Results from the 2021-22 implementation of the Beliefs about Investigation and Design Survey (BIDS)

Leighanna Hinojosa, *Science Education Specialist*
Anne Egger, *Principal Investigator*
Central Washington University

Executive Summary

The paired pre- and post-instruction Beliefs in Investigation and Design Survey (BIDS) was distributed to students enrolled in introductory science courses taught at 11 different institutions by TIDeS materials development team members. This report covers data collected in the 2021–22 academic year, prior to implementation of new curricular materials. Details about the development and testing of BIDS and the pre-/post- instruments can be found on the TIDeS website: https://serc.carleton.edu/tides/research/bids.html

Key findings:

- We analyze results from 398 participants, defined as those who completed both the pre- and post-instruction BIDS and who consented to participate.
- The majority of participants (75%) have taken one or more science course at the college level.
- Nearly all (92%) participants declared a major by the end of the course, and 35% indicated that they "might choose" or "have chosen" education as a major, the largest proportion for any major.
- There is a significant change in four of thirteen attitude and belief statements from pre- to post-instruction in the desired direction of agreement/disagreement.
- There was an overall gain in confidence across all science skills that are statistically significant.
- The instructor's coverage of the topics and practices influences confidence of participants more than course discipline.
- Most participants (89%) can envision using the skills they learned or practiced in their courses to address real world problems.
- There were significant self-reported changes in interest in STEM and STEM teaching careers.
- More than half of participants identify as women (62%) and as having one or more parent attend college (67%).
- A large majority of participants identify as a single race/ethnicity (88%). More than half of these identify as White, and 20% identify as of Hispanic, Latinx, or Spanish origin.

Acknowledgements
We thank the TIDeS Material Developers for distributing pre- and post-instruction BIDS to their students and for discussing the tasks and topics that were covered in their courses.

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Introduction

We designed the Beliefs about Investigation and Design Survey (BIDS) to assess changes in students' beliefs about their own abilities to participate in and do science and their attitudes towards science and science teaching. We use a pre-/post-instruction survey design to probe for changes from the beginning to end of a course. In addition, we will use BIDS in courses before and after implementation of new curricular materials developed through the TIDeS project (https://serc.carleton.edu/tides/) that emphasize investigation and design. We consider the data collected prior to implementation of new materials to be control data that will allow us to assess the impact of the new materials. More information about the development and testing of the survey can be found on the TIDeS website (https://serc.carleton.edu/tides/research/bids.html). Here, we describe these control data, collected over the 2021-22 academic year at 11 institutions.

Survey participants

The pre- and post-instruction surveys were administered via Qualtrics. Faculty at 11 institutions sent a link to the pre-instruction survey to their enrolled students during the first week of class and offered credit for completing it. A total of 833 students completed the pre-instruction BIDS and consented to be a part of the TIDeS research. Instructors sent a link to the post-instruction survey in the last week of class, again offering credit for completion; 635 students completed the post-instruction BIDS and consented to be a part of the research.

Responses were exported from Qualtrics and matched in R using students' ID numbers. We were able to match pre- and post- surveys from 438 individuals; of those, 431 were fully completed. After removing duplicates and respondents of unfinished surveys with "NA" for student ID number, there were 398 matched responses, including four unfinished surveys that were over 50% complete. We use the term *participants* to refer to these students who consented to participate in our research study and who completed both pre- and post-surveys that we were able to match (n = 398). Categorical data were transformed into numerical data in R to perform calculations (e.g., computing the mean and standard deviation).

Context questions: Pre-instruction survey only

The first set of questions in the pre-instruction survey asks students about their college experience in science, providing context for responses about their skills and knowledge.

Reason for taking course

In the pre-instruction survey only, students were asked their reason for taking their course and could select all reasons that apply (Table 1).

Table 1. Participant reason for taking course

<table>
<tr><th>Reason</th><th colspan="4">Selected (n=398)</th></tr>
<tr><td>I am interested in the subject area</td><td>36.9%</td><td rowspan="2">12.1%</td><td></td><td rowspan="4">6.5%</td></tr>
<tr><td>It fulfills a general education or distribution requirement</td><td>62.8%</td><td rowspan="2">5.8%</td></tr>
<tr><td>It is required for my major</td><td>43.0%</td><td rowspan="2">3.8%</td></tr>
<tr><td>I think it will be useful in my career</td><td>22.6%</td><td></td></tr>
<tr><td>Other</td><td>2.5%</td><td></td><td></td><td></td></tr>
</table>

Nearly two-thirds selected that the course "fulfills a general education requirement," but only half of those selected *only* that response (31.2%). More than half of all participants selected more than one reason, and the highest proportions of the multiple selections are shown in Table 1. Twelve percent selected that they were interested in the subject area in addition to it fulfilling a general education requirement, and 6.5% selected all four provided reasons.

Previous science experience

Students were then asked, "Before this course, how many science courses (e.g., Biology, Chemistry, Earth Science, Physics) have you taken at the college level?" (Figure 1).

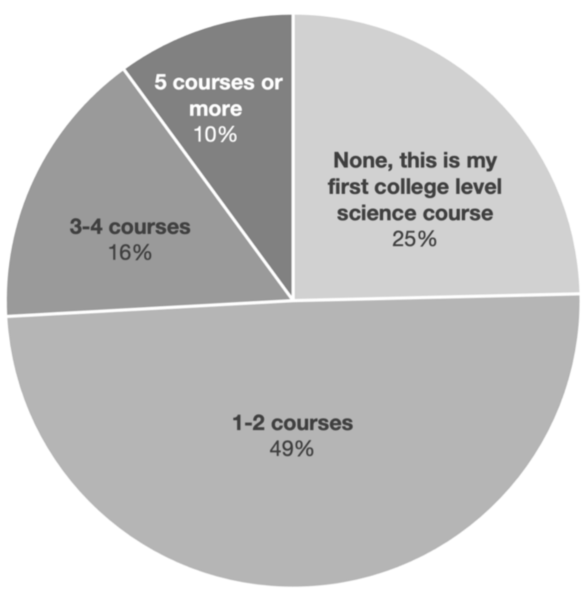

Figure 1. Participants' previous science courses (n = 398).

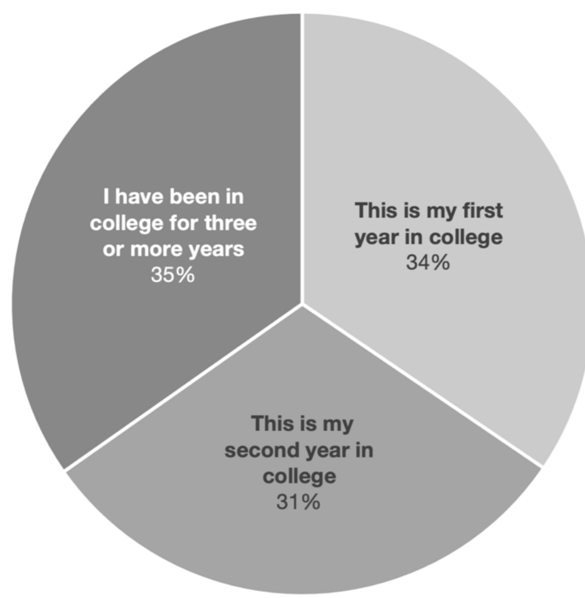

Figure 2. Participants' year in college (n = 397).

The largest proportion of participants, about half, had taken 1-2 courses college-level science courses prior to the one in which they were taking the survey. For 25% of participants, this was their first college-level science course.

To further place their prior knowledge in context, we asked how many years of college experience they had, purposefully avoiding terms like "freshman" or "sophomore" that can be confusing for transfer and non-traditional students. Most participants were in their first or second year (Figure 2), which aligns well with the number of previous science courses they had taken.

Majors

Two questions ask students about their major(s). The first asks if they have formally declared a major. The second question lists 11 major areas and gives students the option to select "will not choose," "might choose," or "definitely or have chosen" for each one. They can also choose "Other" and enter their major in a free-response box. In the pre-instruction survey, 348 participants (87%) indicated that they had formally declared a major; this increased to 367 (92%) in the post-instruction survey. Their choice of majors is shown in Table 2.

Table 2. Major choice of participants, ordered from most to least common "have chosen or will choose" responses.

	Have chosen or will choose		**Might choose**		**Will not choose**	
Major	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Education	24.4%	23.4%	11.3%	11.8%	64.3%	64.8%
Business	17.6%	18.1%	15.1%	12.8%	67.3%	69.1%
Health Professions	15.6%	16.8%	11.8%	11.1%	72.6%	72.1%
Arts & Humanities	14.3%	11.1%	14.6%	12.3%	71.1%	76.6%
Biological Sciences, Agriculture, Natural Resources	13.1%	14.1%	14.3%	11.6%	72.6%	74.4%
Social Sciences	11.8%	12.1%	14.8%	13.1%	73.4%	74.9%
Communication, Media, Public Relations	8.5%	7.5%	17.1%	14.8%	74.4%	77.6%
Computer Science, Mathematics	7.8%	5.5%	9.5%	9.3%	82.7%	85.2%
Physical Science, Chemistry, Physics, Geosciences	7.0%	6.8%	13.8%	10.1%	79.1%	83.2%
Social Services Profession	3.8%	3.8%	12.3%	10.1%	83.9%	86.2%
Engineering	3.5%	2.5%	7.8%	6.3%	88.7%	91.2%
Other	9.3%	9.3%	10.8%	10.8%	78.4%	79.9%

The largest proportion of participants "have chosen or will definitely choose" education as a major in both the pre- and post-instruction survey (~24%). That proportion varied substantially across institutions, however, from a low of 9% at Kennesaw State to a high of 95% at the University of Montana. In the post-instruction survey, 20% selected two or three majors; the most common combination was biological sciences and health professions. Of the participants who chose "other", free-response entries included cybersecurity/criminal justice and psychology.

Although increasing the number of STEM and education majors is not an explicit goal of this project, one of our guiding principles is that *students will engage in authentic and meaningful scenarios that make use of real data and models and reflect the actual practice of science and engineering*. We hope that the authentic and meaningful science learning experiences students have in courses with TIDeS materials and instructors influence their decisions about majors (and careers). Using the matched pre-/post- responses, we can compare the number of students moving towards and away from education and STEM majors (Tables 3-6). Overall, 3.0% of participants moved away from Education as a major (Table 3), 1.1% away from biological sciences, agriculture, and natural resources (Table 4), 3.8% away from computer science and math (Table 5), and 3.1% away from physical sciences (Table 6). These shifts, although they are significant, should be interpreted with caution, however, as the numbers are small.

