

Education Research & Science Communication

Steven W. Tarr

What is an “Education Researcher”?

Is it different from an “Educator”?

Education Researcher

- Your answers here

Both

- Your answers here

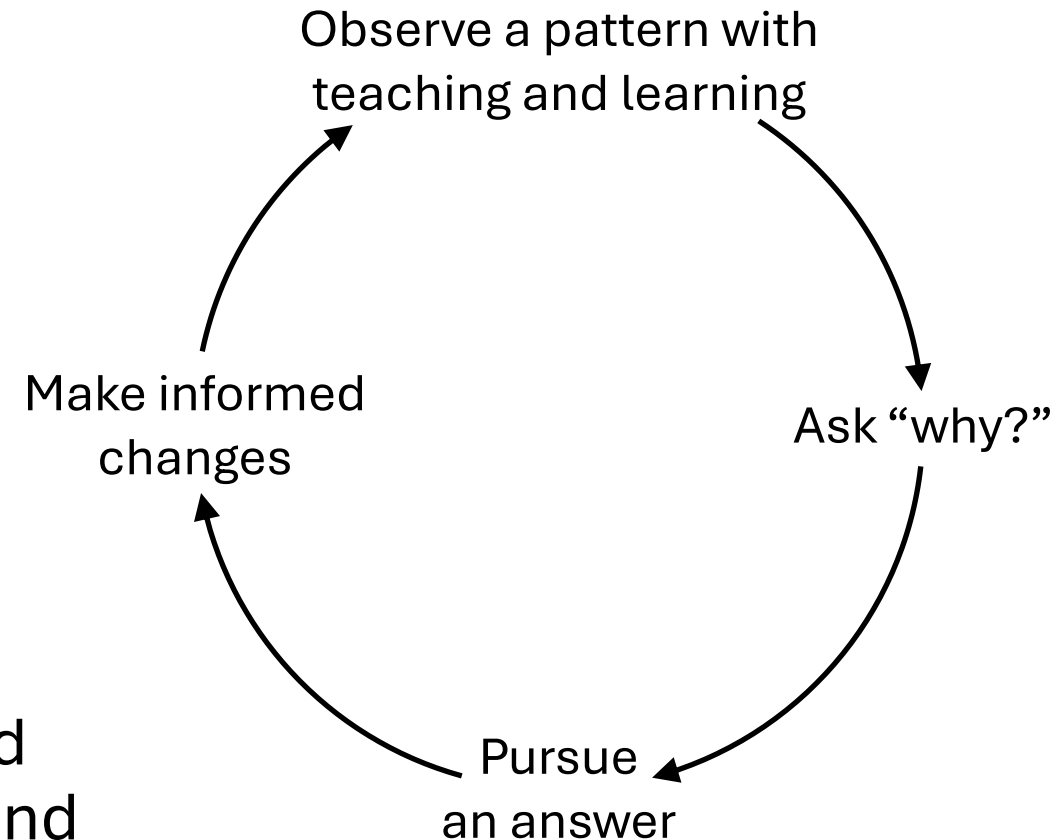
Educator

- Your answers here

Education researchers approach teaching and learning like scientists.

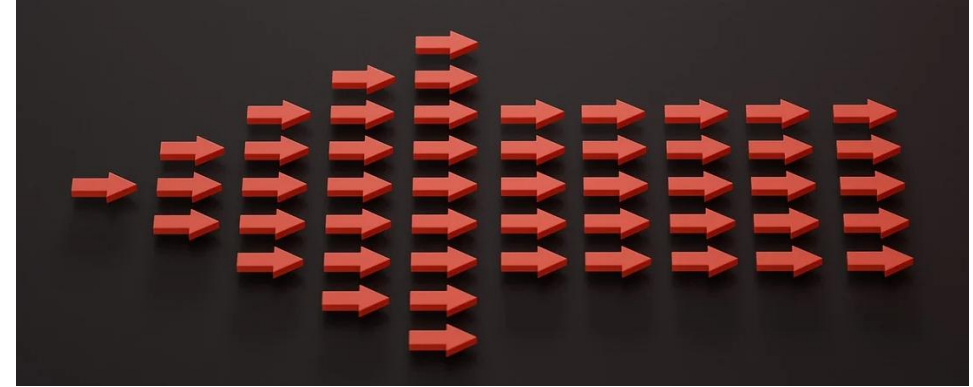
- What does it mean to be a **“good teacher”**?
 - Giving high grades?
 - Liked by students?
 - Lecturing like a wordsmith?
 - Teaching how I was taught?
- How do we know our students are **learning**?
 - We can't go inside their minds.
 - Autonomy can lead to misaligned goals.
 - Behaviors can deceptively suggest understanding.
- **Examining literature** on pedagogy, implementing **research-based practices**, and **probing** our classrooms can help us understand how students become motivated and learn.

Education Research Cycle



Education research is challenging but rewarding.

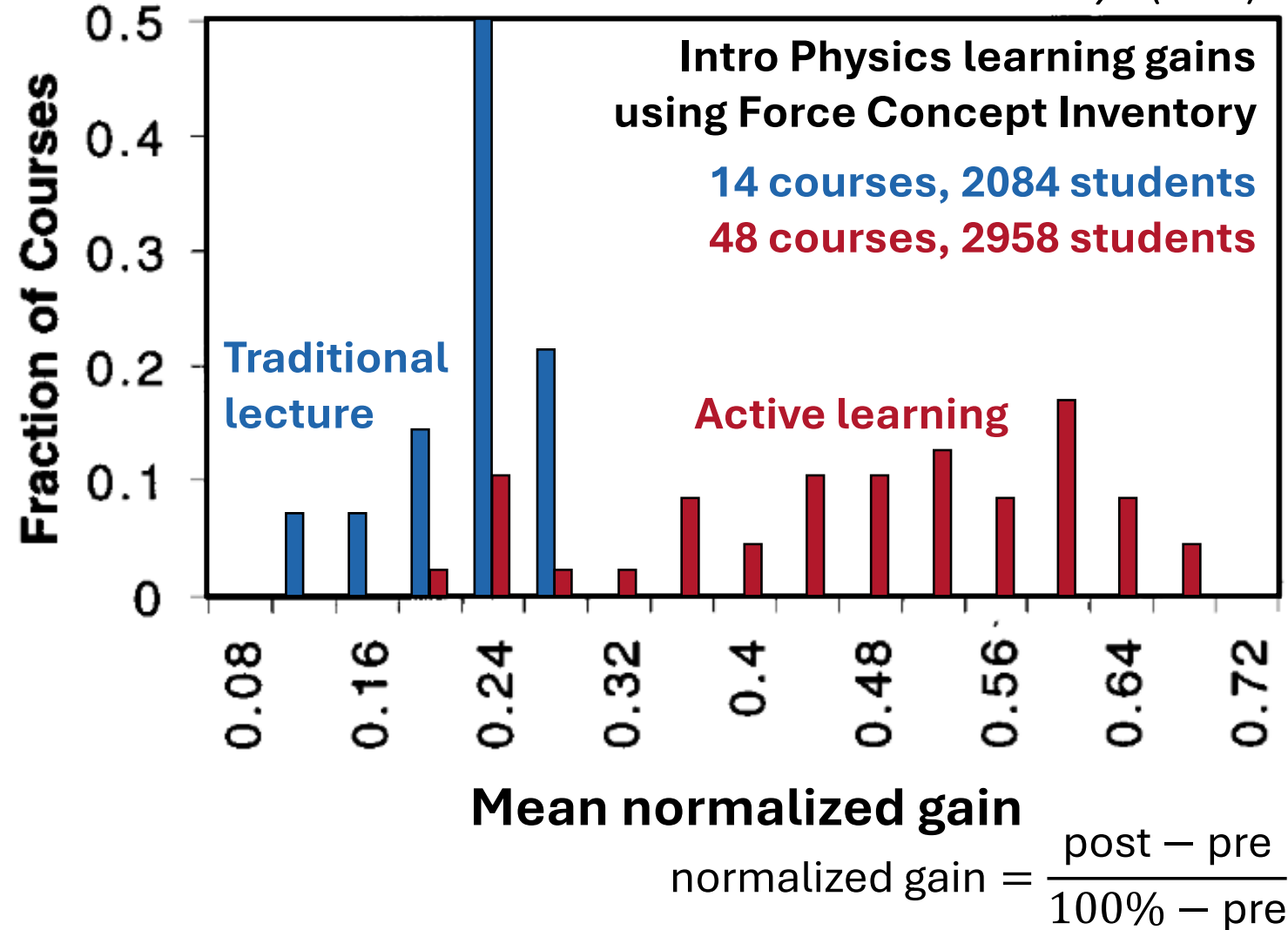
- Social sciences come with unique **difficulties**.
 - Qualitative analyses
 - Frequent contradictions
 - Lack of generalizability
 - Resistance to change
- Still, education-research-based teaching methods **improve learning and retention** for students at **all ability levels** [McKagan, 2016].
- Think of yourselves as education researchers!
What can you do in your spaces?



