Enhancing student learning in a Large-Enrollment, Scientific Computing Workshop in Seismology

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Seismology Skill Building Workshop (SSBW)

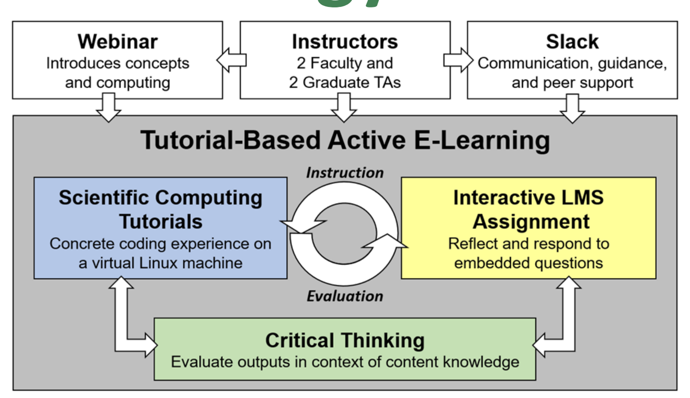


Figure 1. Overview of the SSBW (Brudzinski et al., 2021). Tutorial based learning is supported by a weekly webinar, Instructors, and Slack peer communication. Within each tutorial students experience cycles of instruction and evaluation as they complete scientific computational tutorials and interactive assignments. Students actively employ critical thinking skills while answering questions and receiving immediate feedback.

Contextual Focus:

- Centers on computer programming in the context of seismology

Module and Assignment Structure:

- 6 modules with approximately 6 tutorial assignments per module
- Comprises a total of 1084 questions

Immediate Feedback:

- Provides immediate feedback to students
- Allows for reattempting questions based on feedback

Learning Management System (LMS):

- Utilizes the Moodle LMS for interactivity and data collection

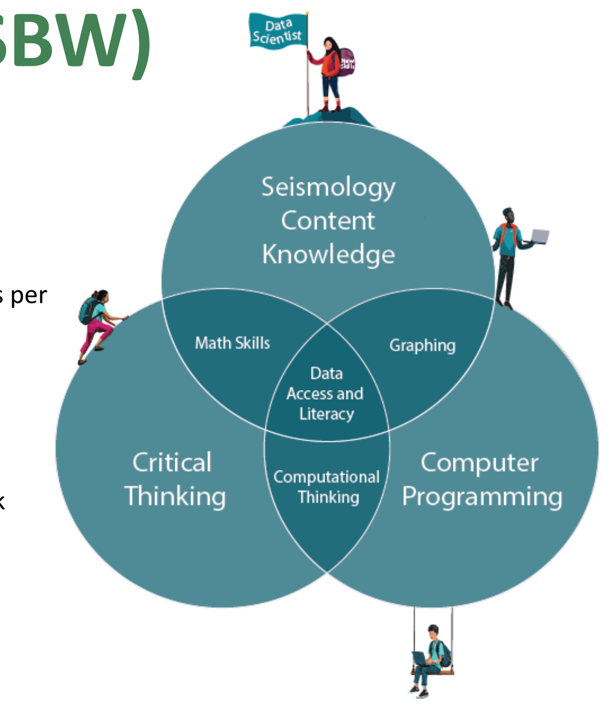


Figure 2: Representation of the skills identified within the SSBW which give students the skills necessary to be successful in modern geoscience careers.

Study Motivation

- Increasingly digital nature of assignments provides an opportunity for in-depth assessment of student learning and course design.
- The SSBW was chosen for analysis due to its high student enrollment, facilitating trend identification within the data.
- There is a need for a shift to hands-on, computational coursework in geoscience and the SSBW addresses this need on a large scale.