Table 3. Education as a Major Selection, Pre to Post Survey (n=398)

Education		**Post**		
		Will not choose	Might choose	Have chosen
Pre	Will not choose	58.3%	4.3%	1.8%
	Might choose	5.3%	5.0%	1.0%
	Have chosen	1.3%	2.5%	20.6%
Total towards education				7.1%
Total away from education				9.1%

Table 4. Biological Sciences as a Major Selection, Pre to Post Survey (n=398)

Biological sciences, agriculture, natural resources		**Post**		
		Will not choose	Might choose	Have chosen
Pre	Will not choose	65.1%	4.5%	3.0%
	Might choose	6.5%	5.8%	2.0%
	Have chosen	2.8%	1.3%	9.0%
Total towards biological sciences				9.5%
Total away from biological sciences				10.6%

Table 5. Computer Science/Math as a Major Selection, Pre to Post Survey (n=398)

Computer science and mathematics		**Post**		
		Will not choose	Might choose	Have chosen
Pre	Will not choose	79.1%	2.0%	1.5%
	Might choose	3.5%	5.0%	1.0%
	Have chosen	2.5%	2.3%	3.0%
Total towards computer science and mathematics				4.5%
Total away from computer science and mathematics				8.3%

Table 6. Physical Sciences as a Major Selection, Pre to Post Survey (n=398)

Physical sciences		**Post**		
		Will not choose	Might choose	Have chosen
Pre	Will not choose	74.1%	3.3%	1.8%
	Might choose	6.0%	5.3%	2.5%
	Have chosen	3.0%	1.5%	2.5%
Total towards physical sciences				7.5%
Total away from physical sciences				10.6%

Attitudes and beliefs about science and engineering

Both surveys present students with a list of 13 statements that "describe different attitudes and beliefs about science and engineering." Students are asked to "reflect on [their] previous science courses" and select the extent to which they agreed with each statement. This report details analysis of attitude and belief statement pre- to post-instruction.

There are 394 completed and matched responses for each of the 13 statements. To calculate means, responses were converted into numerical data as follows: strongly disagree = 1, somewhat disagree = 2, somewhat agree = 3, and strongly agree = 4. Means for each statement from both pre- and post-instruction surveys were calculated and compared to each other using a two-sample, paired t-test in R with a 99% confidence. Where the p-value comparing the pre- and post-instruction means is <0.05, we consider the differences to be statistically significant.

We use histograms to compare pre-/post- frequencies and matrices of the matched responses to show movement between responses. Each histogram shows the frequency distribution of the total number of responses, with the proportion of responses from the pre-instruction survey shown in green and the post-instruction survey in blue. We use matrices to show the change in the matched responses. In the matrices, boxes that are shaded green indicate the shift in agreement that is aligned with the goals of the project, while boxes shaded yellow indicate a shift away from the goals of the project. For each statement, we indicate whether the desired shift is towards agreement or disagreement with the statement and present our reasoning.

For some statements, we also considered other confounding factors that might influence attitudes and changes in attitudes, including number of previous college-level science courses, education as a major, gender identity, and race/ethnicity. Results related to gender identity and race/ethnicity are discussed near the end of this report, see the section titled, *Demographic influences on data*.

In exploring the influence of major, we compared responses from participants who selected they have chosen or might choose education as a major, referred to as the *education group* (n=139 in the pre-instruction survey and 140 in the post-instruction survey), to participants who selected they will not choose education as a major, referred to as the *non-education group* (n=256 in the pre-instruction survey and 258 in the post-instruction survey). We also look at the number of previous science courses taken.

Statement 1: I do not feel comfortable voicing my own ideas in science class

This statement addresses the TIDeS guiding principle that *Faculty and the curricular materials they use will cultivate an equitable learning environment where all students have equal access to learning and feel valued and supported in their learning*, specifically focusing on students' self-efficacy, and feeling valued in science courses. The TIDeS materials focus on engaging students in productive discourse and helping instructors value the funds of knowledge that students bring to their courses. Therefore, this is a statement that we would hope to see a shift towards disagreement from pre- to post-instruction with use of the TIDeS materials.

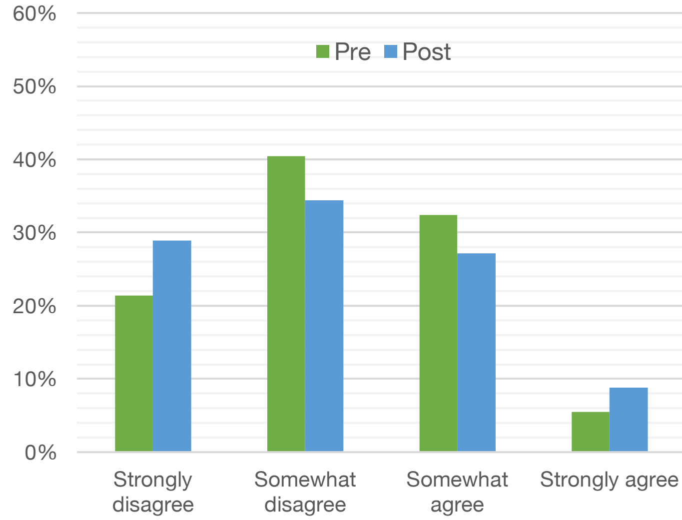

Figure 3. Histogram comparing pre- and post-instruction responses to the statement "I do not feel comfortable voicing my own ideas in science class."

In both the pre- and post-instruction surveys, the largest proportion of participants responded "somewhat disagree," but the difference between pre- and post-instruction responses is not significant (p-value = 0.23) (Figure 3). The matched results show that the largest proportion of participants who reported a change in attitude (12.2%) moved from disagreeing somewhat to disagreeing strongly, but the overall shift is insignificant (Table 7).

Table 7. Pre- to post-instruction change in responses, largest shift is bold.

I do not feel comfortable voicing my own ideas in science class		**Post**			
		Strongly disagree	Somewhat disagree	Somewhat agree	Strongly agree
Pre	Strongly disagree	12.2%	3.6%	3.0%	2.5%
	Somewhat disagree	**12.2%**	18.8%	8.6%	1.3%
	Somewhat agree	3.8%	10.7%	14.2%	3.6%
	Strongly agree	1.0%	1.8%	1.3%	1.5%
Total towards disagreement			17.3%		
Total away from disagreement			15.5%		
Net gain in disagreement			1.8%		

For this statement, we compared the responses to the number of previous college-level science courses that participants reported (Figure 1). In both pre-instruction responses, 63% of participants who had taken any previous science courses disagreed with this statement compared to 58% of those who had taken none. In the post-instruction survey, more participants who had taken any previous science courses disagreed with this statement (67%), whereas the proportion of students who had taken no previous courses (i.e., for whom this was their first course) decreased (54%).

Statement 2: Everyone can contribute useful ideas in a scientific investigation or engineering design process.

This statement also addresses the guiding principle that *Faculty and the curricular materials they use will cultivate an equitable learning environment where all students have equal access to learning and feel valued and supported in their learning.* This statement takes the focus away from the student, however, and places it on the community, specifically probing students' beliefs about others' role in contributing. Here, we would hope to see a shift towards more agreement from pre- to post-instruction in courses where the TIDeS materials are implemented.

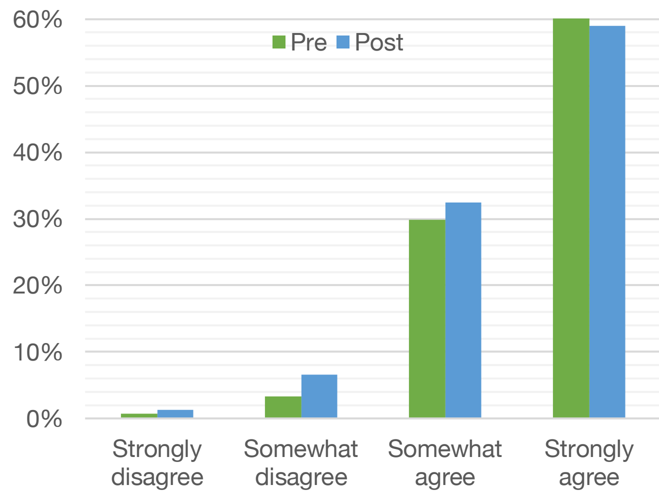

Figure 4. Histogram comparing pre- and post-instruction responses to the statement "Everyone can contribute useful ideas in a scientific investigation or engineering design process."

Overall, there is general agreement with this statement, with <5% of participants disagreeing in the pre-instruction survey (Figure 4). The matched pre-/post- results show a small but significant shift *away* from agreement (p-value = 0.0045, Table 8). The largest proportion of students (15.2%) shifted from strong agreement to agreeing somewhat.

Table 8. Pre- to post-instruction change in responses, largest shift is bold.

Everyone can contribute useful ideas in a scientific investigation or engineering design process.		**Post**			
		Strongly disagree	Somewhat disagree	Somewhat agree	Strongly agree
Pre	Strongly disagree	0.0%	0.0%	0.5%	0.3%
	Somewhat disagree	0.0%	0.8%	1.8%	0.8%
	Somewhat agree	0.0%	3.8%	15.2%	10.9%
	Strongly agree	1.3%	2.0%	**15.2%**	47.5%
Total towards agreement			3.3%		
Total away from agreement			7.1%		
Net gain in agreement			-3.8%		

Statement 3: Talking about data with other students helps me develop explanations

This statement emerges from the guiding principle that *Students will engage in scientific investigation and engineering design to deepen their understanding of core ideas.* A key component of deepening understanding is engaging in productive discourse; in introductory courses, that productive discourse is typically facilitated by instructors. In a classroom where TIDeS materials are used and instructors engage students in talking with each other about data, their analyses, and interpretation, we would hope to see a shift towards greater agreement from pre- to post-instruction.

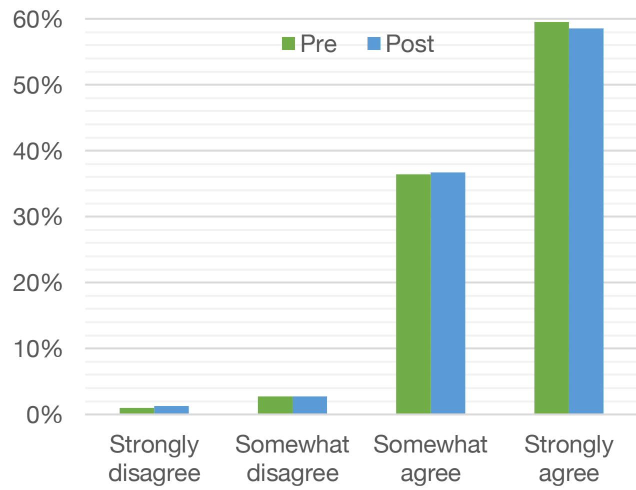

Figure 5. Histogram comparing pre- and post-instruction responses to the statement “Talking about data with other students helps me develop explanations.”

As with the previous statement, we see overall agreement, with <4% disagreeing in both the pre- and post-instruction survey and no significant difference (p-value = 0.79) between pre- and post- (Figure 5). In the matched data (Table 9), the most substantial shifts are within the extent of agreement, with an insignificant shift away from agreement overall.

Table 9. Pre- to post-instruction change in responses, largest shift is bold.

Talking about data with other students helps me develop explanations		**Post**			
		Strongly disagree	Somewhat disagree	Somewhat agree	Strongly agree
Pre	Strongly disagree	0.0%	0.3%	0.5%	0.3%
	Somewhat disagree	0.0%	0.0%	2.5%	0.3%
	Somewhat agree	0.3%	0.8%	18.3%	**17.5%**
	Strongly agree	1.0%	1.8%	15.7%	40.9%
Total towards Agreement			3.6%		
Total away from Agreement			3.8%		
Net gain in agreement			-0.3%		

Statement 4: The most important thing you need to teach science is to know a lot of facts within a discipline.

This statement is the first of two that focuses on beliefs about teaching science. As such, it is relevant to all four guiding principles, but perhaps especially to the principle that *Students will engage in scientific investigation and engineering design to deepen their understanding of core ideas.* Inherent to this guiding principle is the idea that "facts" (core ideas) are a result of engaging in the process of science, they do not themselves represent science. Additionally, it addresses the principle that *Students will engage in authentic and meaningful scenarios that make use of real data and models and reflect the actual practice of science and engineering.* A component of this guiding principle is the idea that authentic scenarios and real data do not have pre-determined answers, and both students and instructors will be engaged in the process of science to establish new knowledge ("facts").