Across STEM fields, active learning improves student outcomes and closes gaps for underrepresented students.

- Students **rarely learn** from lectures or demonstrations [McKagan, 2016].
- Despite **frequent resistance** from students, active learning techniques **consistently improve learning** outcomes [e.g., Freeman et al., 2014; Tharayil et al., 2018].
- **Open-ended inquiry** similarly promotes critical thinking in **lab courses** [e.g., Holmes et al., 2015; Tarr et al., 2025].

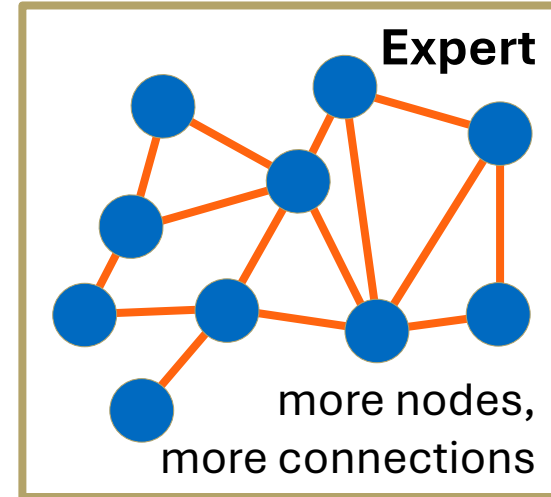
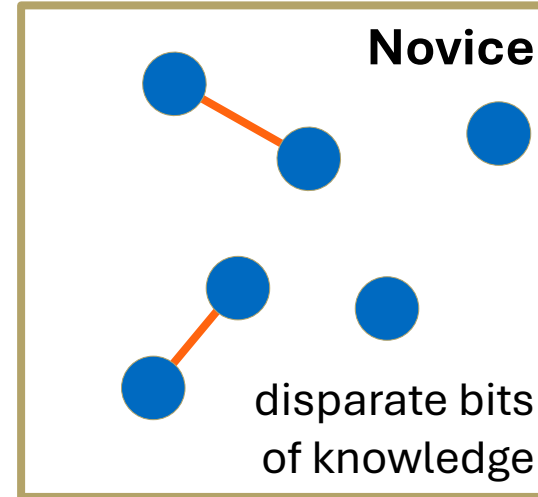
Hake,
Am. J. Phys. (1998)



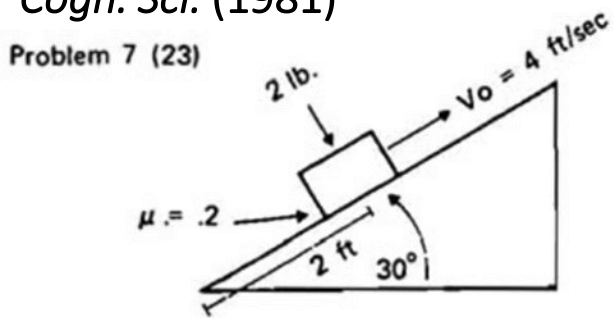
Knowledge structure organization affects both how we learn and apply what we know.

Students often...

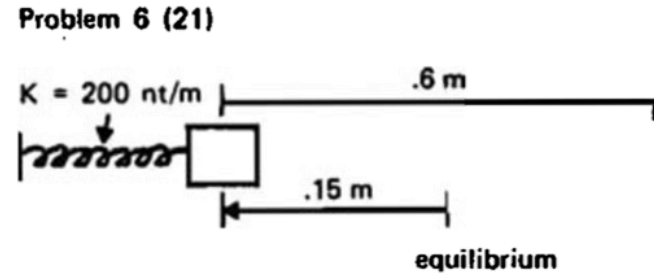
- **Know less** about a subject
- **Lack connections** between broad concepts
- **Organize** course content **differently**



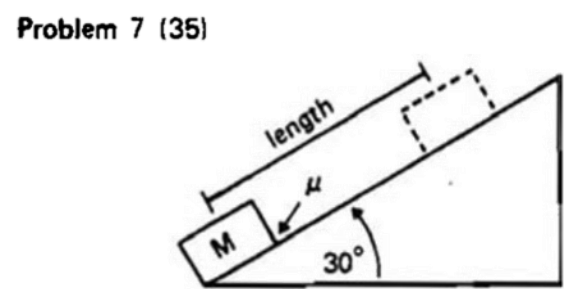
Chi et al.,
Cogn. Sci. (1981)



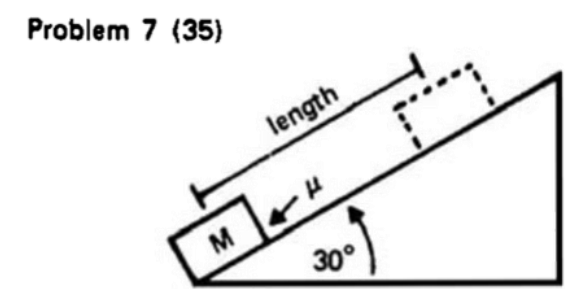
Novice 1: "These deal with blocks on an inclined plane"
Novice 5: "Inclined plane problems, coefficient of friction"
Novice 6: "Blocks on inclined planes with angles"



Expert 2: "Conservation of Energy"
Expert 3: "Work-Energy Theorem. They are all straight-forward problems."
Expert 4: "These can be done from energy considerations. Either you should know the Principle of Conservation of Energy, or work is lost somewhere."