Who The SSBW Reaches

- Since 2020, international participation in the workshop has surged from 46% to 83% by 2024.
- US participants have included ~60% women and ~30% marginalized racial and ethnic groups, surpassing diversity levels in undergraduate geoscience degrees awarded to women in 2019 46%) and doubling those awarded to marginalized groups in 2016 (15%).
- Learn more Tuesday 8:30—12:20 at Poster Board Number: ED21F-2372

~1,400 Students in 2024

Skill and Taxonomy Characterization

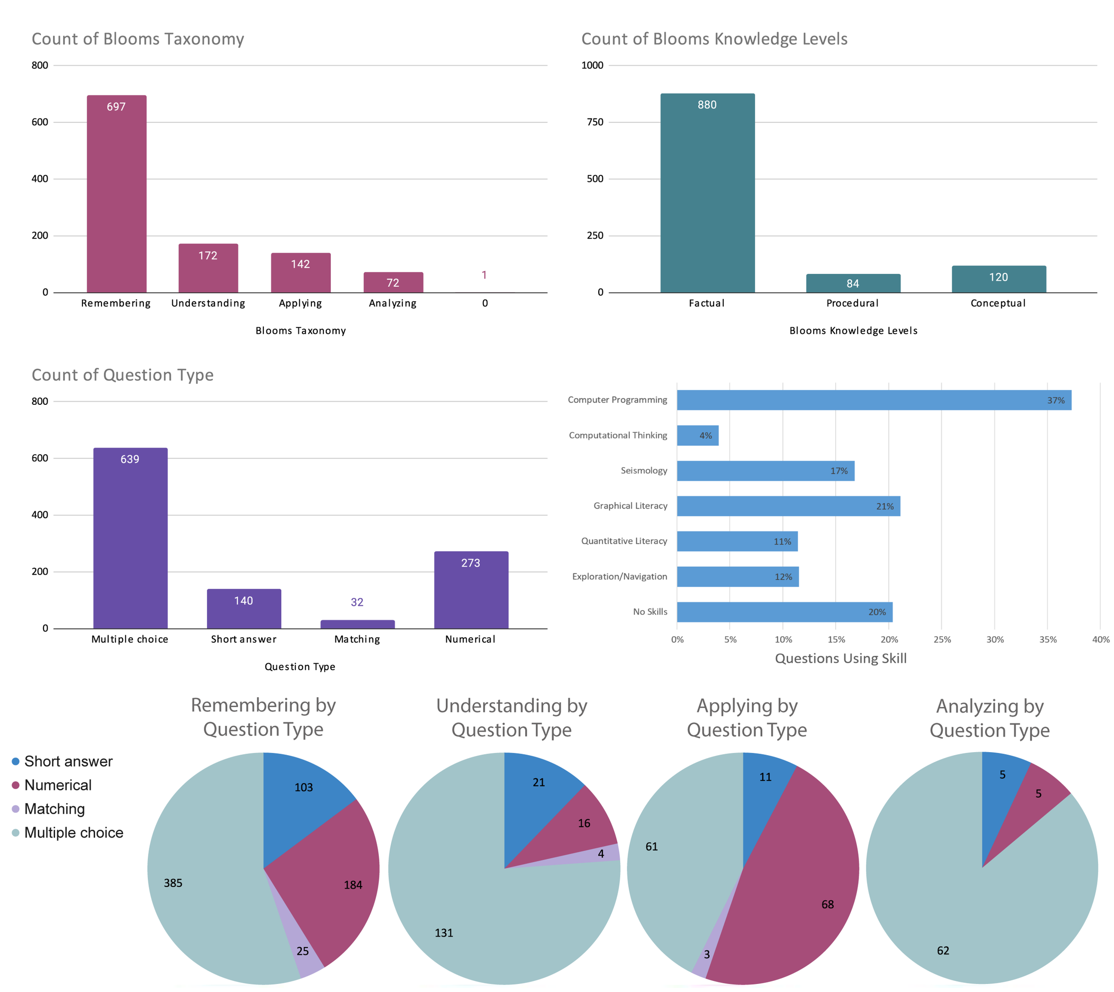


Figure 3. Distribution of variables in our SSBW dataset. Histograms display the number of questions categorized by a) Bloom's Taxonomy , b) Bloom's Knowledge Levels, c) question type, and d) percentage of questions requiring a skill. The pie charts at the bottom illustrate the percentage of questions of a particular type for each of the Bloom's Taxonomy levels

