WHAT DO STUDENTS IN BIOLOGY COURSES UNDERSTAND AND APPRECIATE ABOUT STATISTICS

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Learning standards for biology courses have called for increasing statistics content. Little is known, however, about biology students' attitudes towards statistics content and what students actually learn about statistics in these courses. This study aims to uncover changes in attitudes and content knowledge in statistics for students in biology courses. One hundred thirty-four introductory biology students across five different instructors participated in a pre-post study of statistical thinking and attitudes toward statistics. Students performed better on the statistics conceptual inventory at the end of a biology course compared to the beginning. Student attitudes showed no change. These preliminary results suggest the potential importance for laying a conceptual foundation in statistics prior to taking biology courses with little formal statistical instruction.

INTRODUCTION

The practice of biology has transitioned over the last two decades to become increasingly reliant on quantitative approaches to drawing conclusions from data (National Research Council, 2009). Widespread access to publicly available large-scale datasets, frequent generation of medium to large-scale datasets within classroom settings, and pervasive access to high-performance computing means that the teaching of biology now faces significant questions about how it will integrate data-informed thinking (statistical thinking) into its curricula (Brewer & Smith, 2011). In response, the undergraduate biology community in the United States has chosen to include descriptive statistics and hypothesis testing (e.g., chi-square test) as part of its requirements for students (Aikens & Dolan, 2014) in introductory biology courses (Bio 101, the Advanced Placement Biology equivalent course which includes a set of course objectives utilized at institutions across the United States as a benchmark for course objectives). Thus, an introduction to both descriptive and inferential statistical thinking is now standard practice for the more than 1.2 million students from the United States who take introductory biology each year. Despite the large numbers of students in introductory biology courses, there is a dearth of active discussion about teaching and assessment when integrating statistical thinking into biology courses.

Concurrently, the statistics education community has established guidelines (Guidelines for Assessment and Instruction in Statistics Education (GAISE)) for assessment and instruction in introductory statistics courses that are based on published educational research (GAISE College Report ASA Revision Committee, 2016). These recommendations are to (a) teach statistical thinking, (b) focus on conceptual understanding, (c) integrate real data with a context and purpose, (d) foster active learning, (e) use technology to explore concepts and analyze data, and (f) use assessments to improve and evaluate student learning. Furthermore, there is a prominent movement to embrace GAISE by using modern, computationally intensive statistical methods (e.g., simulation, randomization tests, and bootstrapping) and using active learning pedagogical strategies. These methods have shown preliminary evidence of improving student learning in introductory statistics courses (Chance et al., 2016; Cobb, 2007; Tintle et al., 2011, 2012, 2014).

The GAISE guidelines are now well-accepted 'best practices' in statistics education circles and were developed by statisticians with a focus on introductory statistics courses. It is unknown how, or if, these guidelines necessarily represent best practices when teaching statistics in introductory biology courses. Currently, limited venues exist to discuss and coordinate best practices for the teaching and assessment of statistical thinking for biology students—many of whom may never take an introductory statistics course or will take such a course at a very different time than their introductory biology course.

The Statistical Thinking in Undergraduate Biology (STUB, n.d.) network was created to help address these gaps. The network consists of both introductory biology instructors and statistics educators and was created to discuss, reflect on, and coordinate the teaching of statistics in introductory

In S. A. Peters, L. Zapata-Cardona, F. Bonafini, & A. Fan (Eds.), *Bridging the Gap: Empowering & Educating Today's Learners in Statistics. Proceedings of the 11th International Conference on Teaching Statistics (ICOTS11 2022), Rosario, Argentina.* International Association for Statistical Education. iase-web.org

biology courses by offering workshops, modules, and coordinated assessment. As part of network initiatives, a pilot assessment project was recently conducted recruiting biology instructors in the STUB network to have their students participate in pre- and post-course conceptual and attitudinal assessments in statistics to provide initial documentation of statistical learning in introductory biology courses.