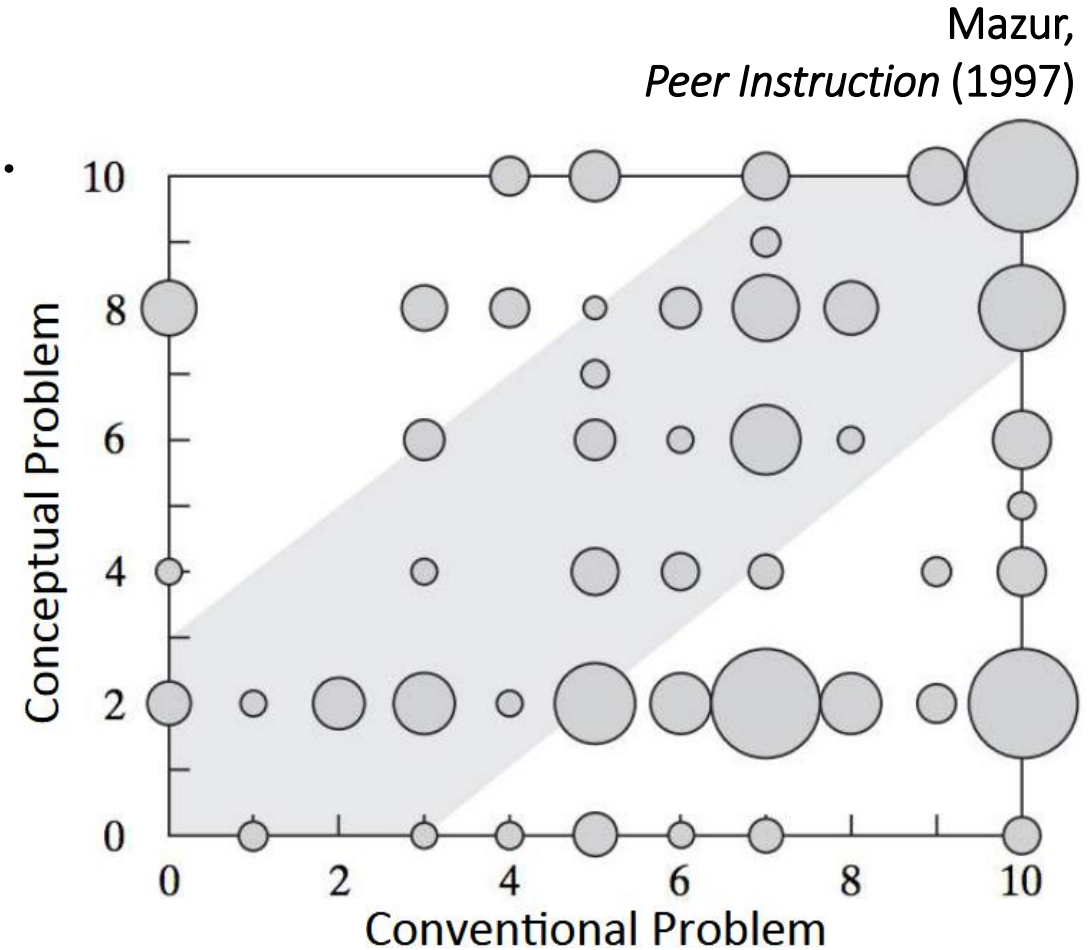
Novices categorize by superficial features.



Experts categorize by underlying principles.

How students engage in problem-solving often reinforces rote behaviors without deeper learning.

- Problem-solving alone **does not** lead to conceptual understanding [McKagan, 2016].
 - However, conceptual understanding **can** improve problem-solving ability.
- Students often solve problems through **pattern recognition** rather than critical thinking [e.g., Tuminaro & Redish, 2007].
- Standard instructional **scaffolding can limit** students' problem-solving flexibility [Kuo et al., 2017].

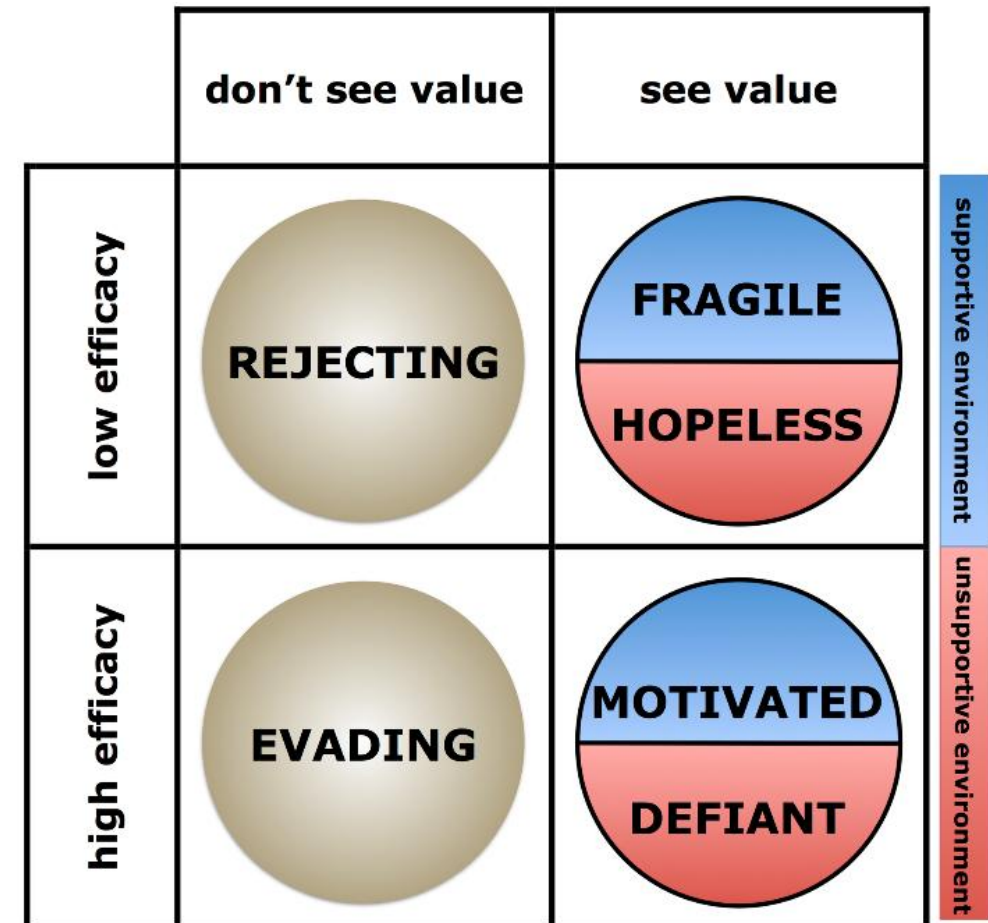


Students often perform better on conventional textbook-style problems than concept problems.

Contextual details about students, instructors, and course structure affect learning outcomes.

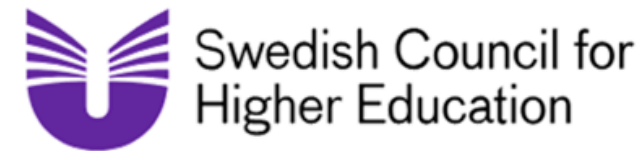
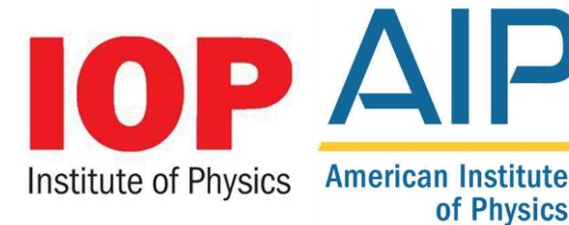
Ambrose et al.,
How Learning Works (2010)

- Students bring all of themselves to class.
 - **Prior knowledge** can be leveraged to develop more effective curricula [Smith & Wittmann, 2007; Sadler et al., 2013].
 - Student **beliefs about the subject** impact learning [Milner-Bolotin et al., 2011; Bodin & Winberg, 2012].
 - Student **beliefs about themselves** impact learning [Kinnischtzke & Smith, 2021; Cwik & Singh, 2022].
- Classroom environment and **instructor attitudes** strongly influence learning [e.g., Canning et al., 2019].
- **Course context** can impact observed effects [e.g., Madsen et al., 2015; Webb & Paul, 2023].



Implementation of relevant science communication resources has been slow and highly localized.

- National organizations **emphasize** the importance of developing **science communication skills** in students.
- Still, employer accounts suggest physics graduates are **deficient** in social and communicative skills [Sarkar et al., 2016].
- High enrollment and limited class resources present **barriers** to providing students ample opportunities **to practice** presentation skills.



Describe the best and worst lectures that you have attended. Be specific!

What made their lecturing the best?

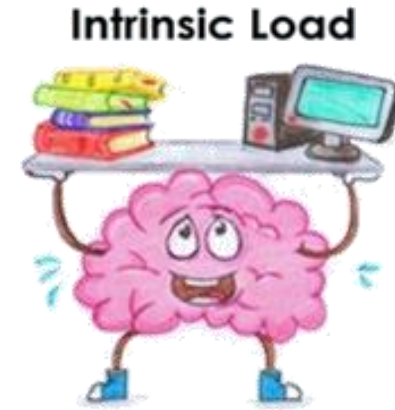
- Your answers here

What made their lecturing the worst?

- Your answers here

Psychology lends multiple theories to understand multimedia learning.

