the New England Aquarium. Additionally, there is a brief survey at the end of the Postlab and an opportunity to contribute your ZooU Prelab, Lab, and Postlab data to research aimed at improving ZooU for future learners [Appendix IV].

The Postlab is your opportunity to revise your initial challenge ideas and apply your new aquarium knowledge/skills to your proposal. Your responses to the six guiding prompts [Appendix V] should now be complete thoughts as you would compose them for a research proposal. Like in the Prelab, each guiding prompt is followed by a self-assessment of a Science and Engineering Practice (SEP) and three related scientific skills. You can earn up to one point for each of the three skills that you demonstrate in each of your six responses (i.e. up to 18 points total).

Self-Assessment: Which of the following skills (related to [insert each SEP]) do you think you demonstrated successfully in your response above? While your self-assessment is not graded, you should use this checklist to assess and revise your response to demonstrate as many of these skills as you can (each worth up to one point).

Appendix II: ZooU Challenges

Aquarium Challenges

Penguin Nesting Season Aggression

Springtime is nesting season for the New England Aquarium (NEAq) penguins. Just like their wild conspecifics, the NEAq penguins must navigate their neighbors to find the perfect spot to raise their chick, and there is inevitably competition for the best spots. Since each egg is an essential part of the survival of its species, the NEAq penguin keepers want to minimize aggression between parents that can endanger the eggs. The keepers hope that installing barriers between nesting penguins will reduce aggression, but they (and the aquarium visitors) still need to see the penguins. The challenge is to propose a scientific investigation of at least two possible barriers that might reduce aggression during nesting season while preserving viewing opportunities for both keepers and visitors.

Tinbergen: Mechanism (static and proximate)

NGSS: LS1- From Molecules to Organisms: Structures and Processes

Sea Turtle Rescue, Rehab, and Release

The New England Aquarium (NEAq) is a leader in rescuing, rehabilitating, and releasing sea turtles–about 300 per year! A major challenge for sea turtle rehabilitators is providing care while avoiding habituation to humans. Habituated sea turtles that are released to the wild are less likely to survive because they do not have the necessary foraging skills, and they recognize humans as a source of food. As the hungry sea turtles approach humans looking for food, they often have deadly encounters with boats, nets, domestic animals, or humans. The rehabilitators are looking for a solution that helps them continue to provide excellent care for the sea turtles while encouraging their natural foraging behaviors. The challenge is to propose a scientific investigation of at least two possible apparatuses that might encourage the sea turtles' natural foraging behaviors while facilitating feeding and medication administration.

Tinbergen: Adaptation (static and ultimate)

NGSS: LS2- Ecosystems: Interactions, Energy, and Dynamics

Shark Learning Behavior Plasticity

In the fall of 2017, a New England Aquarium (NEAq) aquarist discovered that an epaulette shark had reproduced via parthenogenesis, an extremely rare (among vertebrates) reproductive process where females produce clones of themselves (i.e. without DNA from a male). Since the baby sharks' DNA is identical, any variation in their behavior should be due to their environment. The sharks' aquarists are curious to learn if the young sharks have developed any learning differences over the past five years from their various environments. The challenge is to propose a scientific investigation of at least two possible devices that might highlight differences in learning behaviors between the sharks.

Tinbergen: Ontogeny (dynamic and proximate)

NGSS: LS3- Heredity: Inheritance and Variation of Traits

Pinniped Environmental Enrichment

In 2009, the New England Aquarium (NEAq) opened the New Balance Foundation Marine Mammal Center, an enclosure for Northern Fur Seals and California Sea Lions. The NEAq is also home to Harbor Seals, who live in a separate enclosure. Some zoos and aquariums are now creating networks of enclosures, so animals can move between them for environmental enrichment. While the pinniped (seals and sea lions) enclosures at the NEAq were not originally designed with a connection between them, the keepers think a connection could benefit all three species. The challenge is to propose a scientific investigation of at least two possible connections between the pinniped enclosures that might provide environmental enrichment benefits for all three species.