METHODS

Instructors in the STUB network were invited to participate in a pilot project assessing biology students on statistical outcomes. Five instructors from three different institutions agreed to participate. Institutions included two smaller liberal arts college and one large state university. Students in these classes were encouraged (typically through a homework extra credit grade) to take both a pre-test (during the first or second week of the semester) and a post-test (during the last week of the semester or during final exam week). One hundred and eighty-eight students in introductory biology courses (first biology course) completed the pre-test, representing most students in the participating courses. After applying standard data cleaning that we have used before (Chance et al., 2018), 134 students had complete pre- and post-course data and were included in the analysis. All data was collected pre-pandemic from face-to-face instructional courses. Students took shortened versions of both conceptual and attitudes scales used before in statistics courses (Tintle & VanderStoep, 2018). Institutional review board approval was obtained at Dordt University, and all students provided consent to participate in the research study.

Conceptual Inventory

Students' conceptual understanding was assessed using a shortened version of a recently developed tool for assessing conceptual understanding of introductory statistics concepts (Tintle & VanderStoep, 2018). The original scale consists of 24 items across five domains, whereas the shortened scale consists of 12 items across the same five domains. The tool has been examined with introductory statistics students across the United States and shown to be both valid (construct and predictive validity: correlations greater than 0.3 with most other scales examined) and reliable (Cronbach's alpha greater than 0.65). The scale assesses five domains in introductory statistics courses: data collection and scope, descriptive statistics, confidence intervals, significance, and simulation. See Tintle and VanderStoep (2018) for additional details.

Student Attitudes

Student attitudes were assessed using a shortened (and adapted) version of the Students Attitudes Towards Statistics (SATS) scale (Schau et al., 1995), which consisted of five questions (one from each of five domains). The questions were "I will enjoy learning some statistics in my biology course" [Enjoy]; "I will have no application for statistics in my profession" [Application]; "I will have trouble understanding statistics in this course because of how I think" [Understand]; "Statistics is a subject quickly learned by most people in a biology course" [Quickly]; and "I am interested in using statistics in my biology course" [Interested]. Questions were all assessed on a seven-point Likert scale.

Statistical Analysis

Data analysis focused on change in students' percent correct on the conceptual inventory; achievable gain on the conceptual inventory,

$$\left(\frac{\text{post} - \text{pre}}{1 - \text{pre}}\right)$$

(Chance et al., 2018), or mean score on the Likert scale for attitudes. Differences were tested using paired change approaches and hierarchical linear models to account for repeated measures, clustering by instructor and other demographic covariates (e.g., age, gender, first-generation student, prior experience with statistics). McNemar's test was used to look at change (improved vs. worse attitude) in attitudes over time. A statistical significance threshold of 0.05 was used for this preliminary assessment study.

RESULTS

Description of the Sample

The sample primarily identified as female (n = 83, 62%), were typically in their first year of college (mean age = 19.2 years, SD = 1.5 years) and was primarily white (n = 117, 87%) with limited numbers of first-generation college students represented (n = 14, 10%). Thirty-five percent of the sample (n = 47) reported having no prior coursework in statistics (high school or college), 37% of the sample (n = 50) reported having taken a statistics course in high school, 13% (n = 17) reported taking a statistics course concurrently, and 15% (n = 20) reported having already completed a college statistics course. Most students in the sample attended a small college (n = 117, 87%).

Conceptual Inventory

Overall pre- and post-course performance on the conceptual inventory is depicted in Figure 1.