- **Cognitive Load Theory** emphasizes the limited capacity of short-term memory [Sweller, 1988].
- The **Cognitive Theory of Multimedia Learning (CTML)** models visual and auditory processing [Mayer, 1997].
- CTML makes three foundational **assumptions**:
 1. Independent processing of words and images
 2. Individual limited bandwidths
 3. Learning requires audience engagement



Extraneous Load



Germane Load



Sweller's three types of cognitive load occupy one's short-term memory.

Khurshid et al.,
MedEdPublish (2018)

Adherence to CTML principles is a proxy for presentation quality.

- Principles from CTML provide a framework for **understanding presentation quality**.

- 15 multimedia principles:

Coherence	Segmenting	Voice
Signaling	Pre-training	Image
Redundancy	Modality	Embodiment
Spatial contiguity	Multimedia	Immersion
Temporal contiguity	Personalization	Generative activity

- Which principles apply depends on presentation **context**.



Coherence:
Omit extraneous details.



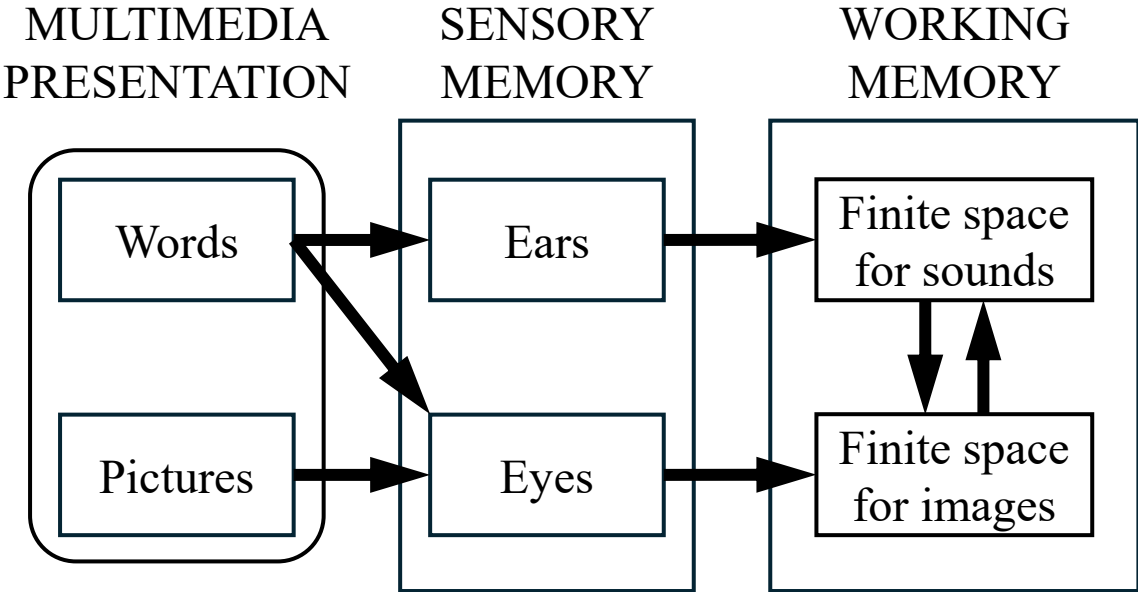
Signaling:
Visually guide learners through content organization.

Yes, short presentations can still be learner-centered.

- **Backward Design** process
[Wiggins & McTighe, 2005]
 1. What key answer(s) should your audience learn?
 2. How will you know if your audience understands?
 3. How will you support your audience achievement?
- **Minimize** extraneous information.
 - e.g., Use meaningful titles.
- Tell a compelling **story**.
- **Motivate** through passion and enthusiasm.
- Prepare for **lapses** in attention.
- Observe and adjust for **audience cues**.



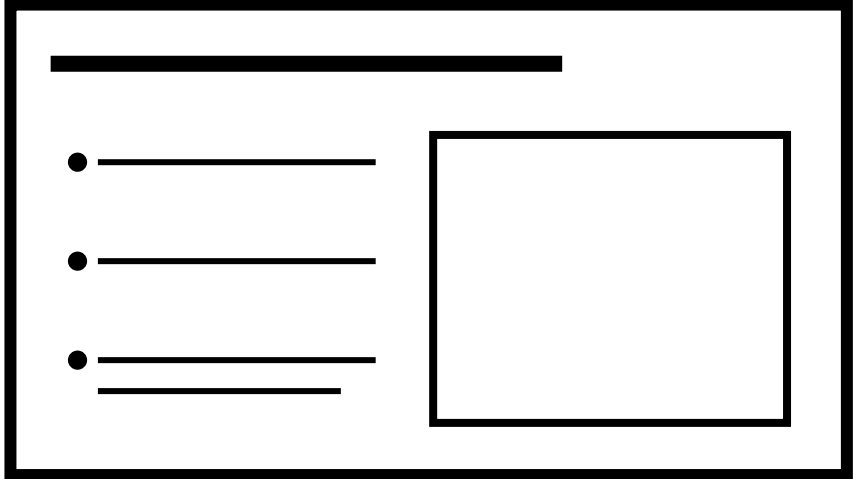
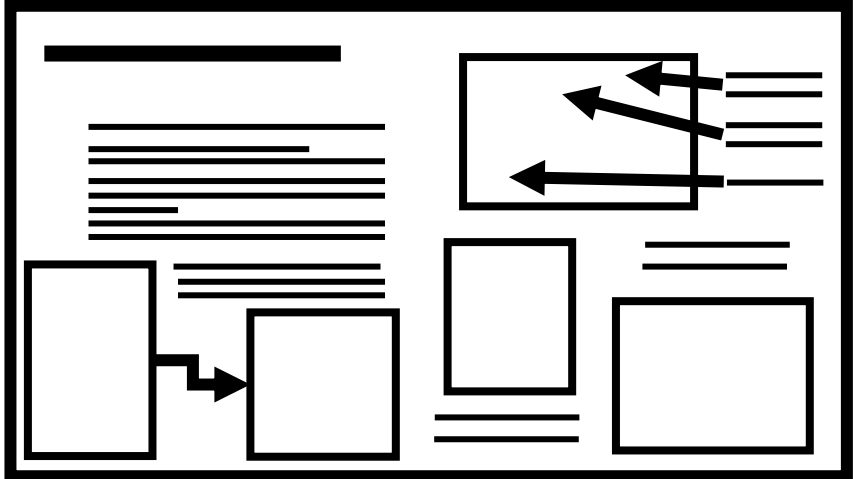
Improve learning outcomes by integrating how people learn into slide composition.



Adapted from Mayer, R., et al. *J. Educ. Psychol.* (2001)