Distribution of Question Type:

- Most common type of question was multiple choice (86%), focused on remembering (64%) factual knowledge (81%)
- The high proportion of remembering questions was not due to a reliance on the multiple choice format as understanding and analyzing used this format more often

Distribution of Skills:

- Computer programming was the most common skill (37%), but computational thinking was the least common (4%)
- Seismology skills were half as common as computing (17%),
- Although basic instructions are needed in tutorial assignments, no skill questions (20%) were a missed opportunity
- No skill questions had higher facility than our target (91%), while questions requiring 2+ skills were more challenging (82%) than 1 skill questions (86%)

Skill Required to Answer a Question:

Skill	Definition	Example
Computational Thinking	Requiring students to perform multiple steps to arrive at the right solution	"What is the correct order of commands below to create, check, and then enter these sac and act1 directories?"
Computer Programming	Requiring students' understanding of programing language and applications to answer the question	"Which command would print just the earthquake depths stored in this file?"
Exploration and Navigation	Requiring students to participate in an element of exploration or navigation within an outside source or reference in finding an answer	"Take a minute to use one of the many tools we have learned in this course to find out the rest of the information for this station, assuming we want data from a broadband, vertical channel, recording at 40 samples per second."
Seismology	Requiring students to learn or rely on previous seismology knowledge to arrive at the correct solution	"Why should we not use a latitude range that goes all the way from -90 to 90?"
Quantitative Literacy	Requiring students' understanding of math within a context	"If there are 200 points with an interval of 0.01 seconds, what is the total length of the signal?"
Pattern Recognition or Graphical Literacy	Requiring students' understanding of a graph or visual depiction	"What is the general trend in the amplitude vs. frequency plot?"

Bloom's Taxonomy and Knowledge Levels:

- Remembering: Recall or recognize information from memory.
- Understanding: Demonstrate comprehension of information.
- Applying: Use acquired knowledge or skills in new situations.
- Analyzing: Break down complex information to understand relationships and patterns.
- Factual Knowledge: Recall basic information such as facts, terms, definitions, or details.
- Conceptual Knowledge: Understand and grasp the relationships and connections between different concepts.
- Procedural Knowledge: Know and understand the steps, methods, or procedures required to perform a task or solve a problem.

Conclusions

- **Clear Improvement**: Mean scores improved from pre-test to post-test across both 2023 and 2024, showing effective student learning gains.
  - Survey feedback aligns with these findings, with 69% of students reporting that they learned "A lot" or "A great deal" in seismology, and 76% expressing similar growth in scientific computing skills.
- **Reliable Findings**: Robust sample sizes in both years indicate results are representative of the student population.
- **Meaningful Growth**: High normalized gains and moderate to large effect sizes indicate that the instructional approach significantly boosted understanding, especially in areas with lower initial scores.
  - This is supported by survey responses, with 88% of students agreeing that the workshop enabled clearer understanding of seismology concepts, and 96% noting that it improved their scientific computing abilities.
  - Aligns with surveys showing high normalized gains and moderate to large effect sizes in self-perception of computing capabilities. Minimal gains for our control validates the survey as a measure of impact.
- **Analyzing vs. Remembering**: "Analyzing" questions generally saw higher gains and effect sizes than "Remembering" questions, suggesting students improved more in higher-order thinking skills.
- **Consistent Impact**: Similar gains in both years suggest a consistently effective instructional approach across cohorts.