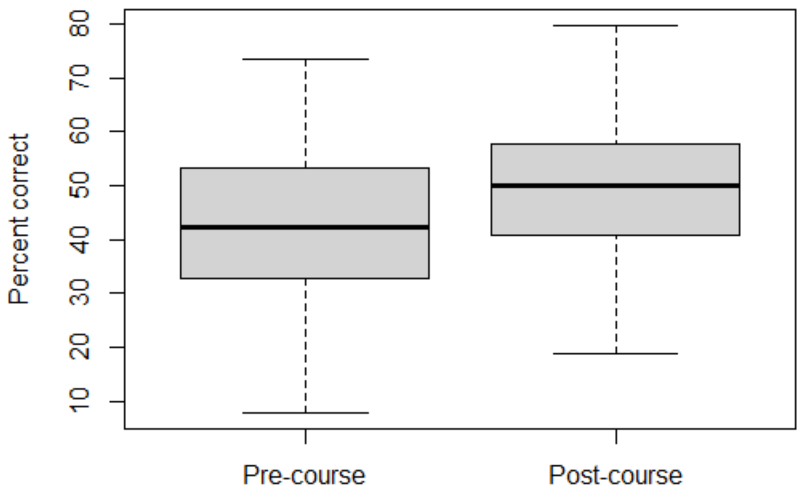

Figure 1. Pre- and post-course biology student performance on statistics concept inventory (n = 134)

Table 1. Mixed effects general linear model of pre-course score and demographics

Characteristic	Estimate [95% CI]	*p*-value
Age	-0.004 [-0.019, 0.012]	0.63
Gender–Female	-0.001 [-0.043, 0.048]	0.96
First generation	0.016 [-0.06, 0.083]	0.67
Prior or concurrent statistics course	0.023 [-0.024, 0.074]	0.34

A mixed effects model accounting for instructor effects and the repeated measures aspect of the data identified no statistically significant associations between pre-course conceptual score and measured student characteristics (Table 1).

However, students' average performance on the pre-course conceptual inventory was 42.7% correct (SD = 13.2%), compared to 49.2% (SD = 12.3%) on the same inventory post-course. This amounts to an average achievable gain of 8.8% (SD = 22.4%) and is a statistically significant improvement ($p < 0.001$).

Table 2. Mixed efforts general linear model of achievable gain score and demographics

Characteristic	Estimate [95% CI]	*p*-value
Age	-0.011 [-0.039, 0.014]	0.38
Gender–Female	0.008 [-0.062, 0.077]	0.82
First generation	0.04 [-0.079, 0.168]	0.51
Prior or concurrent statistics course	0.12 [0.038, 0.198]	*0.004*

A mixed effects model accounting for instructor effects and the repeated measures aspect of the data identified one statistically significant association between a student's achievable gain and measured student characteristics (Table 2). Students with prior or concurrent statistics coursework accounted for an estimated 0.12 (95% CI [0.038, 0.198]) higher achievable gain, meaning that students gained approximately 12% statistical knowledge overall in a biology course if they had taken a prior statistics course (versus if they did not). In a comparable model with separate effects estimates for the type of prior course, similar estimated impact of prior or concurrent statistics course was observed across high school statistics courses (0.13; 95% CI [0.039, 0.212]), concurrent college statistics courses (0.10; 95% CI [-0.027, 0.221]), and prior college statistics courses (0.12; 95% CI [-0.026, 0.246]).

Student Attitudes

None of the five pre-course student attitudes were associated with any student characteristics ($p > 0.05$ for age, gender, first generation, or prior statistics course in all models). Generally, attitudes towards statistics changed little pre- to post-course (Table 3a, 3b), with the largest change attributed to interest (32.8% of students reported less interest compared to 23.8% of students reporting more interest at the end of the course), though this comparison was not statistically significant ($p > 0.05$).