<u>Tinbergen</u>: Phylogeny (dynamic and ultimate)

<u>NGSS</u>: LS4- Biological Evolution: Unity and Diversity

<u>Requirements for All Challenges</u>:

1. Your investigation must include a control (no design solution implemented) and test at least two alternate design solutions.
2. Your design solutions must be made from animal-safe materials, be reusable and portable, and look natural in the animals' enclosure(s).

Appendix III: ZooU Active Learning Activities and Learning Reflection

Active Learning Activities

(aligned with numbered SEPs and lettered skills in Appendix V)

Note: The activity number also indicates the number of skills aligned with the activity (e.g. activity 1.3 is aligned with three skills within SEP 1).

1.1: Take one photo of one species at the aquarium. Read all the signs around its enclosure. Then, **write three questions** about its behavior that you cannot find answers to on the signs but that you could explore with a scientific investigation. **A**

1.2: Take one photo of a food source in an exhibit. Identify which species might use that food source and observe one individual from one of those species for 5 minutes; **record all behaviors** you observe. **Take one photo** of the individual you observed. Based on your observations, **write three questions** about the species' foraging behavior that could be explored scientifically through additional observation sessions. **AB**

1.3: Take one photo of a sign that describes a species at the aquarium facing a specific conservation threat. **Write two questions**; a clarifying question about information on the sign and a question related to the species behavior/conservation threat not answered on the sign. Observe the species to identify one natural behavior that causes the species to be at risk due to this conservation threat and **take one photo** of an individual doing that behavior. **Write one scientific question** that, if explored, would help demonstrate the connection between the behavior and the conservation threat. Finally, **take one photo** of a physical representation of the conservation threat at the aquarium (i.e. the actual threat, not the sign describing it). **ABC**

2.1: Take one photo of an aquarium sign displaying a model of animal behavior. Aquarium visitors often wonder if animal behavior is different in the aquarium compared to the wild. **Describe three reasons** why the specific modeled behavior might be different for wild animals compared to animals in the aquarium. **A**

2.2: Choose a species at the aquarium and observe one individual's behavior for 5 minutes; **record all behaviors** you observe. **Take two photos** of behaviors: one that could be evidence for and one that could be evidence against a classic animal behavior model (e.g. optimal foraging, socioecological, hawk-dove). **Explain one way** that the model might (or might not) be useful in exploring the species' behavior further. **AB**

2.3: Find three species from different animal classes (e.g. mammals, birds, reptiles, amphibians, bony fish, cartilaginous fish). **Take three photos**: one of each species doing the same behavior. **Create a model** (e.g. diagram, drawing, flowchart, etc.) highlighting at least three similarities and three differences in the behavior across the three species as evidence either for or against these species' common ancestry. **Describe one limitation** of your model and something you could do to address it. **ABC**

3.1: Take one photo of an aquarium sign with a question. Identify the independent and dependent variables you would investigate to explore the question scientifically. **Formulate two hypotheses/predictions** (one null and one alternate) that could describe the relationship between these variables. Be sure to include at least one relevant control variable/group in your hypotheses/predictions. **A**

3.2: Ask an aquarium staff member what animal behavior data they collect, how they collect the data, and what they currently do with the data. Then, **take two photos**: one with the aquarium staff member and one with their favorite aquarium species. **Formulate one hypothesis/prediction** about that species' behavior that could be explored using the aquarium's research methods. **Describe three similarities and three differences** between the methods used at the aquarium and those used in field/laboratory settings to highlight why collaboration between these three research settings is important. **AB**

3.3: Take one photo of an animal doing a behavior you find interesting. **Formulate one hypothesis/prediction** about how the behavior relates to the species' environment. **Describe the research methods** you could implement within a five-minute observation period to collect data to support/refute your hypothesis/prediction. Using your methods, collect data for five minutes and **take one photo** of an individual you observed. Identify one benefit and one drawback of your methods and **revise your methods** accordingly. Using your revised methods, collect data for an additional five minutes and **take one photo** of an individual you observed. Further **revise your methods** so you could efficiently collect enough data to make a significant claim about the behavior. **ABC**