In a course where the TIDeS materials are used, we would hope to see a shift towards disagreement, that "the most important thing" is not knowing a lot of facts. We acknowledge that this is a complicated question, however, students may feel that instructors should know a lot about a discipline (and we agree). Knowing facts, however, is not the most important thing for teaching others how to do science themselves.

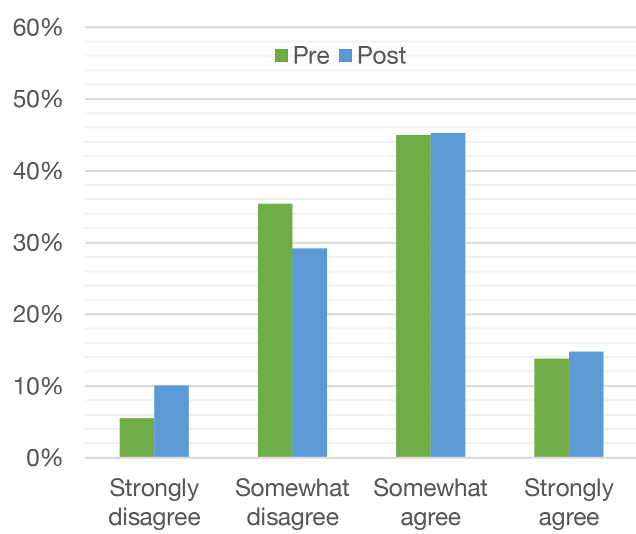

Figure 6. Histogram comparing pre- and post-instruction responses to the statement "The most important thing you need to teach science is to know a lot of facts within a discipline."

The largest proportion of participants "somewhat agree" with this statement in both the pre- and post- surveys, and a small majority agree overall (Figure 6); there is no significant difference between pre- and post-instruction responses. The matched data indicate an insignificant movement away from disagreement, with the largest proportion of participants who shifted (12.7%) moving from "somewhat disagree" to "somewhat agree" (Table 10).

Table 10. Pre- to post-instruction change in responses, largest shift is bold.

The most important thing you need to teach science is to know a lot of facts within a discipline.		Post			
		Strongly disagree	Somewhat disagree	Somewhat agree	Strongly agree
Pre	Strongly disagree	2.0%	2.0%	1.3%	0.3%
	Somewhat disagree	6.1%	15.2%	**12.7%**	1.3%
	Somewhat agree	1.5%	10.4%	27.4%	6.1%
	Strongly agree	0.5%	1.5%	4.3%	7.4%
Total towards disagreement			14.0%		
Total away from disagreement			15.5%		
Net gain in disagreement			-1.5%		

Because this statement presents a belief about teaching, we compared the responses of the education and non-education groups. A bigger change is seen in the non-education group, which goes from 41.4% disagreement in the pre-instruction survey to 38.3% disagreement in the post-instruction survey, whereas the education group stays at just over 40% disagreement from pre- to post-instruction.

Statement 5: The most important thing you need to teach science is how to do science.

This statement contrasts directly with the previous statement and is the second to probe beliefs about teaching science. In a course where the TIDeS materials are used, we would hope to see a shift towards agreement.

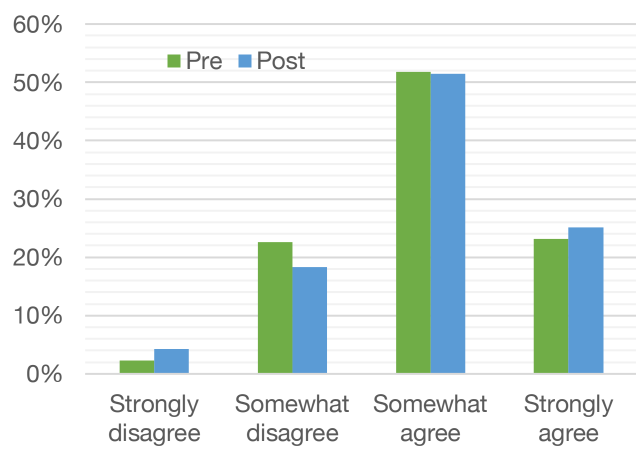

Figure 7. Histogram comparing pre- and post-instruction responses to the statement “The most important thing you need to teach science is how to do science.”

Just over half of participants in both the pre- and post- instruction survey responded that they “somewhat agree” with this statement, with a substantial majority agreeing overall (Figure 7) and no significant difference between pre- and post- responses. This suggests that many participants agreed with *both* statements, suggesting that participants believe that knowledge of a discipline and science skills are both important for teaching science. The matched data (Table 11) show that >10% of participants shifted from somewhat disagreeing to somewhat agreeing, but overall shift towards agreement is not significant (p-value = 0.53).

Table 11. Pre- to post-instruction change in responses, largest shift is bold.

The most important thing you need to teach science is how to do science.		**Post** Strongly disagree	Somewhat disagree	Somewhat agree	Strongly agree
Pre	Strongly disagree	0.3%	1.3%	0.5%	0.3%
	Somewhat disagree	1.0%	7.4%	**11.4%**	3.0%
	Somewhat agree	2.5%	7.9%	30.5%	10.7%
	Strongly agree	0.3%	2.0%	9.6%	11.4%
Total towards agreement			15.2%		
Total away from agreement			12.7%		
Net gain in agreement			2.5%		

As with the previous statement, we compared the responses of the education and non-education groups. Here we see substantially more agreement with the statement in the non-education group (73% pre, 77% post) compared to the education group (59.5% both pre and post). This is an interesting result that we intend to explore further.

Statement 6: Science and engineering can address questions and problems in my everyday life outside of classes.

This statement directly addresses one of our guiding principles, that *students will engage in addressing questions and solving problems that are relevant to their lives*, and asks students the extent to which they agree with the idea that science and engineering *can* be relevant to their lives. In a course where the TIDeS materials are used, we would expect to see a shift towards agreement from pre- to post-instruction.

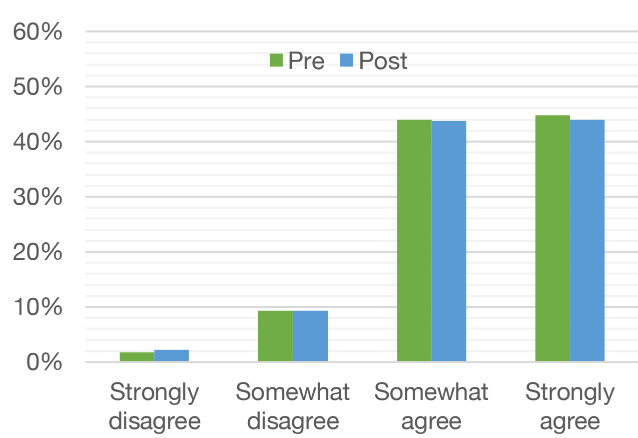

Figure 8. Histogram comparing pre- and post-instruction responses to the statement “Science and engineering can address questions and problems in my everyday life outside of classes.”

In courses without the use of the TIDeS materials, the large majority of participants (>85%) strongly or somewhat agree with this statement (Figure 8) and there is no significant change from pre- to post-instruction (p-value = 0.77). The matched data show no overall gain, and the most substantial shifts occurred within the extent of agreement, with the largest proportion moving from "somewhat" to "strongly agree" (Table 12).

Table 12. Pre- to post-instruction change in responses, largest shift is bold.

Science and engineering can address questions and problems in my everyday life outside of classes.		Post Strongly disagree	Somewhat disagree	Somewhat agree	Strongly agree
Pre	Strongly disagree	0.0%	0.8%	0.8%	0.3%
	Somewhat disagree	0.5%	1.5%	5.8%	1.5%
	Somewhat agree	0.8%	4.6%	23.6%	**15.0%**
	Strongly agree	1.0%	2.5%	13.7%	27.7%
Total towards agreement			8.4%		
Total away from agreement			8.9%		
Net gain in agreement			-0.5%		

Statement 7: I have a hard time using big ideas and theories in science to help me understand specific concepts.

This statement addresses the concept of three-dimensional learning in the Framework for K-12 Science Education (NRC, 2012), and our guiding principle that *Students will engage in scientific investigation and engineering design to deepen their understanding of core ideas*. Engaging in investigation and design inherently means using cross-cutting concepts to place ideas into context; we correlate "big ideas" in this statement with cross-cutting concepts, and "theories" with disciplinary core ideas. In a course where the TIDeS materials are used, we hope to see a shift towards disagreement from pre- to post-instruction, as students engage in this very process.

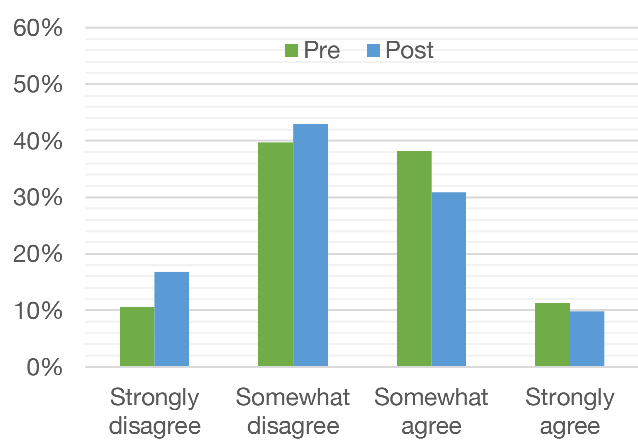

Figure 9. Histogram comparing pre- and post-instruction responses to the statement "I have a hard time using big ideas and theories in science to help me understand specific concepts."

Participants in general feel less strongly about this statement than they do others, as most responses fall within the two “somewhat” categories (Figure 9). The shift to greater disagreement is significant (p-value $\ll 0.001$). The matched responses also show a significant change, with a p-value < 0.05 and the largest proportion of participants shifting from somewhat agreeing to somewhat disagreeing (Table 13).

Table 13. Pre- to post-instruction change in responses, largest shift is bold.

I have a hard time using big ideas and theories in science to help me understand specific concepts.		**Post**			
		Strongly disagree	Somewhat disagree	Somewhat agree	Strongly agree
Pre	Strongly disagree	5.8%	3.6%	0.8%	0.5%
	Somewhat disagree	7.1%	21.6%	8.6%	2.3%
	Somewhat agree	2.5%	**15.5%**	16.5%	3.8%
	Strongly agree	0.3%	2.8%	5.1%	3.3%

Total towards disagreement	21.1%
Total away from disagreement	12.2%
Net gain in disagreement	8.9%

Because cross-cutting concepts (“big ideas”) are an essential component of STEM teaching, we compared the responses of the education and non-education groups. In the pre-instruction survey, a much larger proportion of the education group (61.1%) agreed with this statement than the non-education group (43.4%). Post-instruction, the gap narrows to 45.0% agreement for the education group and 38.8% agreement for the non-education group, which suggests that instruction has a more significant impact on the education group.

Statement 8: I can use my skills to figure out how to investigate a scientific question even if I don’t know that much about the details.

This statement addresses the guiding principles that *Students will engage in scientific investigation and engineering design to deepen their understanding of core ideas* and that *Students will engage in authentic and meaningful scenarios that make use of real data and models and reflect the actual practice of science and engineering*. Because students in courses where TIDeS materials are being used will engage in authentic scientific investigation multiple times, we would hope that they would see an improvement in their skills and thus we would see a shift towards more agreement from pre- to post-instruction. In addition, this statement refers to the concept of *transfer*, which is often challenging for students.