Table 3a. Students' attitude toward statistics for pre versus post (%)

	Enjoy		Application*		Understand*		Quickly*		Interested	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Very Strongly Disagree (1)	1.5	0.01	0.7	1.5	0.7	0.7	1.5	0.7	1.5	0.7
Strongly Disagree (2)	1.5	3.0	0.7	0.7	3.7	4.5	6.7	3.7	3.7	3.0
Disagree (3)	8.2	6.7	2.2	5.2	11.9	13.4	26.1	28.4	9.0	13.4
Neutral (4)	20.1	26.9	14.2	11.2	19.4	17.9	38.1	26.9	19.4	24.6
Agree (5)	48.5	41.0	36.6	36.6	35.8	31.3	24.6	34.3	49.3	41.0
Strongly Agree (6)	14.9	17.2	33.6	30.6	20.1	23.1	1.5	3.7	14.2	13.4
Very Strongly Agree (7)	5.2	5.2	11.9	14.2	7.5	8.2	0.7	2.2	2.2	3.7

*Table shows responses after reverse coding to facilitate cross item comparison

Table 3b. Change in students' attitudes toward statistics for post minus pre (%)

Change in score (1-7) Post minus Pre	Enjoy	Application*	Understand*	Quickly	Interested
Decrease by 2 or more	10.4	8.8	11.2	3.7	9.7
Decrease by 1	19.4	20.9	22.4	20.1	23.1
Neutral	44.0	38.1	33.6	44.0	42.5
Increase by 1	14.2	25.4	20.9	19.5	14.9
Increase by 2 or more	11.8	6.7	10.4	12.0	8.9

*Table shows responses after reverse coding to facilitate cross item comparison

In mixed effect models, accounting for instructor effects and the repeated measures nature of the data, predicting change in attitudes separately for each of the five attitude scales by age, gender, first generation, and prior statistics course, only age ever reached statistical significance, with gender, first generation, and prior statistics course non-significant in all models. Age was negatively associated with both interest and enjoyment ($p = 0.002$ and $p = 0.006$, respectively), meaning that older students were less likely to gain in interest or enjoyment of statistics during the course.

CONCLUSION

Little is known about what introductory biology students learn about statistics in their courses, despite increased focus on statistical learning objectives in biology courses. In this preliminary study, we saw that introductory biology students showed improvement in conceptual understanding. Consistent with other studies among introductory statistics students, student attitudes towards statistics, generally showed no change from pre- to post-course.

These preliminary results suggest the potential importance for laying a conceptual foundation in statistics prior to applying statistics in context in courses with little formal statistical instruction. Although student learning trajectories are unknown, it may be the case that students gain a conceptual understanding of statistical ideas in prior or concurrent statistics courses, which, even though it does not appear to lead to better performance on a pre-course test, provides a fertile ground for reinforcement and deeper learning through the course.

A number of limitations of this study are worth noting. The sample size is small and represents only a handful of institutions and instructors, all from the United States. Furthermore, the sample is fairly homogenous with limited ethnic diversity and limited numbers of first-generation students. This lack of diversity (students and institutions) suggests the need for much larger studies with much larger groups of students to better understand these suggestive results and ensure that they replicate in other groups (in the United States and internationally). Although the goals of this study are primarily descriptive, statistical models and reporting of *p*-values are included as preliminary measures of strength of evidence of key associations of interest.

Another limitation is the use of selected items from published assessment tests. Although administration of the full instruments would improve confidence in the validity and reliability of the findings, it was already challenging to find biology instructors willing to have students take a statistics inventory in their courses. It was a necessary compromise to generate participation. Future studies should endeavor to either use the longer instruments, or seek to improve confidence in the validity and reliability of these shortened scales.

Despite increased statistical content in introductory biology courses, the content and pedagogy used in these courses is widely varying. However, many introductory biology courses are teaching the chi-square test (e.g., it is in the Advanced Placement Biology curriculum), and, thus, students are generally learning and using some descriptive and inferential statistics in the courses. By using a conceptual inventory appropriate for an introductory statistics course, much of the widely varying statistical content in introductory biology courses is being assessed.

Further research is needed to replicate these findings and better understand the nuances of the findings with regards to biology students' attitudes and conceptual understanding of statistics.

ACKNOWLEDGMENT

We gratefully acknowledge funding from the U.S. National Science Foundation, NSF-RCN-UBE grant #2231701. The funding agency had no role in the development of this manuscript.