4/5.1: Ask an aquarium staff member how math is a part of their daily work. **Take one photo** with the aquarium staff member. **Explain the math** that the staff member does to highlight the importance of math as a tool for doing and communicating science. **A**

4/5.2: In many exhibits, aquarists consider the behavior of the species when determining how many individuals to house in the enclosure. Find an enclosure housing at least five species with observably different behaviors (e.g. locomotion, foraging, circadian rhythm). Then, count the number of individuals of each species in each exhibit. To highlight how the species' behavior is related to the number of individuals in the exhibit, **make one chart/graph** of the populations by species. **Take two photos**: one of each of the two species with the most different population numbers and **describe one behavioral difference** between them that may have impacted how many individuals were housed in the enclosure. **Explain why** collecting this data for every exhibit would provide greater evidence that the aquarists consider behavior when planning species populations. **AB**

4/5.3: Choose an exhibit with two separate areas (e.g. land/water, light/dark, shallow/deep, etc.) and at least 10 individuals of one species. **Predict the percent** (with reasoning) of individuals of a certain species that will be in each area. **Take one photo** of the enclosure and count the actual number of individuals found in each area. **Take two additional photos** both five and ten minutes later and recount the individuals in each area. **Create a chart/graph** of your results. **Describe the statistics** you would calculate to summarize your data and assess if additional data were needed to support a strong conclusion. **ABC**

6/7.1: One model of foraging strategies is niche partitioning, where species specialize by foraging in different areas or for different food to minimize competition. Find an example of two (or more) species niche partitioning at the aquarium. **Take one photo** that includes both species and highlights their niches. **Explain why** the foraging strategies of these species are an example of niche partitioning. **A**

6/7.2: Find an aquarium sign that makes a claim related to a species' behavior. Observe the species for five minutes and **record every behavior** you observe. Then, sort these behaviors into two categories: behaviors that support the claim and behaviors that do not support the claim. **Take two photos**: one a photo of an individual doing a behavior from each category. **Refine the claim** on the aquarium sign in your own words. **BC**

6/7.3: A classic explanation of mating strategies is that males fight for access to females and females are choosy about their mates; however, there are many other mating strategies. **Take three photos**: one photo of each of three species (a male and female of each) that do not fit this narrow explanation. Then, **write a new general explanation** of mating strategies that better reflects the diversity you discovered using the species you found as evidence and include discussion of the possible limitations of your new explanation. **ABC**

8.1: Summarize and cite a description of an animal behavior from a peer-reviewed scientific journal article. **Take one photo** of an individual (or group) at the aquarium doing the behavior described in the article. **A**

8.2: Find a popular article (i.e. of news/social media origin) about the behavior of a species at the aquarium. **Take two photos**: one of an individual of that species in the aquarium that supports and one that refutes a claim made in the article. **Write a response** to the article for a news/social media audience using your photos as evidence. **AB**

8.3: Animal intelligence is a highly researched and debated topic in animal behavior. **Take three photos**: one of each of three species at the aquarium that are considered especially smart by aquarium visitors. **Discuss three reasons** why visitors consider these animals to be smart to highlight the benefits/drawbacks of anthropomorphism in studying animal behavior. **Summarize and cite evidence** supporting these species' intelligence from at least one peer-reviewed scientific journal article. **ABC**

Learning Reflection

Summarize and reflect on your learning at the aquarium. Below are some possible reflection prompts, but you are encouraged to share any thoughts you have related to learning at the aquarium.

- Why did you choose each activity, and what did you learn from each one?
- Did you accomplish your learning goals from the Prelab?
- Were any Science and Engineering Practices (SEPs) more difficult than anticipated?
- Did you answer any other questions from the Prelab related to your challenge?
- What unexpected obstacles did you overcome?
- What surprised you about learning at the aquarium?

Appendix IV: ZooU Experience Survey and Informed Consent for Research

ZooU Experience Survey

Thank you for your participation in the ZooU Animal Behavior Module! Please take a moment to anonymously answer these questions about your experience. Your feedback will help us improve ZooU for future learners.