Simultaneous sensemaking across **two channels**

Content curated to **avoid cognitive overload**

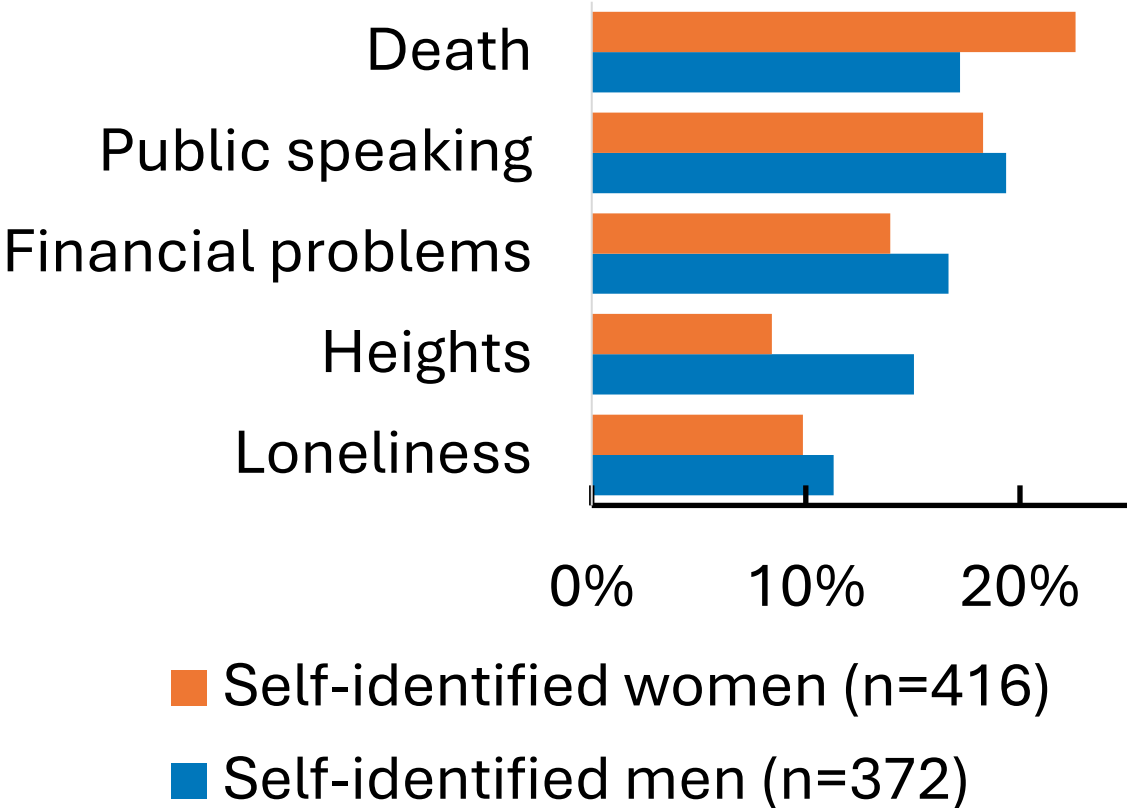


Overwhelming slide design hinders learning.

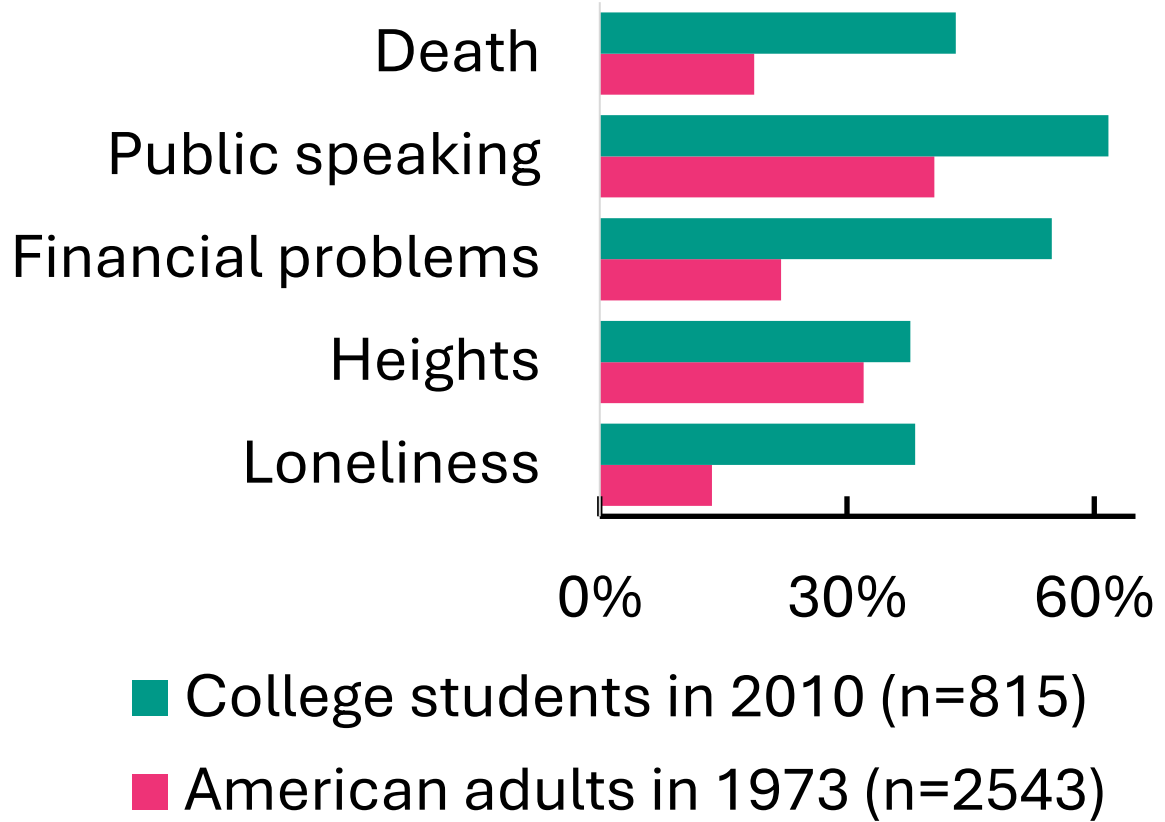
Public speaking ranks highly among common fears.

Adapted from
Dwyer & Davidson,
Commun. Res. Rep. (2012)

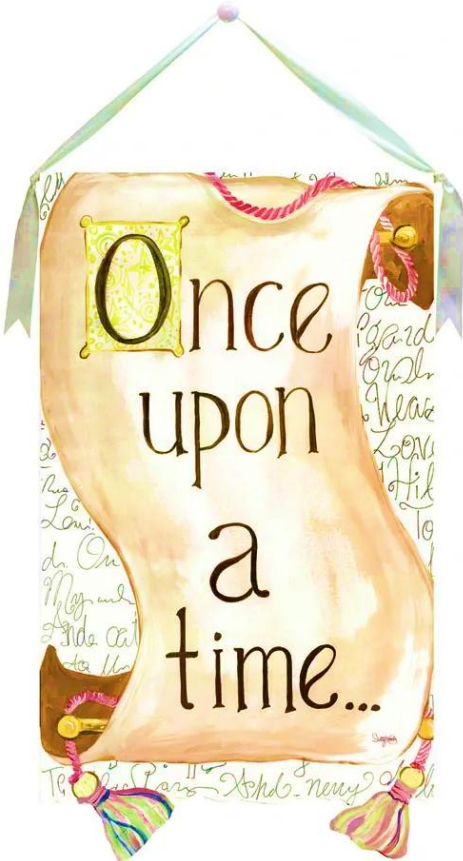
Name your top 3 fears



Check all items that make you fearful or anxious



Novice public speakers often face 3 main challenges.



Organization



Delivery

(Verbal and nonverbal)



Anxiety

Adapted from Young, Self-published (2014)

A compelling narrative helps structure complex material.

- **Hook** your audience with your topic's **significance**.
- Keep the **big picture** at the forefront, especially during the detailed middle.
- “Land the plane **gently**.”
 - Dr. Mary Peek, Chemistry Seminar at GT
 - Succinctly restate goal(s) and take-home message.
 - Avoid abrupt endings and introducing new concepts.



First 2-3 slides,
not counting title

Conversations are more engaging than lectures.

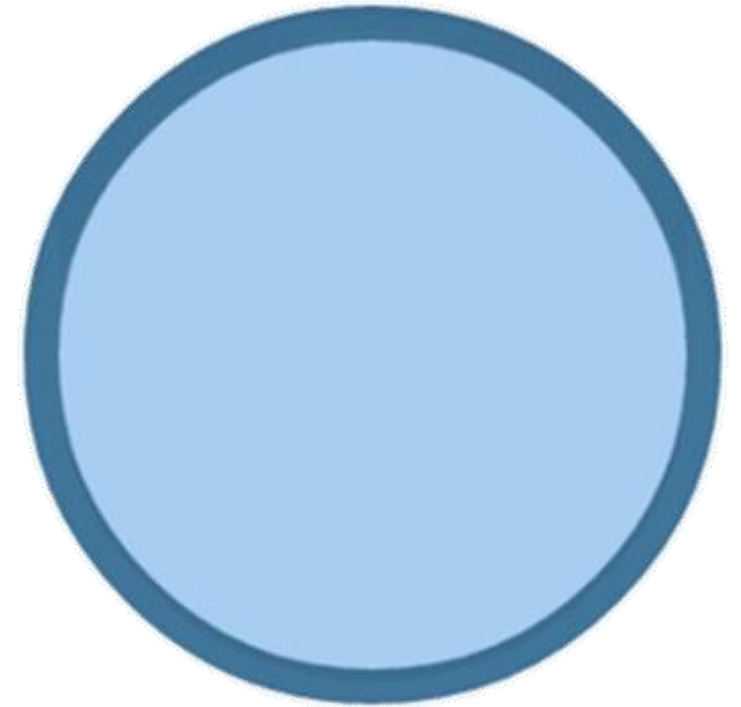
- Deliver a talk like an **elevated conversation**.
 - Avoid memorizing or reading a script.
 - Show your passion, tell a story.
- **Limit** filler and jargon.
 - If jargon is absolutely necessary, **define briefly** and leave on-screen.
- Use **silence** to your advantage.
- Nonverbal cues **humanize** and maintain attention.
 - Eye contact
 - Facial expressions
 - Gestures
 - Voice modulation



Too many nonverbal cues
can be distracting.