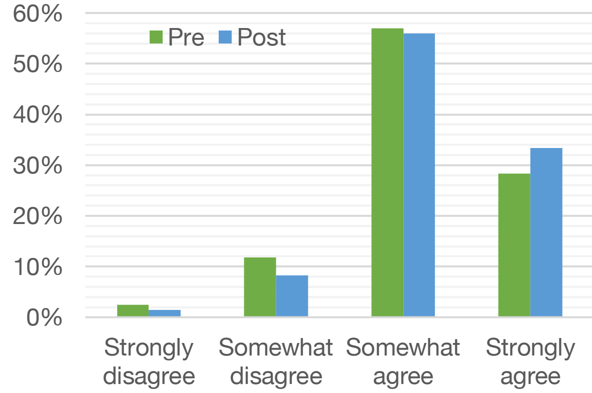

Figure 10. Histogram comparing pre- and post-instruction responses to the statement "I can use my skills to figure out how to investigate a scientific question even if I don't know that much about the details."

The very large majority of participants agree with this statement (Figure 10), and there is a small but significant shift to more agreement (p-value = 0.0059). The matched data show that h the largest proportion of students move from "somewhat agree" to "strongly agree" (Table 14).

Table 14. Pre- to post-instruction change in responses, largest shift is bold.

I can use my skills to figure out how to investigate a scientific question even if I don't know that much about the details.		**Post** Strongly disagree	Somewhat disagree	Somewhat agree	Strongly agree
Pre	Strongly disagree	0.3%	0.5%	1.0%	0.8%
	Somewhat disagree	0.5%	2.3%	6.6%	2.5%
	Somewhat agree	0.5%	4.3%	37.3%	**15.2%**
	Strongly agree	0.3%	1.0%	11.7%	15.2%
Total towards Agreement			10.9%		
Total away from Agreement			6.1%		
Net gain in agreement			4.8%		

Statement 9: Science classes are primarily about learning what we already know in a discipline, as opposed to actively investigating questions or solving problems.

This statement directly addresses our guiding principle that *Students will engage in authentic and meaningful scenarios that make use of real data and models and reflect the actual practice of science and engineering*. Students' responses to this statement in the pre-instruction survey are likely to be strongly influenced by their past learning experiences in science. In courses where TIDeS materials are used, we would hope to see a shift towards disagreement. However, we also acknowledge that their post-instruction responses may also be strongly influenced by previous experience. If their previous experiences were dominated by learning about what we already know, they may respond in agreement with this statement even if they believe that science courses *should* be about actively investigating questions or solving problems.

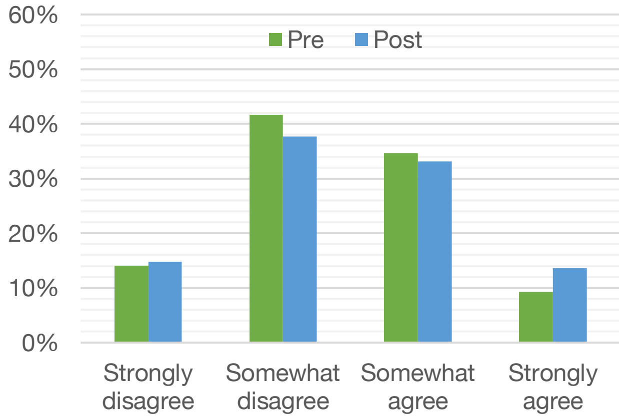

Figure 11. Histogram comparing pre- and post-instruction responses to "Science classes are primarily about learning what we already know in a discipline, as opposed to actively investigating questions or solving problems."

The majority of participants responded in the "somewhat" categories, with a small but insignificant shift towards more certainty from pre- to post-instruction (p-value = 0.16) (Figure 11). The matched data show an overall shift away from disagreement (Table 15).

Table 15. Pre- to post-instruction change in responses, largest shift is bold.

Science classes are primarily about learning what we already know in a discipline, as opposed to actively investigating questions or solving problems.		**Post**			
		Strongly disagree	Somewhat disagree	Somewhat agree	Strongly agree
Pre	Strongly disagree	5.1%	6.3%	2.0%	0.8%
	Somewhat disagree	5.3%	19.3%	**14.0%**	3.3%
	Somewhat agree	3.6%	9.6%	15.5%	5.8%
	Strongly agree	0.8%	2.8%	2.0%	3.8%
Total towards disagreement			16.8%		
Total away from disagreement			20.1%		
Net gain in disagreement			-3.3%		

Because this question implies previous science learning experiences, we compared the pre- and post-instruction responses to the number of previous science courses (Figure 1). The groups do not differ substantially in the pre-instruction survey. In the post-instruction survey, 54% of participants for whom this was their first college-level science course agree with this statement, whereas 44% of those who have previously taken science courses at the college level agree.

Because this statement also describes an approach to teaching, we also compared responses of the education and non-education groups. The education group shows an overall shift to disagreement, from 51.8% to 54.3% who selected somewhat or strongly disagree, whereas the non-education group shows an overall shift away from disagreement, from 58.1% to 52.1%.

Statement 10: Similar approaches to conducting investigations are used in all science disciplines (Biology, Chemistry, Earth Science, Physics).

This statement addresses the guiding principles that *Students will engage in scientific investigation and engineering design to deepen their understanding of core ideas*, and probes student beliefs about the idea of science and engineering practices as a dimension of the framework of learning and doing science. We recognize that there are broad similarities that are well-described and encoded in the science and engineering practices, and that different disciplines emphasize different methods and have some techniques and approaches that are unique. After instruction with TIDeS materials that emphasize investigation and design and the practices, we would hope to see a shift towards more agreement.

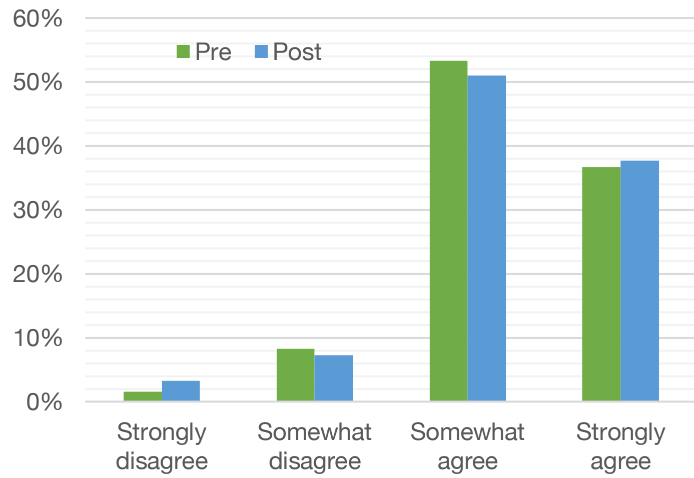

Figure 12. Histogram comparing pre- and post-instruction responses to the statement "Similar approaches to conducting investigations are used in all science disciplines (Biology, Chemistry, Earth Science, Physics)."

Over 90% of participants agree with this statement, and over half agree somewhat (Figure 312), which may reflect its ambivalent nature. There is no significant difference between pre- and post- instruction responses. The matched data show no significant shift from pre- to post-instruction, with the largest change occurring in the extent of agreement (Table 16).

Table 16. Pre- to post-instruction change in responses, largest shift is bold.

Similar approaches to conducting investigations are used in all science disciplines (Biology, Chemistry, Earth Science, Physics).		**Post** Strongly disagree	Somewhat disagree	Somewhat agree	Strongly agree
Pre	Strongly disagree	0.0%	0.0%	0.5%	1.0%
	Somewhat disagree	1.0%	1.8%	3.8%	1.8%
	Somewhat agree	1.8%	3.3%	33.0%	**15.2%**
	Strongly agree	0.3%	2.3%	14.2%	20.1%
Total towards agreement			7.1%		
Total away from agreement			7.6%		
Net gain in agreement			-0.5%		

Statement 11: When I am asked to explain data, I don't really know how to start.

This statement addresses the guiding principles that *Students will engage in scientific investigation and engineering design to deepen their understanding of core ideas* and that *Students will engage in authentic and meaningful scenarios that make use of real data and models and reflect the actual practice of science and engineering*. This statement is meant to probe students' beliefs in their own abilities to explain data, a key component of science investigation. Because TIDeS materials focus on the use of real data and engaging students in investigation, we would hope to see students' beliefs in their own abilities change from pre- to post- instruction towards more disagreement. We might also expect to see differences between students with more and less experience in science at the college level.

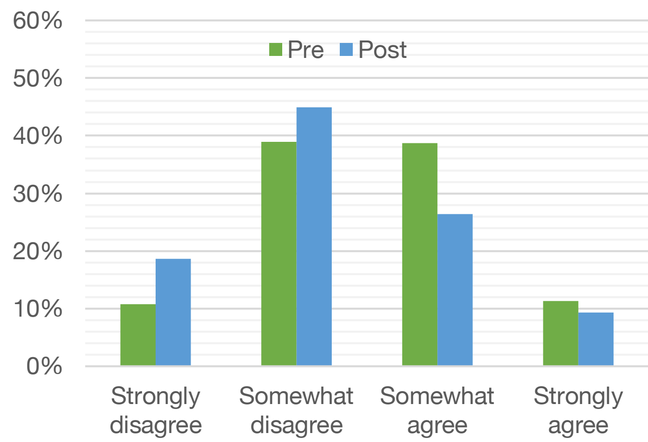

Figure 13. Histogram comparing pre- and post-instruction responses to the statement "When I am asked to explain data, I don't really know how to start."

A small majority of students disagree with this statement in the pre-instruction survey, and that majority grows in the post-instruction survey (Figure 13); the difference in distribution between pre- and post- responses is significant (p-value << 0.001). The matched data show that the largest proportion of participants who changed their responses went from "somewhat agree" to "somewhat disagree" (Table 17), and that the overall shift is statistically significant.

Table 17. Pre- to post-instruction change in responses, largest shift is bold.

When I am asked to explain data, I don't really know how to start.		**Post**			
		Strongly disagree	Somewhat disagree	Somewhat agree	Strongly agree
Pre	Strongly disagree	6.1%	3.6%	1.3%	0.0%
	Somewhat disagree	7.9%	22.3%	6.9%	2.0%
	Somewhat agree	4.3%	**17.5%**	12.7%	4.1%
	Strongly agree	0.5%	2.0%	5.6%	3.3%
Total towards disagreement			24.4%		
Total away from disagreement			10.2%		
Net gain in disagreement			14.2%		

Because explaining data is a skill that we would expect students to gain and develop as they take more science courses, we compared the distribution of pre- and post-instruction responses to the number of previous science courses at the college level. In the pre-instruction survey, 56% of participants with no previous science courses agreed with this statement, which decreased to 35% in the post-instruction survey. Similarly, 48% of participants with any previous science courses agreed with this statement, which decreased to 36% post-instruction. The decrease is greater among those with no previous college-level science courses.

Statement 12: Learning science and engineering that is not directly relevant to or applicable to my life is not worth my time.

This statement directly addresses one of our guiding principles, that *students will engage in addressing questions and solving problems that are relevant to their lives*, probing students' attitudes towards relevance and how important it is to them as learners. The TIDeS materials emphasize relevance, but also different kinds of relevance, not solely direct, personal relevance. In a course where the TIDeS materials are used, we would hope to see a shift towards more disagreement, as students engage in science that is relevant to their lives and also in investigations that are relevant to society as a whole, to the discipline, and beyond. However, we might also see a shift towards agreement as students see how science can address questions that are relevant to their lives.