Please indicate how you feel about the following statements:

(Select one: Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree)

Q1: The ZooU Activities gave me an opportunity to explore my own interests.

Q2: The ZooU Activities gave me an opportunity to demonstrate my new learning.

Q3: I learned more doing the ZooU Activities than I would have during a regular visit to the aquarium.

Q4: The ZooU Activities provided unique learning opportunities that augmented those in regular labs.

Q5: I learned about animal behavior doing the ZooU Activities.

Q6: I enjoyed doing the ZooU Activities.

Please provide additional feedback and/or suggestions that could help us improve ZooU:

ZooU Research Study Informed Consent

The ZooU Animal Behavior Module that you have just completed as part of CAS/MET BI 407/607 (Animal Behavior) is a new educational tool currently being studied by Ben Recchia, a BU graduate student in biology advised by Dr. Kathryn Spilios. The data you have generated by completing the ZooU Prelab, Lab, and Postlab is valuable and could help improve ZooU for future learners; however, this data belongs to you, so it will only be used if you give your consent.

You are not required to share your data with the ZooU Research Study. Choosing not to share your data will not impact your course grade, relationship with your course's teaching team, or educational experience in any way. There are neither benefits nor risks of sharing your data, and no additional time is required because you have already generated all of the data requested. Grades are not part of the ZooU Research Study, so your grades will not be shared with the researchers. All data is gathered confidentially and password-protected in BU's Google Drive and Blackboard. Downloaded data will be password-protected on the researchers' computers, and individual identifiers collected will be removed through aggregation and/or anonymization once the data has been paired (e.g. Prelab and Postlab matched by student). The Institutional Review Board (IRB) at BU may review the data to verify that this research study was conducted ethically.

Please contact Ben Recchia at *brecchia@bu.edu*, Dr. Spilios at *kspilios@bu.edu*, or Boston University Charles River Campus IRB at (617) 358-6115 with any questions or concerns. The *IRB Office webpage* has information where you can learn more about being a participant in research, and you can also complete a Participant Feedback Survey.

Read the following statement and choose below:

I am at least 18 years old, I understand the information above, and I consent to sharing my ZooU Prelab, Lab, and Postlab confidentially for research that will improve ZooU for future learners.

- ○ Yes, I consent.
- ○ No, I do not consent.

Type your full name (First Name and Last Name as recognized by BU) to electronically sign your consent choice.

Your electronic signature will be automatically date/time stamped when submitted.

Electronic Signature: ____

Thank you for your contribution to zoology education at zoos and aquariums!

Appendix V: ZooU NGSS-Aligned Assessment

Guiding Prompts (underlined)

(aligned with the NGSS SEPs (numbers), Skills (letters), and Assessment Criteria)

What research question do you propose to focus your investigation and why?

SEP 1: Asking questions (for science) and defining problems (for engineering)

A. Identify and originate scientific questions that can be answered empirically

Criteria: relates multiple variables and uses scientific language

B. Contextualize questions through connections to scientific observations

Criteria: connects to relevant observations and explains their importance

C. Ask probing questions to understand known and identify unknown conditions

Criteria: inspires further investigation and demonstrates scientific curiosity

How do you propose to model your investigation (diagram, flowchart, etc.) and how might your investigation change your model?

SEP 2: Developing and using models

A. Use a model to test the effectiveness of a design or investigation

Criteria: represents experimental design and includes explanation of representation

B. Discuss the limitations of a model to suggest improvements and refinements

Criteria: identifies limitations and addresses limitations of representation

C. Construct and annotate representative drawings/diagrams as models

Criteria: represents designs and includes explanation of representation

What are your proposed hypotheses/predictions and data collection methods?

SEP 3: Planning and carrying out investigations

A. Formulate a hypothesis/prediction using independent, dependent, and controlled variables

Criteria: incorporates multiple variables and predicts a directional relationship

B. Determine and implement appropriate investigatory methods for the data qualities needed

Criteria: describes plans for variable manipulation (and control) and measurement

C. Establish data quantity goals to generate an appropriate level of precision

Criteria: proposes data quantity goals and includes explanation/justification of them

How do you propose to analyze your data mathematically/statistically and represent your data tabularly/graphically?