Resulting Changes from Previous Analysis

- Investigating Bloom's taxonomy and skill usage in our assignments identified that our active e-learning design had less higher order learning and balanced skill development than we sought.
- Changes enacted to implement more higher order thinking and multi-skill requirements.
- Learning analytics presents an excellent opportunity as courses become more digital to achieve evaluation of instructional design to ensure alignment with student learning outcomes and author designed goals.

Pedagogical Changes Based On Findings:

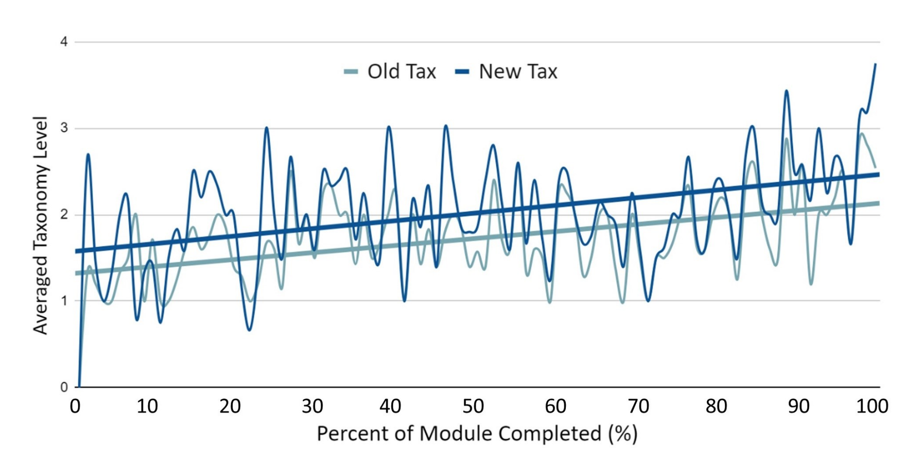


Figure 4. Averaged Taxonomy levels new verses old per percent of Tutorial completed for Modules 4,5 and 6. The x-axis is the percent of any given tutorial completed for each tutorial. The y axis is the averaged taxonomy level across each tutorial in module. 1 is remembering, 2 is understanding, 3 is applying and 4 is analyzing. The thin line shows the averaged taxonomy for each percent of tutorial and the thicker straight line shows the trend of that data. Light green is the taxonomy for 2022 and blue is the taxonomy for 2023. We worked to reduce prompting and increase taxonomy as students progress within modules and from module to module.