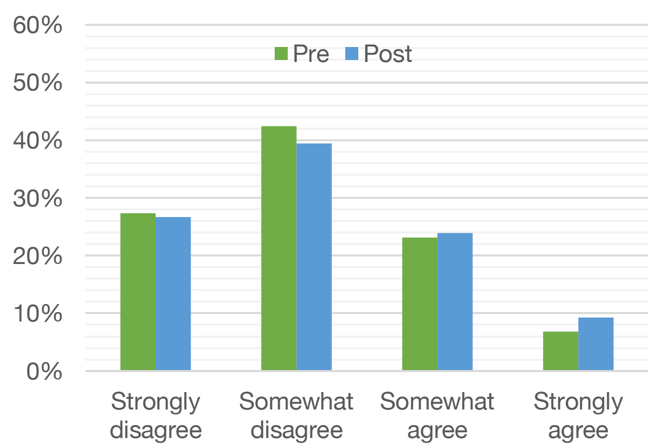

Figure 14. Histogram comparing pre- and post-instruction responses to the statement "Learning science and engineering that is not directly relevant to or applicable to my life is not worth my time."

About three-quarters of participants disagree with this statement in both the pre- and post-instruction survey (Figure 14), and there is no significant difference between pre- and post-responses (p-value = 0.20). The matched data show that the biggest shifts occurred within the extent of disagreement (Table 18).

Table 18. Pre- to post-instruction change in responses, largest shift is bold.

Learning science and engineering that is not directly relevant to or applicable to my life is not worth my time.		Post			
		Strongly disagree	Somewhat disagree	Somewhat agree	Strongly agree
Pre	Strongly disagree	12.9%	9.1%	3.3%	2.0%
	Somewhat disagree	10.2%	21.6%	**8.9%**	2.0%
	Somewhat agree	3.0%	7.4%	9.6%	3.0%
	Strongly agree	0.8%	1.5%	2.3%	2.3%
Total towards disagreement			16.2%		
Total away from disagreement			12.7%		
Net gain in disagreement			3.6%		

Statement 13: Science teachers should help me understand how the scientific concepts are relevant to me today.

This statement also directly addresses the guiding principle that *students will engage in addressing questions and solving problems that are relevant to their lives*. This statement probes students' beliefs about their instructors and the extent to which it is their role to show relevance. In courses where TIDeS materials are used, instructors will focus on relevance, which we hope would result in a shift towards more agreement from pre- to post-instruction. However, we anticipate that most students will agree with this statement.

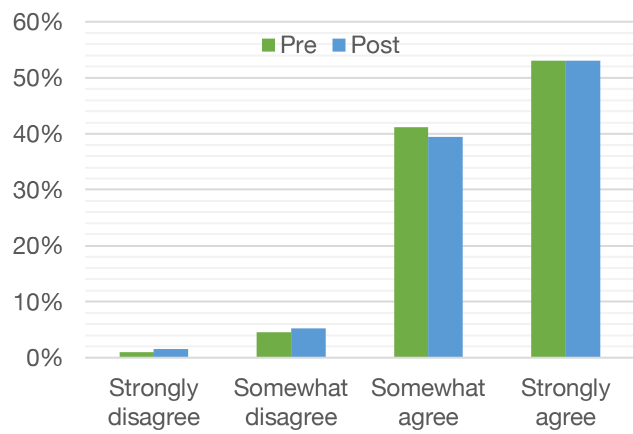

Figure 15. Histogram comparing pre- and post-instruction responses to the statement "Science teachers should help me understand how the scientific concepts are relevant to me today."

In fact, >90% of participants agreed with this statement in both the pre- and post-instruction survey (Figure 15), with no significant difference between pre- and post- responses (p-value = 0.69). The matched data show the biggest shifts between "somewhat" and "strongly" agree (Table 19), with no significant overall change.

Table 19. Pre- to post-instruction change in responses, largest shift is bold.

Science teachers should help me understand how the scientific concepts are relevant to me today.		**Post** Strongly disagree	Somewhat disagree	Somewhat agree	Strongly agree
Pre	Strongly disagree	0.0%	0.3%	0.3%	0.5%
	Somewhat disagree	0.3%	0.5%	2.8%	1.0%
	Somewhat agree	0.0%	3.6%	24.1%	**13.7%**
	Strongly agree	1.3%	1.0%	12.7%	38.1%

Total towards agreement	4.6%
Total away from agreement	5.8%
Net gain in agreement	-1.3%

Correlations between responses

In developing the attitudes and beliefs section of BIDS, we deliberately included multiple statements that address particular concepts, such as relevance, as internal validation and to look for correlations between responses.

The first two statements ("I do not feel comfortable voicing my own ideas in science class" and "Everyone can contribute useful ideas in a scientific investigation or engineering design process") both address inclusion, the first from the perspective of belonging and the individual, and the second looking out at others. We expected there to be a negative correlation between these two statements—if one felt that they were not comfortable contributing in science class, they would also feel that not everyone can contribute useful ideas—but there is no correlation between responses to these two statements.

We also explored the correlation between the two statements about the most important thing you need to teach science: knowing a lot of facts and knowing how to do science. As these two statements offer different alternatives, we expected there to be a negative correlation in responses. However, there is a weak positive correlation of 0.40 for pre-instruction responses (p-value = <<0.001) and a correlation of 0.44 in post-instruction responses (p-value = <<0.001). As noted previously, this suggests that participants think both are important for teaching.

We expected to see a positive correlation between the statements, "The most important thing you need to teach science is to know a lot of facts within a discipline" and "Science classes are primarily about learning what we already know in a discipline, as opposed to actively investigating questions or solving problems." Indeed, there is a weak positive correlation of 0.34 in both the pre- and post-instruction responses (p-value << 0.001).

The statements "Science and engineering can address questions and problems in my everyday life outside of classes" and "Learning science and engineering that is not directly relevant to or applicable to my life is not worth my time" both address relevance. Nearly 90% of participants agree with the first statement (Figure 8) and about 75% disagree with the second statement

(Figure 14). In addition, there is a weak negative correlation of -0.33 in pre-instruction responses (p-value = <<0.001), and -0.29 in post-instruction responses (p-value = <<0.001). This suggests that participants are both aware that science and engineering is relevant to their lives, but it doesn't *have* to be relevant for them to be interested in it.

Summary of changes in attitudes and beliefs

Participant responses to four statements indicate a significant change from the pre- to post-instruction surveys:

- A small net gain in disagreement with the statement "Everyone can contribute useful ideas in a scientific investigation or engineering design process," though over 90% of participants agree with the statement in both the pre- and post-instruction surveys;
- A net gain in disagreement (8.8%) with the statement, "I have a hard time using big ideas and theories in science to help me understand specific concepts;"
- A <5% gain in agreement with the statement, "I can use my skills to figure out how to investigate a scientific question even if I don't know that much about the details;" and
- A 13% gain in disagreement with the statement, "When I am asked to explain data, I don't really know how to start."

Participants' responses to some statements are correlated with the number of their previous college-level science courses and whether or not they have chosen education as a major.

Confidence in investigation and design skills

In both the pre- and post-instruction surveys, students are presented with a set of 20 items designed to assess their confidence in their investigation and design skills. The prompt states: "The following items describe science and engineering-related tasks. Don't actually try to complete the tasks. Instead, rate your confidence in being able to address the task, or if you do not understand it." The statements that follow are performance expectations from the Next Generation Science Standards worded as "I can…" statements. The 20 statements come from both the middle-school level and high-school level grade bands and are roughly evenly distributed across the three disciplines of the NGSS (Figure 16).

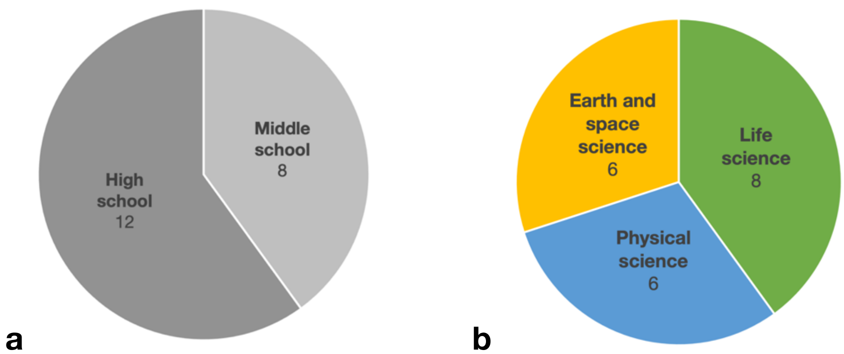

Figure 16. Distribution of the 20 confidence statements (a) by grade level and (b) by discipline.

The statements include performance expectations that cover seven of the eight science and engineering practices (SEPs) of the NGSS (Figure 17). This distribution is approximately representative of the distribution of SEPs within the NGSS, and we attempted to follow the disciplinary distribution of the practices as well, while overall limiting the number of statements included in the survey. Note, the SEP "asking questions and defining problems" is not included in the confidence statements.

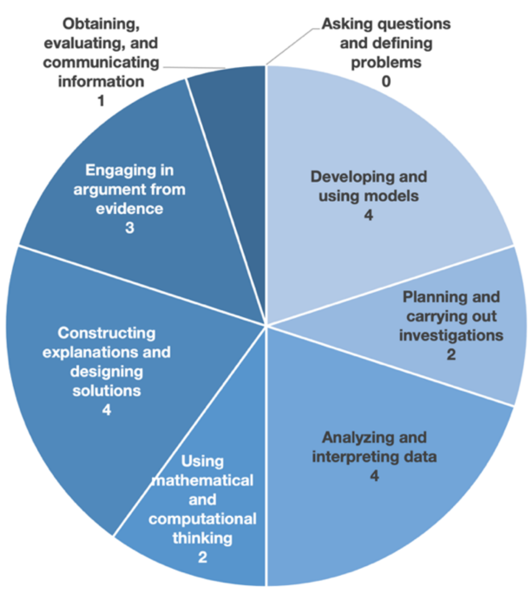

Figure 17. Distribution of the 20 confidence statements by science and engineering practice.

Change in confidence from pre- to post-instruction

For each of the 20 confidence statements, students can select “Highly confident,” “Somewhat confident,” “Not at all confident,” or “I do not understand the task.” In order to calculate means, we assigned a value of 0 to the response “I do not understand the task” and values of 1, 2, and 3 to the levels of confidence (3 = highly confident). Averages of each pre- and post- score from survey data was calculated and a two-tailed, paired t-test was performed. In aggregate, all statements saw a statistically significant gain in confidence from pre- to post-instruction (p-value << 0.001) (Table 20).

Table 20. Pre- to post-instruction change in confidence (means).