SEP 4: Analyzing and interpreting data

SEP 5: Using mathematics and computational thinking

A. Evaluate the strength of a conclusion mathematically/statistically based on the dataset

Criteria: includes appropriate statistical test(s) and an explanation(s) of their use

B. Represent data in tables and graphs to identify patterns that could address hypotheses

Criteria: visualizes data according to scientific standards and addresses hypotheses

C. Analyze data using mathematics/statistics to summarize trends that could address hypotheses

Criteria: mathematically processes raw data and addresses hypotheses

<u>How do you propose to interpret your results regarding your hypotheses/predictions and explain your findings in the context of animal behavior?</u>

SEP 6: Constructing explanations (for science) and designing solutions (for engineering)

SEP 7: Engaging in argument from evidence

A. Construct explanations based on scientific theories, models, and evidence

Criteria: connects to broader animal behavior concepts and includes explanation

B. Use data to evaluate hypotheses/predictions and suggest possible revisions

Criteria: uses results to test hypotheses and uses hypotheses to address challenge

C. Identify and address limitations of explanations using evidence

Criteria: identifies limitations and addresses limitations of the designs/investigation

<u>How do you propose to communicate your findings and recommendations to the aquarium (an audience with varied scientific backgrounds) while incorporating scientific literature?</u>

SEP 8: Obtaining, evaluating, and communicating information

A. Explain the key ideas communicated through scientific text

Criteria: summarizes scientific text and explains relevance to challenge

B. Use words, figures, and mathematical expressions to communicate scientific understanding

Criteria: communicates using multiple methods and considers diverse audiences

C. Engage critically with scientific literature and media

Criteria: discusses supporting/opposing evidence and explains relevance to the challenge

Assessment Scores

Self-assessment:

0 points = skill not demonstrated

1 point = skill demonstrated

Researcher Assessment:

0 points = no evidence of skill

0.5 points = at least one criterion met as evidence of skill, but requires clarification of application to the designs/investigation

1 point = both criteria met as evidence of skill, and appropriate application to the designs and investigation is demonstrated

Appendix VI: Statistical Analyses by Figure

Figure 1.1:

Table A.1: Chi-squared p Values for Positive Response Rates by Survey Question

	Chi-squared p value
Q1	1.39E-04 (Significant)
Q2	1.75E-06 (Significant)
Q3	6.82E-07 (Significant)
Q4	1.26E-07 (Significant)
Q5	3.95E-12 (Significant)
Q6	1.00E-01 (Not significant)

Chi-squared Conditions

☑ Categorical variables: question number and responses are both categorical

☑ Independent observations: data were collected from each student independently

☑ Mutually exclusive cells: students choose only one response per question

☑ Count >5 for >80% of cells: minimum count in a cell was 7 students

Figure 1.2:

Table A.2: T-test p and Cohen's D Values for Change in Skills by SEP

	Self-Assessment	**Researcher Assessment**	
	T-test p value	**T-test p value**	**Cohen's D value**
SEP 1	1.32E-15 (Significant)	4.58E-09 (Significant)	0.92 (Large)
SEP 2	1.22E-11 (Significant)	5.49E-09 (Significant)	0.74 (Medium)
SEP 3	6.22E-11 (Significant)	8.55E-09 (Significant)	0.80 (Medium)
SEP 4/5	1.50E-08 (Significant)	1.26E-04 (Significant)	0.38 (Small)
SEP 6/7	1.34E-13 (Significant)	7.67E-08 (Significant)	0.64 (Medium)
SEP 8	4.06E-12 (Significant)	4.31E-09 (Significant)	0.84 (Large)
Total	2.79E-18 (Significant)	1.54E-17 (Significant)	1.00 (Large)

T-test (paired, two-tailed) and Cohen’s D Conditions

☑ Independence: data were collected from each student independently

☑ Normality: N=72 (>30)