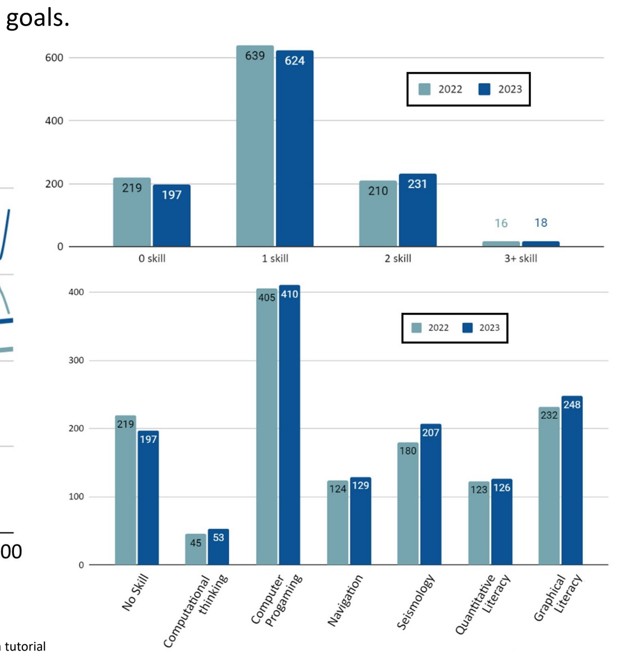
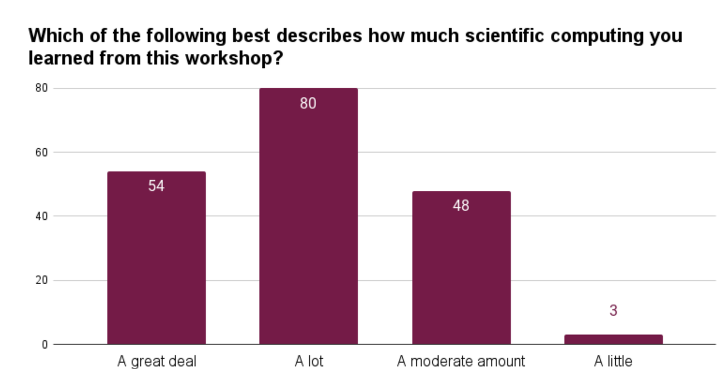
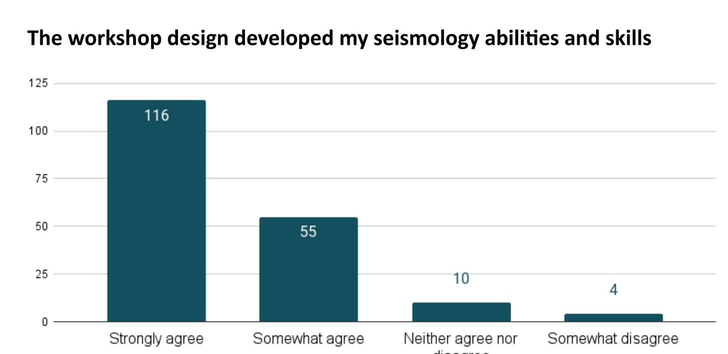
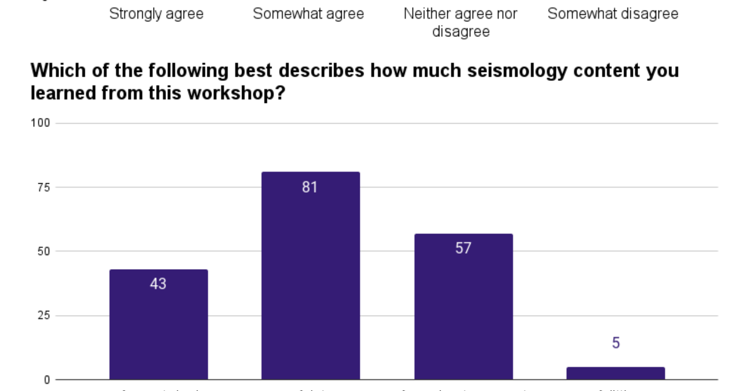


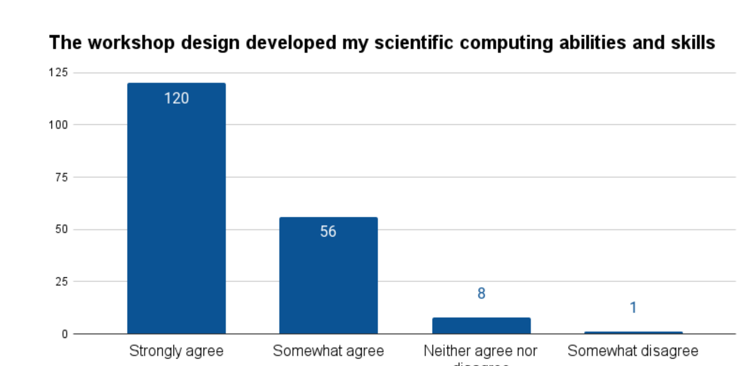
Figure 5. Skill requirement changes (2022 to 2023) for (a) number of skills and (b) questions addressing each skill. We removed excessive no skill questions when possible and added skills to questions that were previously lacking.