REFERENCES

Aikens, M. L., & Dolan, E. L. (2014). Teaching quantitative biology: Goals, assessments, and resources. *Molecular Biology of the Cell*, *25*(22), 3478–3481. https://doi.org/10.1091/mbc.E14-06-1045

Brewer, C., & Smith, D. (Eds.). (2011). *Vision and change in undergraduate biology education: A call to action*. American Association for the Advancement of Science.

Chance, B., Mendoza, S., & Tintle, N. (2018). Student gains in conceptual understanding in introductory statistics with and without a curriculum focused on simulation-based inference. In M. A. Sorto, A. White, & L. Guyot (Eds.), *Looking back, looking forward. Proceedings of the Tenth International Conference on Teaching Statistics (ICOTS10, July, 2018). Kyoto, Japan.* ISI/IASE. https://iase-web.org/icots/10/proceedings/pdfs/ICOTS10_3B2.pdf?1531364254

Chance, B., Wong, J., & Tintle, N. L. (2016). Student performance in curricula centered on simulation-based inference: A preliminary report. *Journal of Statistics Education*, *24*(3), 114–126. https://doi.org/10.1080/10691898.2016.1223529

Cobb, G. W. (2007). The introductory statistics course: A Ptolemaic curriculum? *Technology Innovations in Statistics Education*, *1*(1). https://doi.org/10.5070/T511000028

GAISE College Report ASA Revision Committee. (2016). *Guidelines for assessment and instruction in statistics education college report 2016*. https://www.amstat.org/docs/default-source/amstat-documents/gaisecollege_full.pdf

National Research Council. (2009). *A new biology for the 21st century*. The National Academies Press. https://doi.org/10.17226/12764

Schau, C., Stevens, J., Dauphinee, T., & del Vecchio, A. (1995). The development and validation of the survey of attitudes toward statistics. *Educational and Psychological Measurement*, *55*(5), 868–875. https://doi.org/10.1177/0013164495055005022

STUB. (n.d.). *Statistical thinking in undergraduate biology*. Consortium for the Advancement of Undergraduate Statistics Education. https://www.causeweb.org/stub/

Tintle, N. L., Rogers, A., Chance, B., Cobb, G., Rossman, A., Roy, S., Swanson, T., & Vanderstoep, J. (2014). Quantitative evidence for the use of simulation and randomization in the introductory statistics course. In K. Makar, B. de Sousa, & R. Gould (Eds.), *Sustainability in statistics education*. *Proceedings of the Ninth International Conference on Teaching Statistics (ICOTS 9, July, 2014) Flagstaff, Arizona, USA*. ISI/IASE. https://iase-web.org/icots/9/proceedings/pdfs/ICOTS9_8A3_TINTLE.pdf

Tintle, N., Topliff, K., VanderStoep, J., Holmes, V., & Swanson, T. (2012). Retention of statistical concepts in a preliminary randomization-based introductory statistics curriculum. *Statistics Education Research Journal*, *11*(1), 21–40. https://iase-web.org/documents/SERJ/SERJ11(1)_Tintle.pdf

Tintle, N., & VanderStoep, J. (2018). Development of a tool to assess students' conceptual understanding in introductory statistics. In M. A. Sorto, A. White, & L. Guyot (Eds.), *Looking back, looking forward. Proceedings of the Tenth International Conference on Teaching Statistics (ICOTS10, July, 2018) Kyoto, Japan.* ISI/IASE. https://iase-web.org/icots/10/proceedings/pdfs/ICOTS10_3B1.pdf?1531364253

Tintle, N., VanderStoep, J., Holmes, V., Quisenberry, B., & Swanson, T. (2011). Development and assessment of a preliminary randomization-based introductory statistics curriculum. *Journal of Statistics Education*, *19*(1). https://doi.org/10.1080/10691898.2011.11889599