	Statement	Discipline	Level	SEP	Pre-mean (±SD)	Post-mean (±SD)	Difference (post-pre)
1	I can evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios	ESS	HS	Engaging in argument from evidence	1.32 ±0.86	1.68 ±0.88	0.36
2	I can use mathematical representations to support explanations of how natural selection may lead to increases and decreases of specific traits in populations over time	LS	MS	Using mathematical and computational thinking	1.65 ±0.77	1.92 ±0.79	0.27
3	I can analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects	ESS	MS	Analyzing and interpreting data	1.51 ±0.80	1.92 ±0.79	0.41
4	I can construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object	PS	MS	Analyzing and interpreting data	1.58 ±0.79	1.88 ±0.85	0.30
5	I can develop and use a model of the Earth-sun-moon system to describe the cyclic patterns of lunar phases, eclipses of the sun and moon, and seasons	ESS	MS	Developing and using models	1.70 ±0.85	1.90 ±0.88	0.20
6	I can collect data to provide evidence for how the motions and complex interactions of air masses results in changes in weather conditions	ESS	MS	Planning and carrying out investigations	1.37 ±0.77	1.78 ±0.85	0.41
7	I can plan an investigation to provide evidence that the change in an object’s motion depends on the sum of the forces on the object and the mass of the object	PS	MS	Planning and carrying out investigations	1.57 ±0.81	1.89 ±0.84	0.32
8	I can evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem	LS	HS	Engaging in argument from evidence	1.77 ±0.78	2.10 ±0.79	0.33
9	I can use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media	PS	HS	Using mathematical and computational thinking	1.49 ±0.82	1.74 ±0.84	0.25
10	I can apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population	LS	HS	Analyzing and interpreting data	1.66 ±0.80	1.96 ±0.81	0.30
11	I can construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity	ESS	HS	Constructing explanations and designing solutions	1.78 ±0.78	2.14 ±0.81	0.37
12	I can develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere	LS	HS	Developing and using models	1.76 ±0.77	2.05 ±0.80	0.29
13	I can evaluate the evidence for the role of group behavior on individual and species’ chances to survive and reproduce	LS	HS	Engaging in argument from evidence	1.78 0.76	2.06 ±0.77	0.27

14	I can use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate	ESS	HS	Developing and using models	1.54 ±0.76	2.04 ±0.82	0.50
15	I can analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth under the assumption that natural laws operate today as in the past	LS	MS	Analyzing and interpreting data	1.45 0.77	1.86 ±0.83	0.41
16	I can design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity	LS	HS	Constructing explanations and designing solutions	1.65 ±0.75	2.08 ±0.78	0.44
17	I can evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter	PS	HS	Obtaining, evaluating, and communicating information	1.24 ±0.77	1.59 ±0.87	0.35
18	I can use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms	PS	HS	Developing and using models	1.58 ±0.81	1.83 ±0.86	0.25
19	I can apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision	PS	HS	Constructing explanations and designing solutions	1.24 ±0.81	1.56 ±0.90	0.32
20	I can construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms	LS	MS	Constructing explanations and designing solutions	1.66 ±0.77	2.02 ±0.77	0.37

Influence of grade-level on change in confidence

We considered that participant responses to questions about confidence may be influenced about the level of difficulty of the item. Because the items in this section include statements from both the middle- and high school-level performance expectations, we used the level as a proxy for difficulty and grouped the difference in means to see if confidence gains differed between the groups (Figure 18).

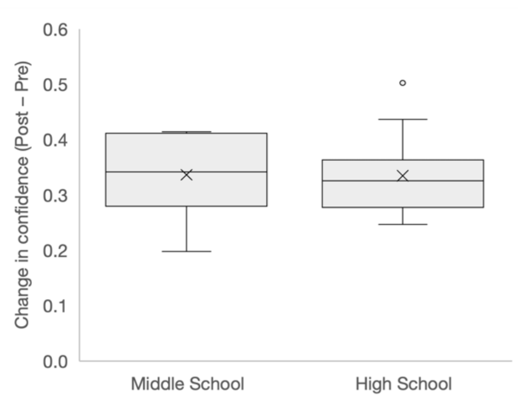

Figure 18. Boxplot of pre- to post- gains in confidence statements binned by grade-level.

Both groups had an average confidence gain of 0.3 – 0.4, with no difference in pre-to-post gains. We calculated the correlation (<0.02) for confidence statements at the middle school (recoded numerically to 1) and high school level (recoded numerically to 2). There was no correlation based on grade level.

Influence of type of scientific and engineering practice on confidence

We also considered that the practice presented in the statement might have an impact on participants' confidence, so we grouped the difference in means by practice (Figure 19).

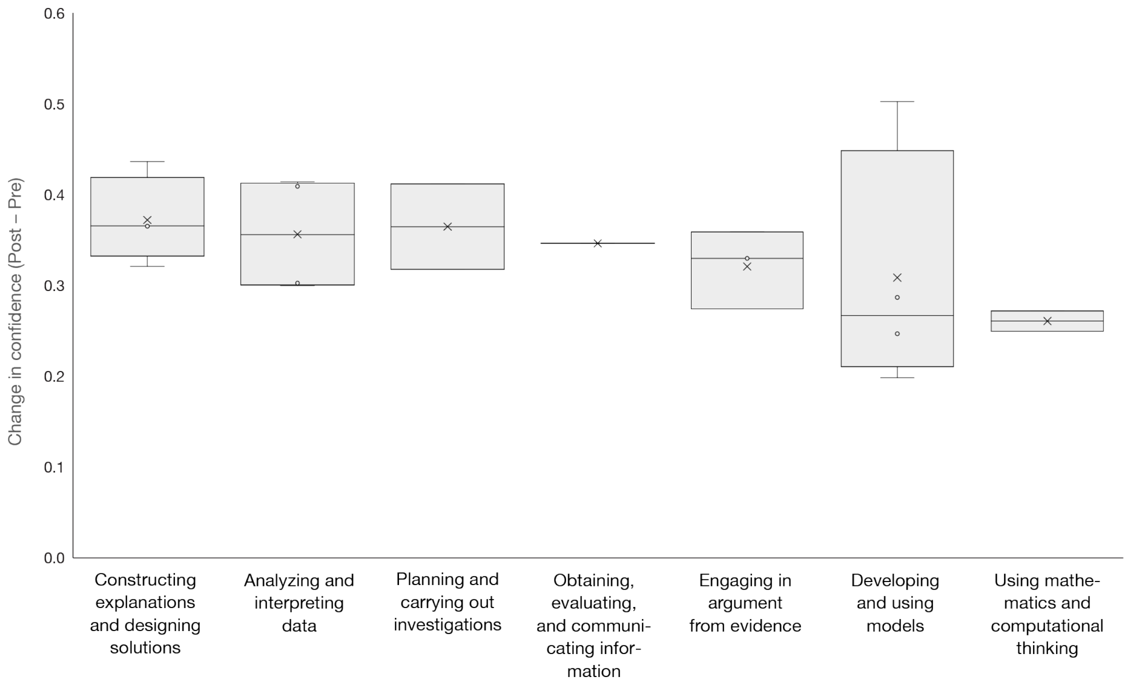

Figure 19. Boxplot of change in confidence for statements binned by science and engineering practice.

The ranges of the difference in means are overlapping across six of the seven practices—note that there is only one statement that addresses "obtaining, evaluating, and communicating information" (Figure 19). However, the range for "using mathematical and computational thinking" differs from all but "developing and using models," with a lower confidence gain. Similarly, Kang et al. (2018) found that elementary teachers self-reported the lowest confidence in their ability to support students in using mathematical and computational thinking. "Developing and using models" has the widest range, with both the lowest and highest confidence gains. This distribution reflects results from Carpenter et al. (2019) that the practice of modeling is understood and interpreted differently by potential and pre-service teachers. These results suggest that these two practices may be more difficult for students to gain confidence in and may need to be the subject of explicit instruction.

Influence of science and course discipline on confidence gains

As previously noted, the confidence statements span the disciplines of the NGSS, but the survey was administered in disciplinary courses in the life sciences, Earth and space sciences, physical sciences, and environmental science. We binned the confidence gains by discipline of the statement (Figure 20) and then compared participants' gains in the statements in their course discipline to participants' gains in courses outside the statement discipline.

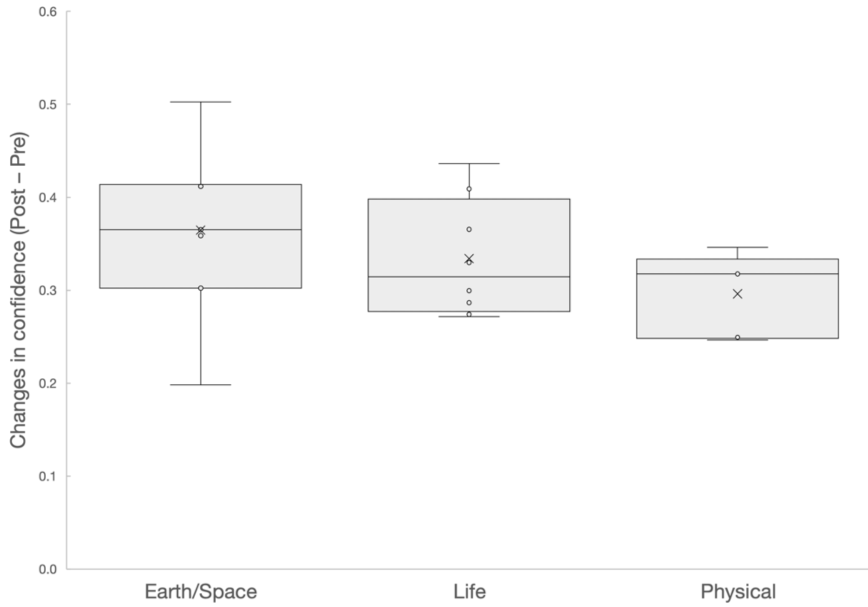

Figure 20. Boxplots of gains in confidence statements binned by NGSS disciplines.

The range of confidence gains overlaps across the three disciplines. We saw no statistically significant correlation between discipline and confidence gain.

More importantly, however, we compared participants' confidence gains for the statements whose discipline matched the course in which they were enrolled to the means gains for participants in courses not in that discipline. For each discipline, we calculated the pre- and post-averages for both groups and conducted two-tailed, paired t-tests to test for difference between the groups (Tables 21, 22, 23).

Table 21. Comparison of confidence gains on Earth and space science items.

	Mean confidence gain			
Statement	**ESS courses** (n = 101)	**Non-ESS courses** (n = 297)	**Difference**	**p-value**
I can analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects.	0.61	0.35	0.26	0.77
I can construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.	0.53	0.32	0.21	0.10
I can evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.	0.51	0.31	0.20	0.64
I can develop and use a model of the Earth-sun-moon system to describe the cyclic patterns of lunar phases, eclipses of the sun and moon, and seasons.	0.32	0.16	0.16	0.70
I can use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.	0.5	0.46	0.04	0.07
I can collect data to provide evidence for how the motions and complex interactions of air masses results in changes in weather conditions.	0.32	0.37	-0.05	0.73

Table 22. Comparison of confidence gains on life science items.

Statement	Mean confidence gain: LS courses (n = 56)	Mean confidence gain: Non-LS courses (n = 338)	Difference of means	p-value
I can use mathematical representations to support explanations of how natural selection may lead to increases and decreases of specific traits in populations over time.	0.52	0.34	0.18	0.07
I can evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem.	0.47	0.31	0.16	0.85
I can apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population.	0.40	0.25	0.15	0.90
I can develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.	*0.38*	*0.29*	*0.09*	*0.02*
I can evaluate the evidence for the role of group behavior on individual and species' chances to survive and reproduce.	0.43	0.41	0.02	0.30
I can analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth under the assumption that natural laws operate today as in the past.	0.20	0.28	-0.08	0.40
I can design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.	0.16	0.31	-0.15	0.32
I can construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms.	0.30	0.46	-0.16	0.42

Table 23. Comparison of confidence gains on physical science items.