2022-2024 Surveys









Normalized Gains (%) based on Post compared to Registration for the same user:

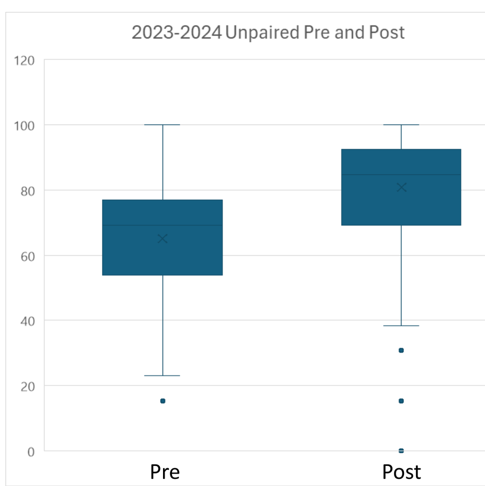
Type	Pre	Post	Normalized Gain
Linux	2.9	5.6	28.4%
GMT	2.7	5.1	26.7%
SAC	1.7	4.9	33.8%
Python	4.2	6.1	30.2%
Jupyter	3.6	5.9	28.0%
Matlab (Control)	3.3	4.6	13.6%

Score Scale	1	2	3	4	5
Description	Not at all interested/ prepared	Not so interested/ prepared	Somewhat interested/ prepared	Very interested/ prepared	Extremely interested/ prepared

Category	Before Survey	After Survey	Normalized Gain
Student Interest Averaged	**3.76**	**4.29**	**42.4%**
Interest in Seismology/Geophysics	3.97	4.4	41.8%
Interest in Scientific Computing	3.65	4.29	47.1%
Interest in Grad School	3.67	4.17	37.5%
Interest in Employment	3.76	4.3	43.3%
Student Preparedness Averaged	**2.85**	**3.65**	**37.3%**
Preparedness for Grad School	2.85	3.69	39.1%
Preparedness for Employment	2.84	3.61	35.5%

2023-2024 Evaluation of Un-Paired Tests

Figure 6. Box plot of unpaired pre- and post-test scores from 2023 and 2024 SSBW assessments, totaling 1,010 tests. The data includes 311 pre-tests from 2023, 458 pre-tests from 2024, and 93 post-tests from 2023, with the remaining 148 post-tests from 2024. The box plots show the distribution of scores for pre- and post-tests, with the median, interquartile range, and outliers displayed. The overall increase in median and range of scores from pre- to post-tests indicates improvement in student performance across the assessments, despite the unpaired nature of the data.



- Most questions show increased mean scores by approximately 10-20% from pre-test to post-test, indicating better student performance after instruction.
- Moderate to large Cohen's D values on many questions highlight significant improvements, with some areas like analyzing navigation and analyzing computer programming showing particularly strong gains.
- Post-test scores often have lower standard deviations, suggesting more consistent understanding among students after instruction. Only three questions have higher standard deviation with the two greatest being within the remembering taxonomy.
- Normalized Gain: Many questions display moderate to high gains, showing effective learning, though some areas may need targeted reinforcement.

Statistical Analysis: Independent t-test ($t = -9.68$, $p = 2.04 \times 10^{-18}$) and Mann-Whitney U test ($U = 6106.0$, $p = 2.16 \times 10^{-17}$) both show a significant difference from pre– and post–test averages.

Test	Mean	Median	Standard Deviation	n	Cohen's D	Normalized Gain
Pre-Test	65.1	69.2	17.5	769	0.87	44.9%
Post-Test	80.8	84.6	18.7	241		