Own your talk! Combat anxiety with focused control.

- **Trust is the default.** Ground yourself with this truth.
 - Relieve excess energy by pacing **slowly** and gesturing **meaningfully**.
 - Keep water nearby.
- Rehearse, but **do not memorize**.
 - You know more than you think you do.
- **Familiarize** yourself with the space in advance.
 - Identify friendly faces in the audience.
- Techniques adapted from psychotherapy:
 - [Personal Report of Communication Apprehension](#) [McCroskey, 1982]
 - More resources on Dropbox [Ayres & Hopf, 1989; Wolpe, 1968; McCroskey, 1972]



It's okay to be anxious!
Just breathe.

Students have dual roles in the physics and biochemistry communication courses at GT.

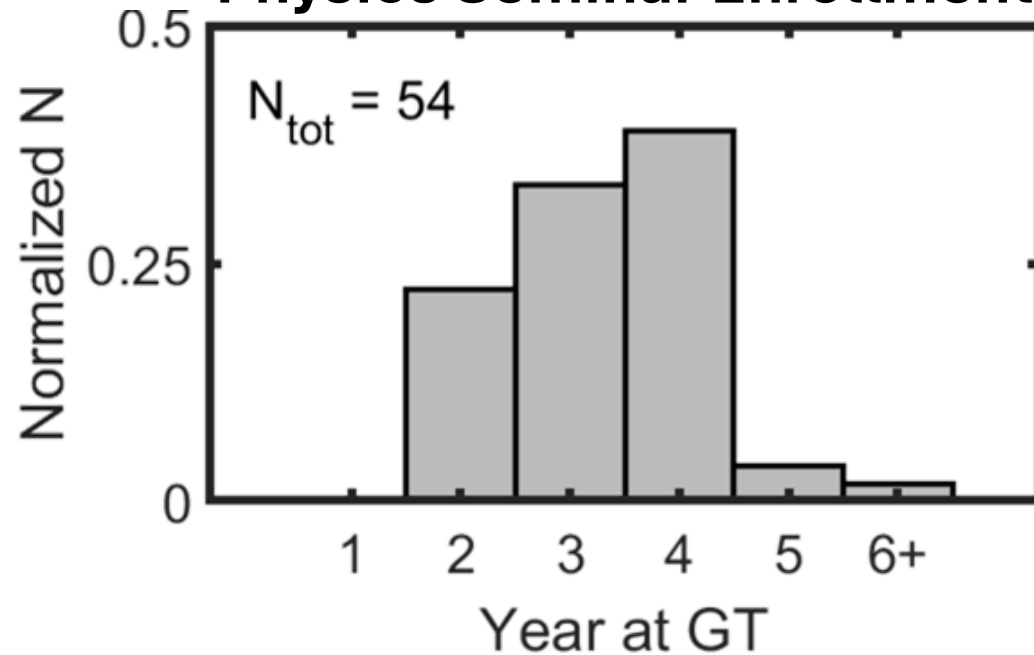
Physics Seminar (1 credit hour)

- Typical semesterly enrollment: 40–50
 - One uncapped section
 - 39% 4th-years, skews younger

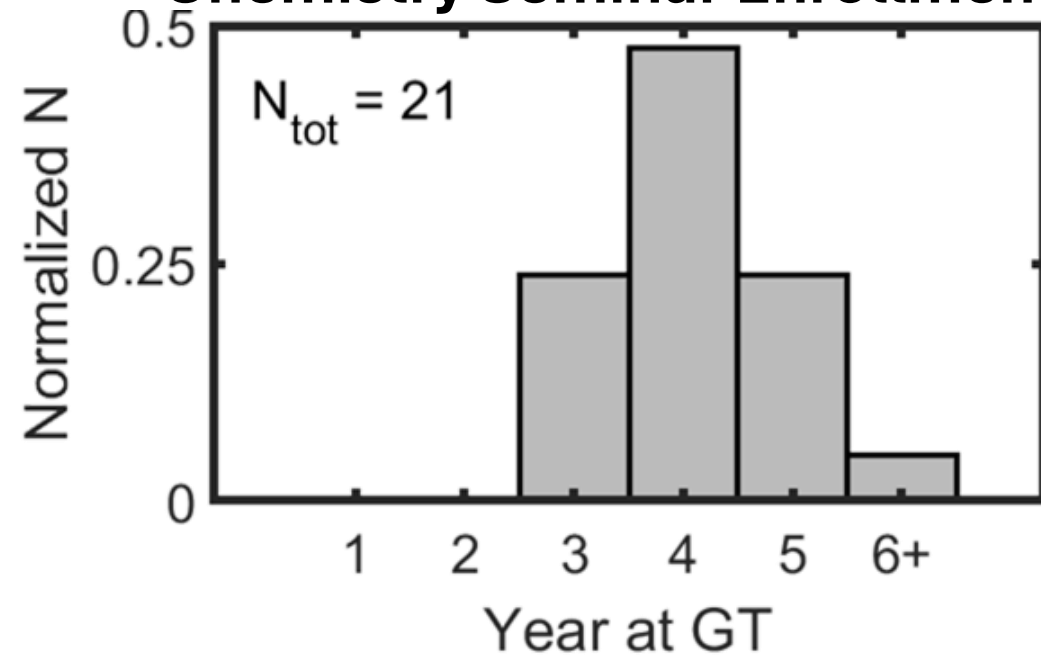
Chemistry Seminar (2 credit hours)

- Typical semesterly enrollment: 29–36
 - Two sections capped at 18 each
 - 48% 4th-years, skews older

Physics Seminar Enrollment



Chemistry Seminar Enrollment



Demographic information is limited to students who filled the survey.

Students have dual roles in the physics and biochemistry communication courses at GT.

Physics Seminar (1 credit hour)

- Typical semesterly enrollment: 40–50
 - One uncapped section
 - 39% 4th-years, skews younger
 - Minimal external SciComm experience
 - Highly varied instruction each semester

Students as presenters

- Students present **1x** per semester.
 - One 8-min presentation + 2-min Q/A
 - Topics: research at GT, summer internships, upper-division course topics

Students as observers

- Randomly assigned written peer evaluations per presentation
- End-of-class quiz on concepts from that day's presentations

Chemistry Seminar (2 credit hours)

- Typical semesterly enrollment: 29–36
 - Two sections capped at 18 each
 - 48% 4th-years, skews older
 - Minimal external SciComm experience
 - 2 hours on slideshows, 1 hour on posters

Students as presenters

- Students present **4x** per semester.
 - One 4-min presentation (No Q/A)
 - Two 20-min presentations + 5-min Q/As
 - One poster symposium + 1-min elevator pitch
 - Topics: journal articles within last 7 years

Students as observers

- Immediate oral feedback per presentation
- End-of-class reflection activity on that day's presentations collectively

Across semesters and departments, students value direct instruction on and practice with presentation skills.