Statement	Mean confidence gain: PS courses (n = 92)	Mean confidence gain: Non-PS courses (n = 302)	Difference	p-value
I can plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.	0.67	0.21	0.46	0.46
I can use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media	0.49	0.27	0.22	0.47
I can construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object	0.47	0.25	0.22	0.08
I can evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter	0.31	0.23	0.08	0.46
I can use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms	0.34	0.35	-0.01	0.46
I can apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision	0.22	0.25	-0.03	0.46

For most statements, the mean change in confidence is greater for those where the discipline of the statement matches the discipline of the course (green values in difference column in Tables 21, 22, and 23). In only one case, however, does this difference achieve statistical significance: the statement about photosynthesis in life sciences (Table 22).

Environmental science is not a separate discipline within the NGSS performance expectations, and environmental science courses tend to take an integrated approach that incorporates aspects of all disciplines. For those reasons, we compared confidence gains from participants in environmental science courses (n = 149) to participants in other courses (n = 245) for all of the 20 confidence statements (Table 24).

Table 24. Comparison of changes in confidence gains for environmental science courses.

	Mean confidence gain			
Statement	**Env Sci courses** (n = 56)	**Non-Env courses** (n = 338)	**Difference of means**	**p-value**
I can design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity	0.64	0.32	0.32	0.26
I can develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere	0.47	0.18	0.29	0.73
I can collect data to provide evidence for how the motions and complex interactions of air masses results in changes in weather conditions	0.56	0.32	0.23	0.51
I can evaluate the evidence for the role of group behavior on individual and species' chances to survive and reproduce	0.39	0.20	0.19	0.31
I can analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects	0.52	0.35	0.18	0.25
I can construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms	0.48	0.30	0.18	0.36
I can use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate	0.61	0.44	0.17	0.89
I can evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem	*0.43*	*0.27*	*0.16*	*0.04*
I can use mathematical representations to support explanations of how natural selection may lead to increases and decreases of specific traits in populations over time	0.35	0.23	0.12	0.68
I can construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity	0.43	0.33	0.10	0.11
I can evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios	0.40	0.34	0.06	0.06
I can evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter	0.36	0.34	0.03	0.45
I can develop and use a model of the Earth-sun-moon system to describe the cyclic patterns of lunar phases, eclipses of the sun and moon, and seasons	0.19	0.20	-0.01	0.28
I can apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population	0.27	0.32	-0.04	0.72

I can construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object	0.27	0.32	-0.06	0.83
I can apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision	0.28	0.35	-0.07	0.43
I can use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media	0.19	0.28	-0.09	0.91
I can analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth under the assumption that natural laws operate today as in the past	0.33	0.45	-0.12	0.78
I can plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object	0.21	0.38	-0.17	0.06
I can use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms	0.10	0.34	-0.24	0.86

The mean confidence gain was higher for twelve of the twenty statements for participants in environmental science courses than in non-environmental science courses, though only one difference achieves statistical significance, that about changes in ecosystems (Table 24). The statements span the three disciplines of the NGSS, though only one is in the physical sciences (Table 20). The statements for which the mean confidence gains are lower for participants in environmental science courses are primarily in the physical sciences.

These results are as we might expect: students generally gain more confidence in the skills tied to the discipline in which they are applying those skills than in another discipline. However, given the significant gains across all of the statements (Table 20), these data also suggest the possibility that students are also becoming more confident in their ability to transfer these skills.

Influence of course content on confidence

Within their introductory courses, instructors make decisions about what to cover. In order to determine the influence of the content covered (rather than just the discipline of the course) on confidence gains, we asked instructors to select to what extent they covered the skills and content of each statement. They could choose, "Out of the realm of the course," "Not at all covered," "Covered somewhat," or "Covered explicitly." We merged "Out of the realm of the course" and "Not at all covered" into one group and compared pre- and post-instruction responses from those three groups (Figure 21).

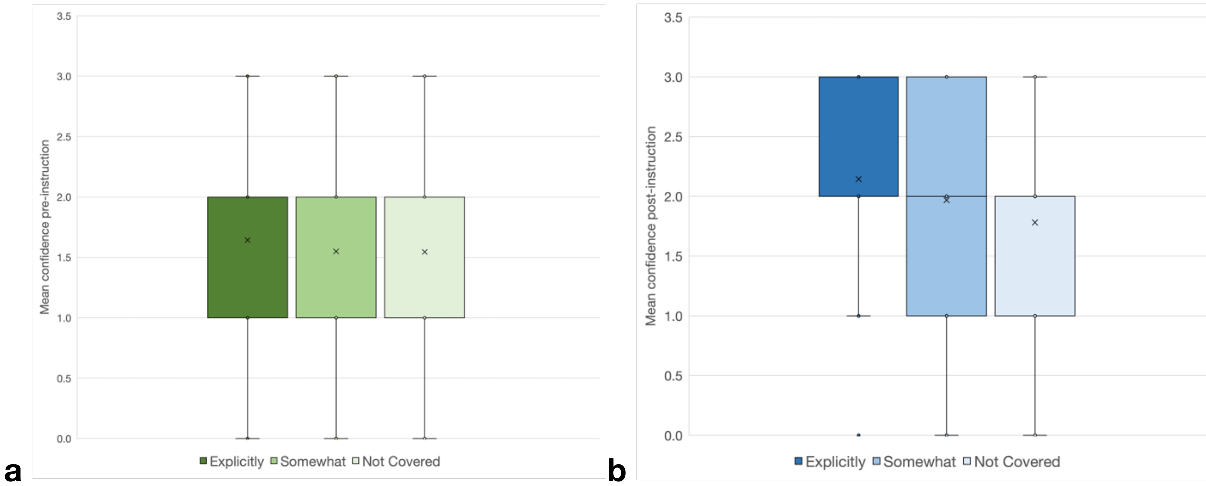

Figure 21. Boxplots showing (a) pre- and (b) post-instruction data for all confidence statements binned into groups in courses which covered these statements "explicitly", "somewhat" or "not covered."

Pre-instruction, the range, averages, and medians of each group are the same (Figure 21a). In the post-instruction data (Figure 49b), the three groups differentiate. For the explicitly covered statements, there was a mean 0.50 confidence gain compared to a 0.23 confidence gain for the not covered statements. There is a wider spread and a gain of 0.42 for the "somewhat" group. These results are not surprising, and they provide a means for us to control for content explicitly covered in the course in our analyses.

Summary of changes in confidence

We see significant confidence gains for all 20 confidence statements in the aggregate data. Those confidence gains appear to be influenced by the discipline of the course and the extent to which the content is covered in that course, but not by level of the performance expectation or the science and engineering practice.

Correlations between beliefs and attitudes and confidence

One of the attitude statements is "I can use my skills to figure out how to investigate a scientific question even if I don't know that much about the details." We might expect that students who agreed with this statement would have higher confidence not only in the discipline of their course, but in all of the statements. To test this hypothesis, we performed a Pearson's product-moment correlation test using the program R on all pre- and post-instruction confidence items to extent of agreement pre- and post-instruction with the attitude statement.

The pre-instruction responses to the attitude statement have a very weak to no linear relationship with responses to the pre-instruction confidence statements. There is, however, a very weak to weak positive correlation to all confidence statements in the post-instruction data, regardless of discipline, science and engineering practice, or level. All correlations are statistically significant. In other words, participants that agree with the statement, "I can use my skills to figure out how to investigate a scientific question even if I don't know that much about the details," do tend to have slightly higher confidence than those who disagree with the statement.

Using skills beyond the course: Post-instruction questions

Four questions appear only in the post-instruction survey and ask students to reflect on the course. Two questions address career interests, and a paired yes/no and open-response set of questions asks students about how they will use the skills learned or practiced in the course.

Careers

We used graphs to depict conceptual changes in student interest in careers, providing four options (Figure 22) for two questions:

- Which of the following graphs most accurately depicts your level of interest in a career in science or engineering before and after taking this course?
- Which of the following graphs most accurately depicts your level of interest in a career in **teaching** science or engineering before and after taking this course?

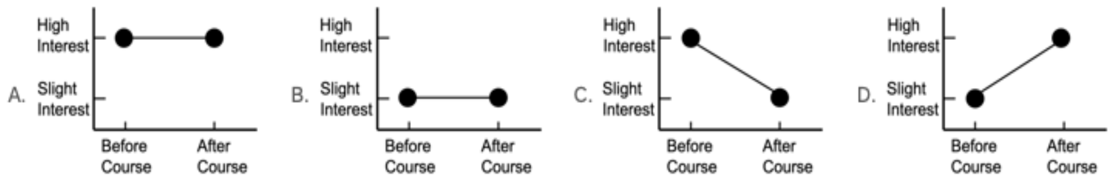

Figure 22. Options that students could choose from to depict their level of interest and how it changed (or not).

The largest proportion of students began and ended the course with slight interest in a career in STEM or STEM teaching (Figure 23), as might be expected in an introductory course. However, a substantial proportion reported increased interest: 22% went from slight to high interest in STEM careers, and 17% went from slight to high interest in STEM teaching careers.

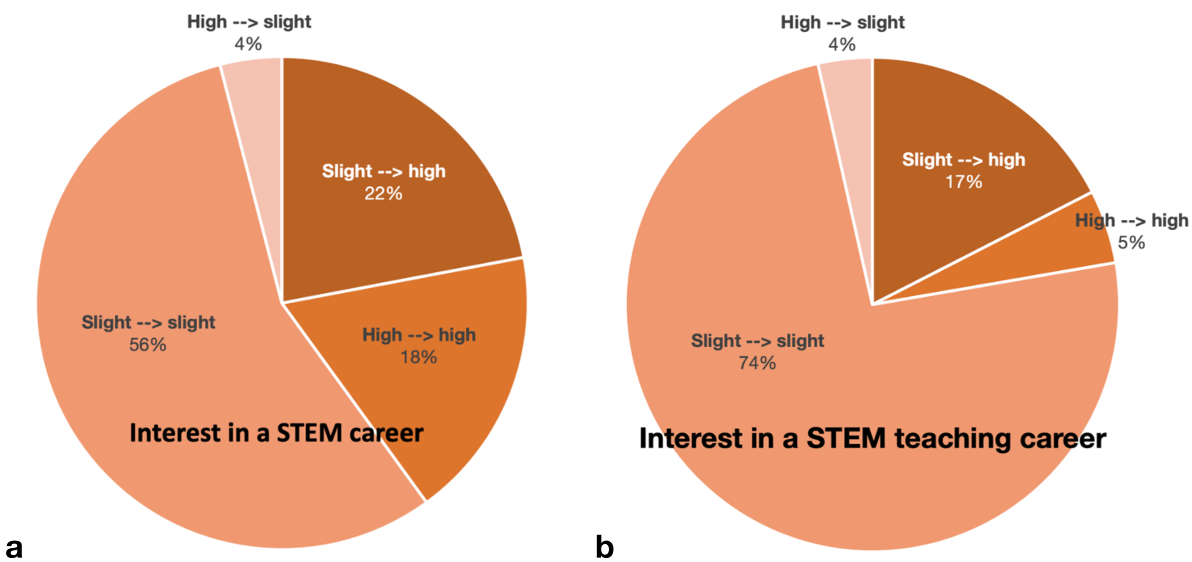

Figure 23. Participants' interest in (a) STEM and (b) STEM teaching careers (n = 395).