2023-2024 Evaluation of Paired Skill Gains

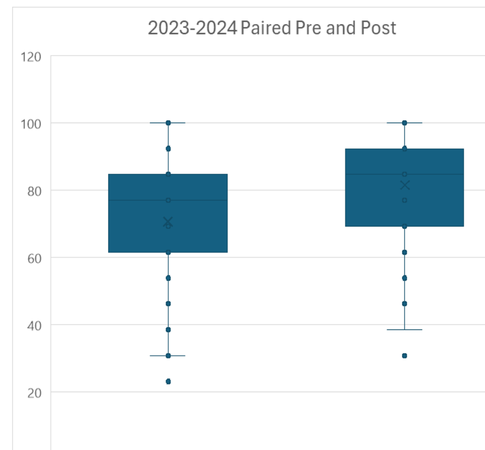


Figure 7. Box plot of paired pre- and post-test scores from 2023 and 2024 SSBW assessments, totaling 194 tests. The data includes 81 paired tests from 2023, and 112 paired tests from 2024. The box plots show the distribution of scores for pre- and post-tests, with the median, interquartile range, and outliers displayed. The overall increase in median and range of scores from pre- to post-tests indicates improvement in student performance across the assessments.

Statistical Analysis: Paired t-test ($t = -5.05$, $p = 2.06 \times 10^{-6}$) and Wilcoxon signed-rank test ($W = 705.0$, $p = 8.51 \times 10^{-7}$) both show a significant improvement from pre– to post–test averages.

Test	Mean	Median	Standard Deviation	n	Cohen's D	Normalized Gain
Pre-Test	68.1	69.2	17.3	194	0.69	38.3%
Post-Test	80.3	84.6	18.2	194		

- Assessed skill gain in 82 students during the 2023 SSBW and 112 students during the 2024 SSBW using matched pre-/post-test questions.
- Analyzing questions generally exhibit higher normalized gains compared to remembering questions.
- Strong gains observed in programming and seismology skills.
- Despite fewer higher-order thinking questions, students show significant improvement in analyzing skills, suggesting that the active e-learning pedagogy effectively supports the development of higher-order skills.

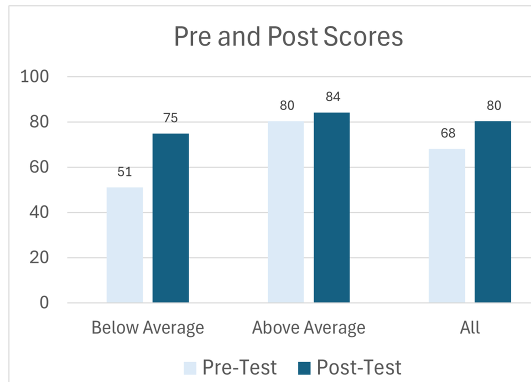


Figure 8. Combined skill gains for 2023 and 2024 cohorts (total of 194 students) during the SSBW, evaluated through matched pre- and post-test questions. List blue is the pre-test and dark blue–shows the post-test. Students that scored below average on either the pre-test or the post-test are to the right. Students who scored above average or average on both the pre-test and the post-test are in the middle. All students are shown to the left.