☑ Homogenous variance: maximum variance ratio = 2.93, which is less than 4

Table A.3: ANOVA Values for Change in Skills Across Challenges

ANOVA	**Count**	**Sum**	**Average**	**Variance**
Penguin Nesting Season Aggression	24	72.5	3.02	4.75
Sea Turtle Rescue, Rehab, and Release	30	77.5	2.58	2.98
Shark Learning Behavior Plasticity	14	33.5	2.39	5.58
Pinniped Environmental Enrichment	4	16.5	4.13	9.40

Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	11.89	3	3.96	0.91	0.44	2.74
Within Groups	296.5	68	4.36			
Total	308.44	71				

ANOVA Conditions

☑ Independence: data were collected from each student independently

☑ Normality: Shapiro-Wilk tests (p>0.10)

☑ Equal variance: F=0.91

Figures 1.3 and 1.4:

Pearson’s Correlation Conditions

☑ Measurement: data collected in intervals of whole skills

☑ Linear relationship: nonlinear, so correlation generally qualifies trends only

☑ Normality: N>30 and Shapiro-Wilk tests (p>0.10)

☑ Related pairs: both data in a pair are from the same student

☑ No outliers: there are no unreasonable outliers in the context of the study

T-test (two-tailed) Conditions

☑ Independence: data were collected from each student independently

☑ Normality: N>30 and Shapiro-Wilk tests (p>0.10)

☑ Homogenous variance: variance ratio = 2.43, which is less than 4

Figure 1.5:

Table A.5: Mann-Whitney p Values for Change in Skills by SEP

	Times SEP was Practiced	Number of Students	Mean Change in Skills	Mann-Whitney p value
SEP 1	1	19	0.45	<0.23 (Not significant)
	2	15	0.40	
	3	23	0.65	
SEP 2	1	25	0.50	<0.40 (Not significant)
	2	19	0.26	
	3	26	0.65	
SEP 3	1	23	0.37	<0.08 (Significant)
	2	7	0.93	
	3	32	0.67	
SEP 4/5	1	21	0.21	<0.14 (Not significant)
	2	18	0.25	
	3	27	0.59	
SEP 6/7	1	32	0.31	<0.04 (Significant)
	2	27	0.35	
	3	13	0.88	
SEP 8	1	39	0.41	<0.02 (Significant)
	2	15	0.37	
	3	16	0.94	
Overall	1	153	0.35	<0.002 (Significant)
	2	101	0.55	
	3	131	0.60	

Mann-Whitney Test (one-tailed) for Two Independent Samples Conditions

☑ Independence: data were collected from each student independently

☑ Homogenous variance: maximum variance ratio = 2.94, which is less than 4

Figures 1.6 and 1.7:

Table A.5: Summary Values for Practice, Change in Skills, and Initial Deficit by SEP

	Relative Practice		Relative Change in Skills		Relative Initial Deficit	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
SEP 1	20%	10%	23%	43%	12%	4%
SEP 2	16%	7%	16%	33%	18%	3%
SEP 3	19%	8%	21%	29%	16%	4%
SEP 4/5	18%	8%	12%	29%	13%	5%
SEP 6/7	13%	6%	14%	21%	21%	4%
SEP 8	14%	8%	14%	39%	20%	3%

Standard Deviation Conditions

☑ Continuous: relative practice, change in skills, and initial deficit are continuous

☑ Normality: N=72 (>30)

Appendix VII: ZooU Pilot Study

In the summer of 2022, students who enrolled in Boston University’s introductory biology and animal behavior courses (CAS/MET BI 107/407/607) helped pilot the new ZooU lab experience. Based on feedback from the students and teaching teams of these courses, the written content of ZooU was revised for clarity and several structural modifications were implemented as described in Table A.6:

Table A.6: Differences Between the Pilot and Revised Versions of ZooU

Pilot ZooU Summer 2022	Revised ZooU Fall 2022	Explanation of Change
Students visited the aquarium during their regularly scheduled lab session with their peers and teaching/learning assistants.	Students visited the aquarium on their own at any time within a nine-day period.	Students could choose to visit the aquarium at a time that was convenient for them and when there were fewer other visitors. Students could also choose to spend extra time at the aquarium.
ZooU was divided into two Prelabs, two Labs, and one Postlab.	ZooU was divided into one Prelab, Lab, and Postlab.	Streamlining clarified due dates and assignment expectations, but removed the peer collaboration component.