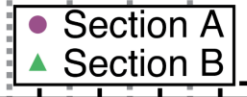
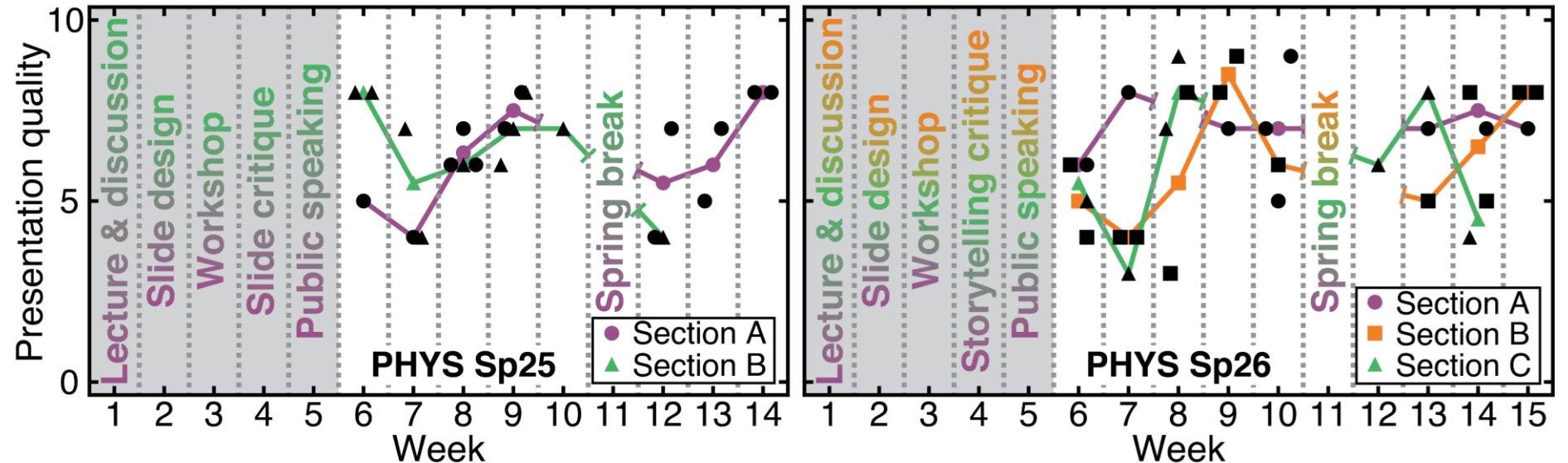
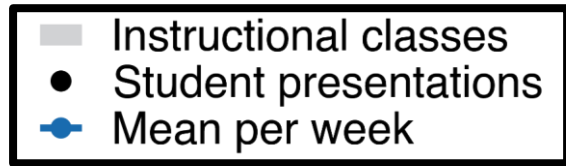
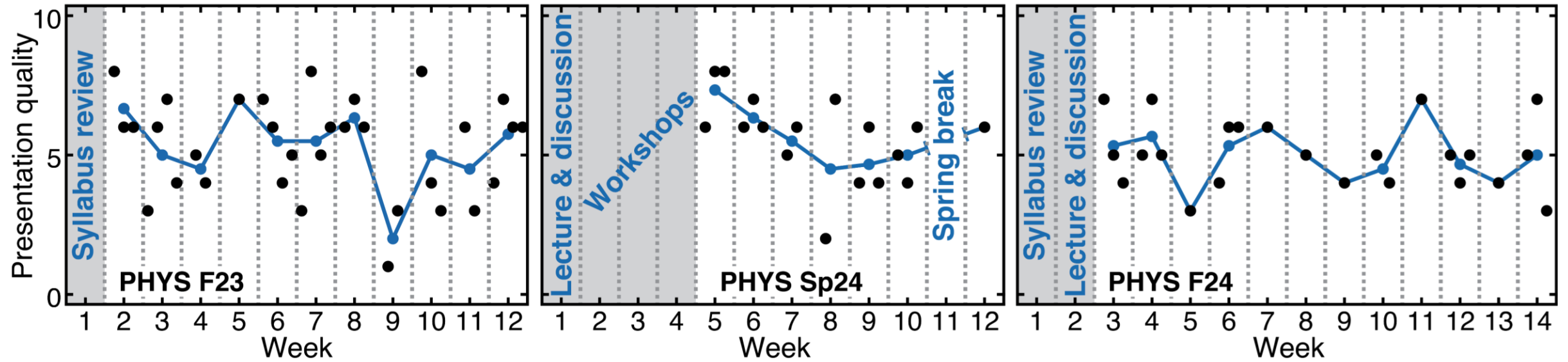
- PHYS F23: W1 Syllabus review
 - *“It maybe **would be helpful** to have **one or two days of class** going over that. Learning how to pick out the key ideas from your slides, presenting them in one sentence, and just talking about why that’s important....”*
- PHYS Sp24: W1 Intro to science presentations, W2–4 Presentation workshops
 - Students **valued guidance** on presentation structure and techniques.
 - **Workshops overstayed** their welcome and did not effectively simulate public speaking.
- PHYS F24: W1 Syllabus review, W2 Intro to science presentations
 - Interesting but **not enough time** for meaningful learning.
 - Not useful or engaging for people with **prior experience**.
- CHEM Sp24 & F24: W1 Science presentations, W4–5 Science posters
 - *“a good introduction into the course and the **expectations**”, “very thorough”, “a good primer”, “very impactful”, “good to **lead by example**”, “good to see how the **structure of a talk** should be set up... and how to **keep the audience engaged**.”*

Students praised many aspects of research-based instruction but still saw room for improvement.

Semester	W1: Intro		W2: Slides		W3: Workshop		W4: Critique		W5: Speech		Ambiguous	
	Sp25	Sp26	Sp25	Sp26	Sp25	Sp26	Sp25	Sp26	Sp25	Sp26	Sp25	Sp26
Positive	1	11	9	9	4	4	1	0	5	2	5	8
Mixed	0	0	1	0	1	1	1	1	1	0	4	4
Negative	0	0	0	0	1	0	4	0	0	0	1	0

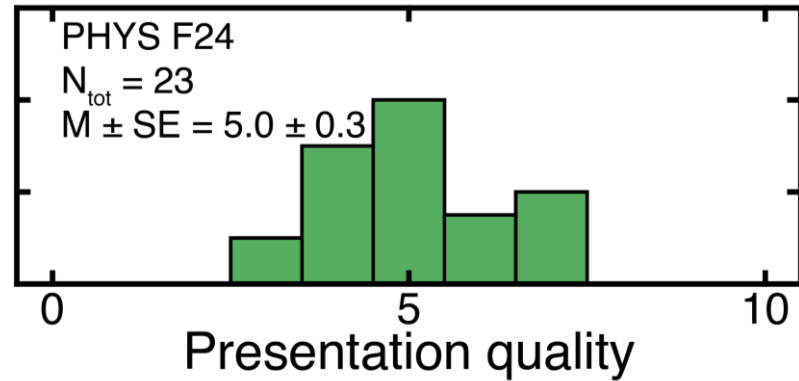
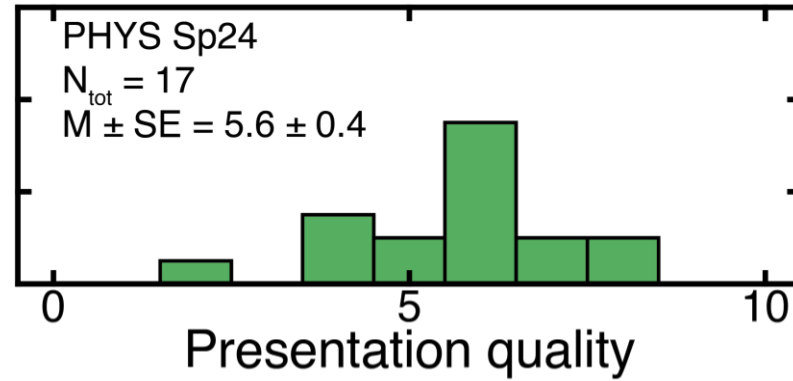
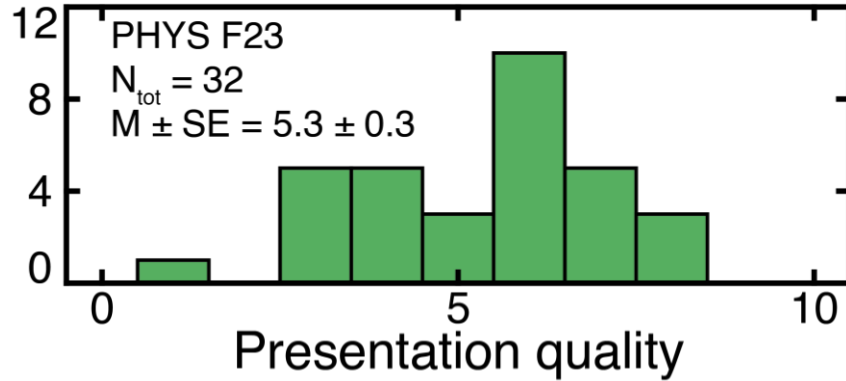
1. A new segment in Sp26 (< 20 min!) on **infusing technical communication with narrative structure** skyrocketed perceptions of the introductory lesson.
2. Students appreciated **learning** slide design **guidelines** (e.g., animations, text and graphic usage) and **practicing implementation** with the hands-on activity.
3. Students found the workshop **useful for building** their slides and getting **feedback**, though some felt it was too soon to focus on slide specifics.
4. Students were **frustrated** by critiquing one key slide because it led to **irrelevant feedback** built on **incorrect assumptions** about the broader presentation. Addressing criticisms in Sp26 using storytelling led to indifference.
5. Students embraced the speaking challenge as **initially scary but very helpful**. Some requested more feedback and exposure to further build confidence.