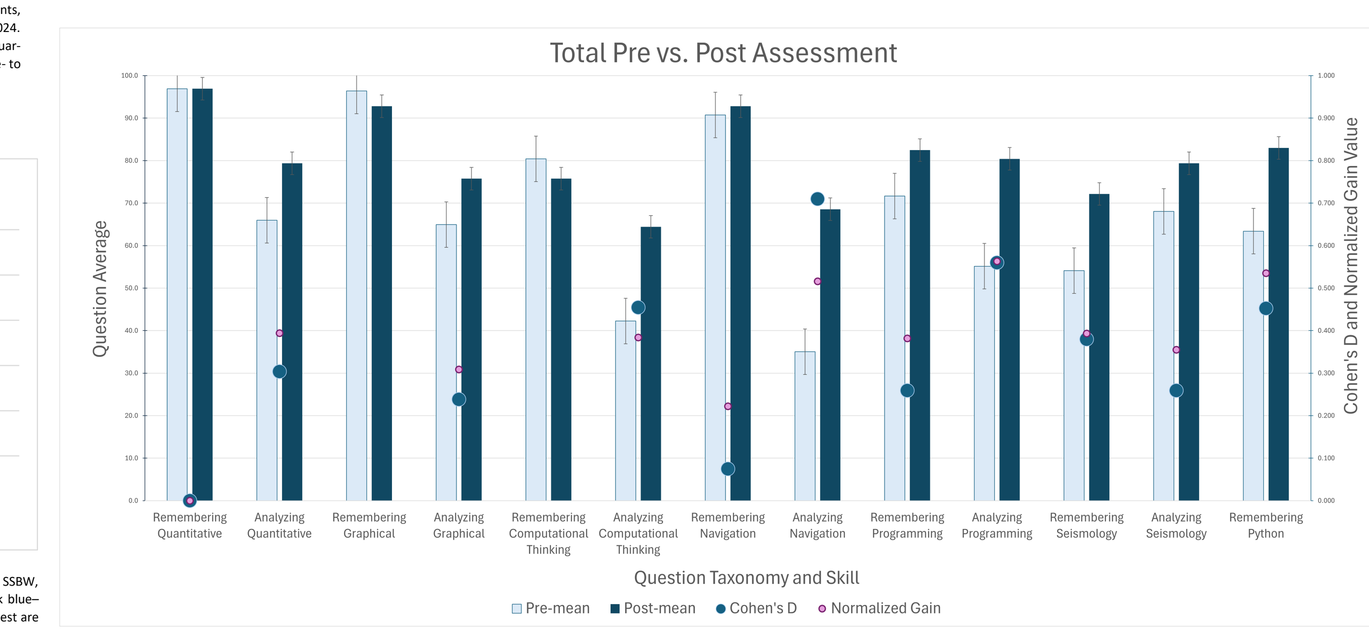


Figure 9. Combined skill gains for 2023 and 2024 cohorts (total of 194 students) during the SSBW, evaluated through matched pre- and post-test questions. Average question scores are displayed for each skill and cognitive level, divided into "Remembering" and "Analyzing" skills across various domains (Quantitative, Graphical, Computational Thinking, Navigation, Programming, Seismology, and Python). Light blue bars represent pre-test averages, while dark blue bars show post-test averages, with error bars indicating standard error. Dark blue circles indicate Cohen's D effect sizes, and pink circles represent normalized gain values.

Skill Domain	Taxonomy	Pre-Mean	Post-Mean	Cohen's D	Pre-Test Std.	Post-Test Std.	Normalized Gain	n (Students)	# of Questions
Quantitative Literacy	Remembering	96.9	96.9	0	17.4	17.4	0.0%	194	11
Quantitative Literacy	Analyzing	66.0	79.4	0.30	47.5	40.6	**39.4%**	194	15
Graphical Literacy	Remembering	96.4	92.8	-0.16	18.7	25.9	-100.0%	194	103
Graphical Literacy	Analyzing	64.9	75.8	0.24	47.8	43.0	**30.9%**	194	45
Computational Thinking	Remembering	80.4	75.8	-0.11	39.8	43.0	-23.7%	194	26
Computational Thinking	Analyzing	42.3	64.4	0.46	49.5	48.0	**38.4%**	194	9
Navigation and Exploration	Remembering	90.7	92.8	0.08	29.1	25.9	22.2%	194	63
Navigation and Exploration	Analyzing	35.1	68.6	**0.71**	47.8	46.6	**51.6%**	194	6
Computer programming	Remembering	71.6	82.5	0.26	45.2	38.1	**38.2%**	194	232
Computer programming	Analyzing	55.2	80.4	**0.56**	49.9	39.8	**56.3%**	194	13
Seismology Content	Remembering	54.1	72.2	0.38	50.0	44.9	**39.3%**	194	53
Seismology Content	Analyzing	68.0	79.4	0.26	46.8	40.6	**35.5%**	194	62
Python	Remembering	63.4	83	0.45	48.3	37.7	**53.5%**	194	72