The self-assessments of SEPs were scored subjectively on a scale from 1-5.	The self- and researcher assessments of SEPs were scored more objectively using criteria to count specific skills demonstrated for each SEP.	The added assessment detail helped students more accurately self-assess and gave them a checklist of skills to demonstrate in their responses.
The Lab included 24 active learning activities, and students were tasked with completing at least eight of them.	The Lab included 18 active learning activities, and students were tasked with completing at least six of them.	Decreasing the number of activities required gave students additional time/effort to allocate to each activity.
All eight SEPs were assessed individually.	SEPs 4/5 and 6/7 were assessed together.	Combining SEPs reduced the total amount of lab work and facilitated both practice and demonstration of the skills aligned with these SEPs.

The experience survey included the following questions: 1. ZooU gave me an opportunity to customize my learning 2. ZooU provided opportunities to learn that I would not have had otherwise 3. ZooU helped me challenge myself academically 4. Doing the ZooU Activities helped me complete the Challenge 5. I learned about animal behavior doing the ZooU Activities 6. I enjoyed doing the ZooU Activities	Pilot survey questions 1 and 2 were subdivided: 1.1 ZooU gave me an opportunity to explore my own interests (new Q1) 1.2 ZooU gave me an opportunity to demonstrate my new learning (new Q2) 2.1 I learned more doing the ZooU Activities than I would have during a regular visit to the aquarium (new Q3) 2.2 The ZooU Activities provided unique learning opportunities that augmented those in regular labs (new Q4) Pilot questions 3 and 4 were removed. Pilot questions 5 and 6 were retained.	Subdividing pilot survey questions 1 and 2 provided greater detail for discussing these concepts. Pilot question 3 was removed because students may not want help being "academically challenged", or they may have interpreted the question as "was ZooU challenging/difficult". Pilot question 4 was removed because the same information was gleaned from assessing the Postlab responses, and this study was primarily focused on the educational impact of the activities not the challenges.

BIBLIOGRAPHY

Association of Zoos and Aquariums. 2022. “Annual Survey.” https://www.aza.org/zoo-and-aquarium-statistics?locale=en

Association of Zoos and Aquariums. 2023. “Currently Accredited Zoos and Aquariums.” https://www.aza.org/find-a-zoo-or-aquarium?locale=en

Deslauriers L, McCarty LS, Miller K, Callaghan K, and Kestin G. 2019. “Measuring actual learning versus feeling of learning in response to being actively engaged in the classroom.” *Proceedings of the National Academy of Sciences*. 116: 19251-19257. https://doi.org/10.1073/pnas.1821936116

Dunning D. 2011. “Chapter five - The Dunning–Kruger Effect: On Being Ignorant of One's Own Ignorance.” In *Advances in Experimental Social Psychology*. Academic Press: 247-296. https://doi.org/10.1016/B978-0-12-385522-0.00005-6

Freeman S, Eddy SL, McDonough M, Smith MK, Okoroafor N, Jordt H, and Wenderoth MP. 2014. “Active learning increases student performance in science, engineering, and mathematics.” *Proceedings of the National Academy of Sciences*. 111: 8410-8415. https://doi.org/10.1073/pnas.1319030111

Gao N, DiRanna K, and Fay MTC. 2022. *The Impact of COVID-19 on Science Education: Early Evidence from California*. Public Policy Institute of California: https://www.ppic.org/?show-pdf=true&docraptor=true&url=https%3A%2F%2Fwww.ppic.org%2Fpublication%2Fthe-impact-of-covid-19-on-science-education%2F

Hoeg DG and Bencze JL. 2017. “Values Underpinning STEM Education in the USA: An Analysis of the Next Generation Science Standards.” *Science Education*. 101: 278-301. https://doi.org/10.1002/sce.21260