We compared participants responses to the two questions (Table 24) and found a weak positive correlation (0.26) that was statistically significant (p-value << 0.001). This indicates students who choose one response in the interest in a STEM career question are slightly more likely to choose that same response in their interest in STEM teaching.

Table 24. Participants' matched responses to career questions (n = 395).

Which of the following graphs most accurately depicts your level of interest in …		… a career in science or engineering before and after taking this course?			
		High to high	Slight to slight	High to slight	Slight to high
… a career in **teaching** science or engineering before and after taking this course?	High to high	2.5%	13.9%	0.0%	1.5%
	Slight to slight	1.0%	45.1%	2.3%	7.6%
	High to slight	0.0%	2.8%	1.3%	0.0%
	Slight to high	1.3%	12.4%	0.0%	8.4%

We compared the responses to these career interest questions with choice of major (Table 2). There is a weak positive correlation to interest in STEM teaching and choosing education as a major in the pre-survey (0.28 with a p-value << 0.001) and in the post-survey (0.32 with a p-value << 0.001), and no correlation between interest in a STEM career and choice of education as a major in either the pre- or post-survey. This suggests that participants in the education group are slightly more likely to select having a high interest in STEM teaching. There was no correlation between the selection of other science majors (biological sciences, computer science, physical science, etc.) in either the pre- or post-survey and interest in a STEM career or to interest in STEM teaching. Nor were there correlations between the number of previous science courses at the college level or year in college and the career questions.

Using skills

The post-instruction survey asked students "[a]s you think about your future, can you envision ways in which you use the skills you learned or practiced in this course to address questions and solve problems that are relevant to you, your family, or your community?" with response options of "yes" or "no." The large majority of participants selected yes, that they **can** envision using the skills from the course to address relevant questions or solve relevant problems (Figure 24).

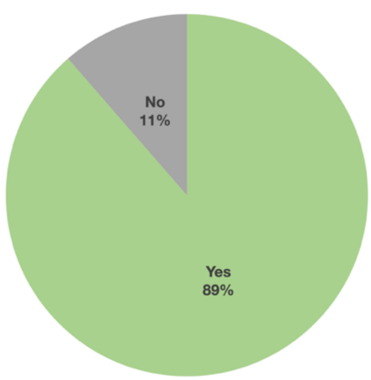

Figure 24. Participants' responses to the question "[a]s you think about your future, can you envision ways in which you use the skills you learned or practiced in this course to address questions and solve problems that are relevant to you, your family, or your community?" (n = 395).

Students who responded "yes" were prompted with the open-ended question, "How do you envision using the skills you learned or practiced in this course to address questions and solve problems that are relevant to you, your family, or your community? Please name the skills in your response." Students who responded "no" were prompted, "Why not?" We coded these responses using an inductive, iterative process in which two researchers independently coded, compared their codes, recoded, and came to agreement on the final codes. This process produced four categories of "yes" codes (Table 24) and six "no" codes (Table 25).

Table 24. Codes for "yes" responses (n=350).

Code	Subcode	Description	Examples	Frequency
Y1	**Irrelevant or unclear**	Answer is n/a, irrelevant, the meaning is unclear, or there is no response	"Melting ice," "environmental engineering firms that can influence urban development," "N/A"	3.9%
Y2	**Not sure**	Response is "I don't know", or otherwise expresses uncertainty.	"I don't know if I will ever apply it in my life," "I'm not sure at the moment."	2.8%
Y3	**Skills that you will use (sum of codes below)**			**42.9%**
	Content-related skills	Response refers to understanding of specific content (anatomy, weather)	"I will use computer science skills," "I like being outside and in nature so I can use the skills I have learned in these environments."	18.7%
	Science skills	Interpreting and/or analyzing data, setting up studies and experiments, using the scientific method, etc.	"Use the scientific method," "Using ways of research and collecting data," "I can analyze a figure or graph …"	6.0%
	General school skills	Critical thinking, writing, reading, study skills, time management	"I will use the skill of being able to think super critically," "communication."	5.5%
	Teaching skills	How to teach	"Being able to teach people," "These skills include teaching students about..."	5.4%
	Problem solving	Response refers to problem solving	"…it gives me a better way of problem solving," "conceptual thinking," "Through problem solving"	5.3%
	Working in teams	Working together, collaboration, group work	"Working together in a group," "cooperation," "Learning to … work effectively as a team."	1.1%
	Math skills	Math skills	"I think I improved my math skills in general," "I learned how to use statistics."	0.6%
Y4	**Ways...you will use the skills**			**59.1%**
	To understand content	Learn about or understand topics, natural phenomena (the weather, growing plants, etc.)	"...understanding the relationships between plant and animals including humans," "...to fully understand environmental issues."	18.4%
	In career	Response refers to either a specific career (doctor, physical therapist) or career in general	"I plan to apply them to my daily work life," "...in order to purse an effective career in veterinary science."	10.9%
	To educate others	Including to raise awareness, to share information, etc. Including family, friends, students, community	"I can inform people better on how climate change is affecting us.," "...to bring awareness to many new topics."	8.5%
	To make the world a better place	To improve the environment through action or knowledge	"… to reduce my personal footprints," "...to make the world more efficient and safer," "...devising plans to protect the environment and wildlife…"	8.4%
	To solve problems	General or specific description of solving problems	"...to solve family issues or issues within my community," "It would also help me analyze and solve real life issues I face in my daily life."	4.7%
	To make better decisions	Make decisions about things in personal life (where to live, mitigating climate change impacts, keeping family safe).	"...in order to make quick and life altering decisions correctly and get positive feedback from it," "...to make better decisions."	4.2%
	In further schooling	Getting into med school or vet school, in future (more advanced) courses	"...it can help me in my other science classes," "will help me as I continue to take STEM courses in the future."	2.0%
	To help others	General or specific ways that "helping others" is mentioned	"I can and I want help them to keep their health," "so I can go back home and serve the community."	1.3%

Table 25. Codes for “no responses (n = 45).

Code	Description	Examples	Frequency
N1	Lack of relevance to everyday life	“Math is not a part of my everyday life,” “…do not see it applicable to everyday use”	26.7%
N2	Lack of relevance to major or career	“I am not going into a science related career”, “I don't think it will be useful at all because of my major.”	28.9%
N3	Lack of interest	“Not interested in science at all,” “my family and I are more interested in the business sector”	11.1%
N4	Lack of science skills	“I would not be able to accurately explain what would be asked,” “Science is not my strong suit”	20.0%
N5	Lack of motivation	“I am only one person”	4.4%
N6	No reason	“I just don’t”	15.6%

We do not sum the frequencies because some responses had multiple codes applied. For the yes responses, not all participants addressed both parts of the question in their responses (Table 24).

The largest proportion of participants who responded “yes” mentioned content-related skills (Y3) and specific content applications (Y4) in their responses (Table 24).

Participant demographics

At the end of the pre-instruction survey only, students were asked a set of questions about their gender identity, race and ethnicity, and the level of education of their parents. The questions are introduced with this statement: "We are interested in understanding how beliefs about and engagement in science, engineering, and teaching are influenced by many factors, including aspects of student identity. We are asking these questions about gender, race and ethnicity, and educational background to better understand the impact of teaching practices on all students."

We asked two questions for gender identity. The first question asks, "Which of the following best describes you?" Students could select from the choices: woman, man, agender, non-binary, gender fluid, gender queer, prefer not to answer, and prefer to self-describe (and fill in the blank). The second question asked students if they are transgender. The majority of participants identify as women (Figure 25). Less than 3% of participants identified as transgender.

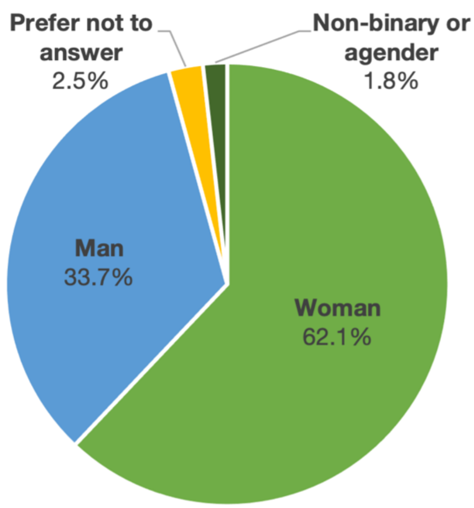

Figure 25. Gender identity of participants (n = 398).

Students were asked, "Which of the following best describes you?" in terms of race/ethnicity. Options are listed in alphabetical order and students can select as many as applied. The majority of participants identify as White (Table 26); 12% of participants selected more than one race.

Table 26. Race/ethnicity of participants (n = 394).

Race/Ethnicity	Proportion of participants
American Indian or Alaska Native	0.0%
Asian or Asian American	5.8%
Black or African American	9.5%
Hispanic, Latinx, or Spanish Origin	27.1%
Middle Eastern or North African	0.3%
Native Hawaiian or Pacific Islander	0.3%
White	57.0%
Another race or ethnicity not listed above:	0.6%

Finally, we asked students, “Did any of your parent(s) complete a four-year college degree?” Students could select from the responses yes, no, unsure, and prefer not to answer. The majority of participants have had at least one parent complete a four-year college degree (Figure 26). About 30% responded “no;” we consider this group to be first-generation college students.

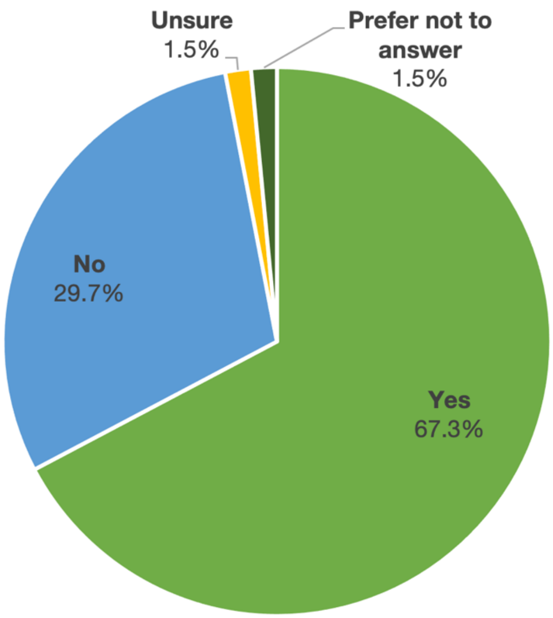

Figure 26. Responses to the question, “Did any of your parents complete a four-year college degree?” (n = 394).

When we implement BIDS in courses where the instructors are using TIDeS materials, we will be able to see if pre- to post- changes are more influenced by type of instruction or by these demographic factors.

Summary of BIDS data 2021-22

About a third of participants in the Beliefs in Investigation and Design Survey (BIDS) were in their first year of college, about a quarter had chosen or will choose education as a major, and most had taken one or two science courses at the college level. These data suggest that we are reaching our target student audience in these courses. Participants were majority women (62%), White (57%), and had at least one parent attend college (67%).

There was a significant change in four of 13 attitude and belief statements from pre- to post-instruction, and correlations between these responses and the number of previous science courses and whether or not students are majoring in education. There was a significant increase in confidence across all 20 confidence statements project-wide; confidence gains were greater when instructors explicitly covered material, with some influence of the course discipline. We saw weak correlations between belief statements about skills and confidence.

Most participants began and ended the course with a slight interest in careers in both STEM and STEM teaching, and about 20% reflected that their interest in these careers changed from slight to high. The large majority can envision using the skills they learned in the course in the future.

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