Katz I and Assor A. 2007. “When Choice Motivates and When It Does Not.” *Educational Psychology Review*. 19: 429-442. https://doi.org/10.1007/s10648-006-9027-y

Krogh A. 1929. “The Progress of Physiology.” *The American Journal of Physiology*. 90: 243-251. https://doi.org/10.1152/ajplegacy.1929.90.2.243

Mellish S, Ryan JC, Pearson EL, and Tuckey MR. 2019. “Research methods and reporting practices in zoo and aquarium conservation-education evaluation.” *Conserv Biol*. 33: 40-52. https://doi.org/10.1111/cobi.13177

Miranda R, Escribano N, Casas M, Pino-del-Carpio A, and Villarroya A. 2023. “The Role of Zoos and Aquariums in a Changing World.” *Annual Review of Animal Biosciences*. 11: 287-306. https://doi.org/10.1146/annurev-animal-050622-104306

National Research Council. 2013. *Next generation science standards: For states, by states*. https://nap.nationalacademies.org/catalog/18290/next-generation-science-standards-for-states-by-states

National Research Council. 2015. *Guide to Implementing the Next Generation Science Standards*. The National Academies Press: Washington, DC. https://doi.org/10.17226/18802

Olimpo JT and Esparza D. 2020. "Active Learning and Conceptual Understanding in Biology." In *Active Learning in College Science: The Case for Evidence-Based Practice*. Springer International Publishing: Cham. 43-57. https://doi.org/10.1007/978-3-030-33600-4_4

Patrick PG and Caplow S. 2018. "Identifying the foci of mission statements of the zoo and aquarium community." *Museum Management and Curatorship*. 33: 120-135. https://doi.org/10.1080/09647775.2018.1438205

Pellegrino JW. 2013. "Proficiency in Science: Assessment Challenges and Opportunities." *Science*. 340: 320-323. https://doi.org/10.1126/science.1232065

Penuel WR and Vanhorne K. 2018. "STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction." UW Institute for Science + Math Education: Published. https://stemteachingtools.org/assets/landscapes/STEM-Teaching-Tool-41-Cross-Cutting-Concepts-Promptsv2_2021-10-07-214154.pdf

Pollio HR and Beck HP. 2000. "When the tail wags the dog: Perceptions of learning and grade orientation in, and by, contemporary college students and faculty." *The Journal of Higher Education*. 71: 84-102. https://doi.org/10.1080/00221546.2000.11780817

Schilbert J and Scheersoi A. 2023. "Learning outcomes measured in zoo and aquarium conservation education." *Conservation Biology*. 37: e13891. https://doi.org/10.1111/cobi.13891

Smith A and Chestnutt C. 2021. "Differentiation for Equity." *Journal of Higher Education Theory & Practice*. 21: https://doi.org/10.33423/jhetp.v21i6.4390

Spooner SL, Jensen EA, Tracey L, and Marshall AR. 2023. "Why we (still) do not know the educational impact of zoos and aquariums: Assessing current evaluation methods and ways to improve them." *Zoos and Aquariums in the Public Mind*. 79-95. https://doi.org/10.1007/978-3-030-84942-9_6

Tinbergen N. 1963. "On the aims and methods of ethology." *Zeitschrift für tierpsychologie*. 20: 410-433. https://doi.org/10.1111/j.1439-0310.1963.tb01161.x

Vanhorne K, Penuel WR, and Bell P. 2016. "STEM Teaching Tool #30: Integrating Science Practices Into Assessment Tasks." UW Institute for Science + Math Education: Published. https://stemteachingtools.org/assets/landscapes/STEM-Teaching-Tool-30-Task-Formats-for-3D-Assessment-Design-v2.pdf

Williams ML. 2021. *How out of school time programs at field-based science institutions impact STEM Pathway Choices: urban minority youth and underrepresented STEM fields*. Concordia University Chicago. https://search.proquest.com/openview/0ea28c7845c35558a405d78a748c3ad6/1?pq-origsite=gscholar&cbl=18750&diss=y

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