In Physics Seminar, presentation quality remains roughly constant throughout semesters regardless of intervention.



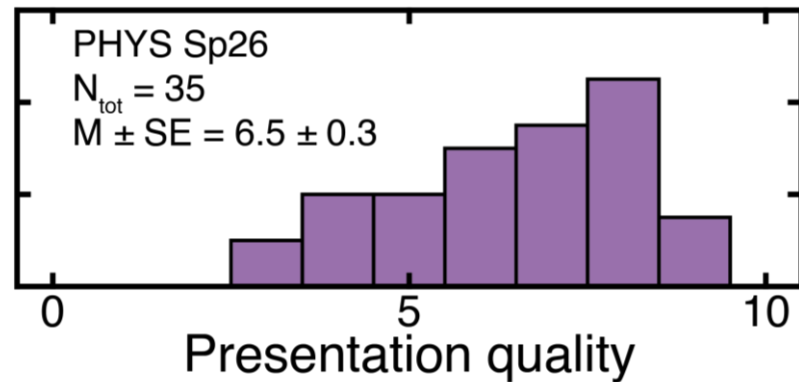
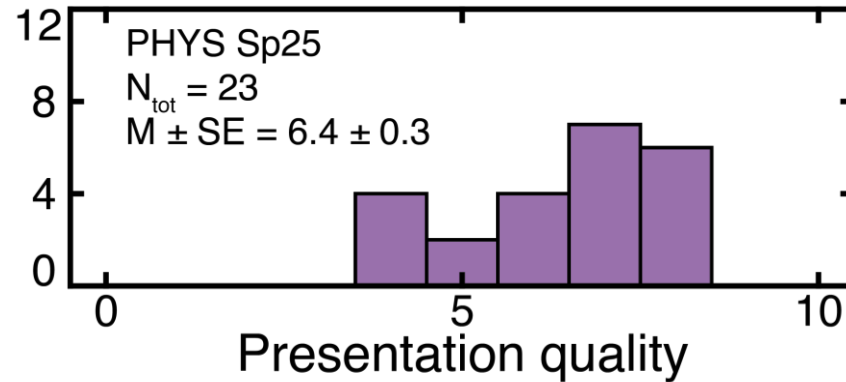
Minor changes between semesters did not significantly impact student presentation quality.

Number of students

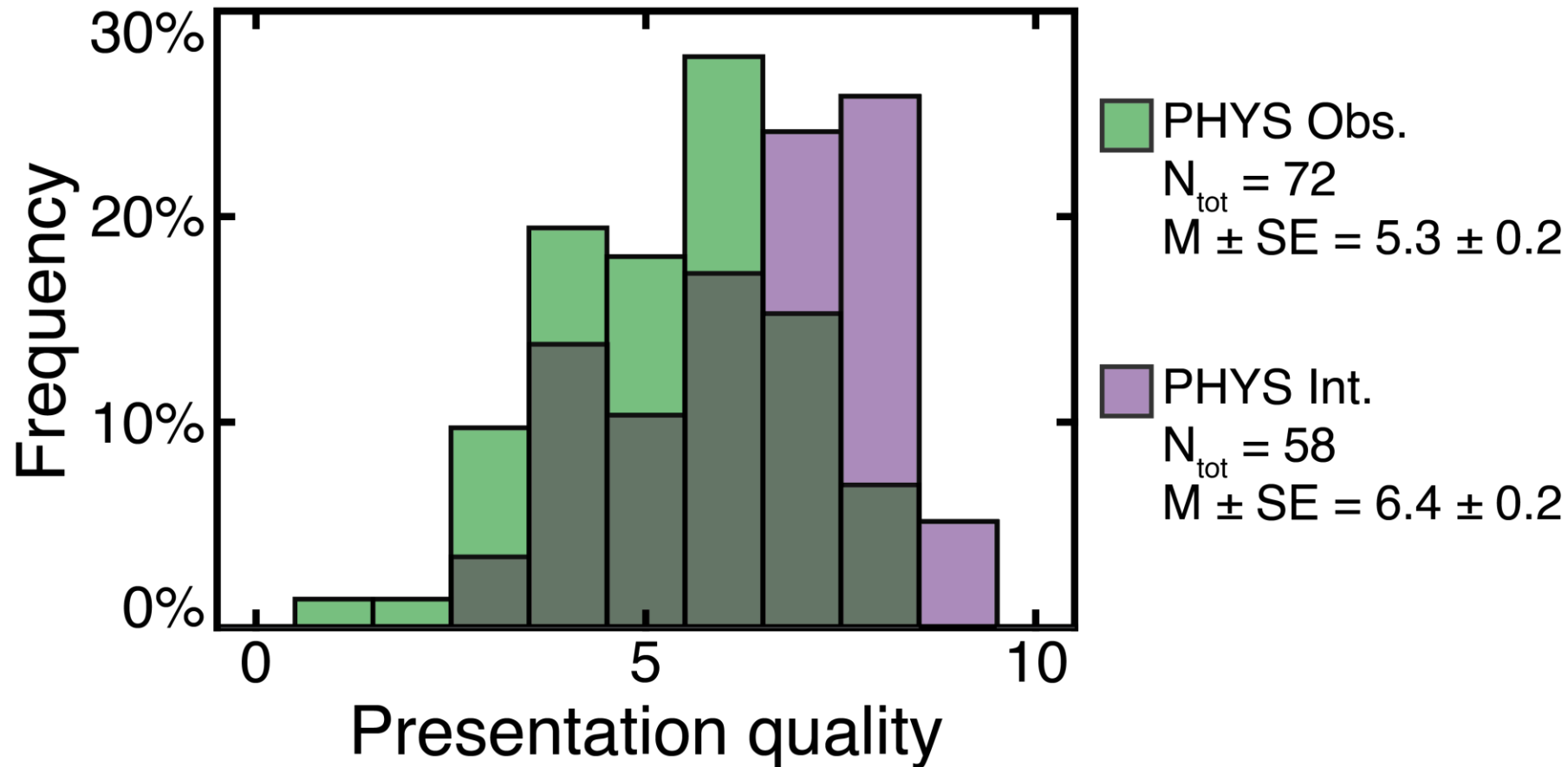


Statistical tests suggest that we can **consider** semester subgroups **in aggregate** without obscuring effects.

Number of students



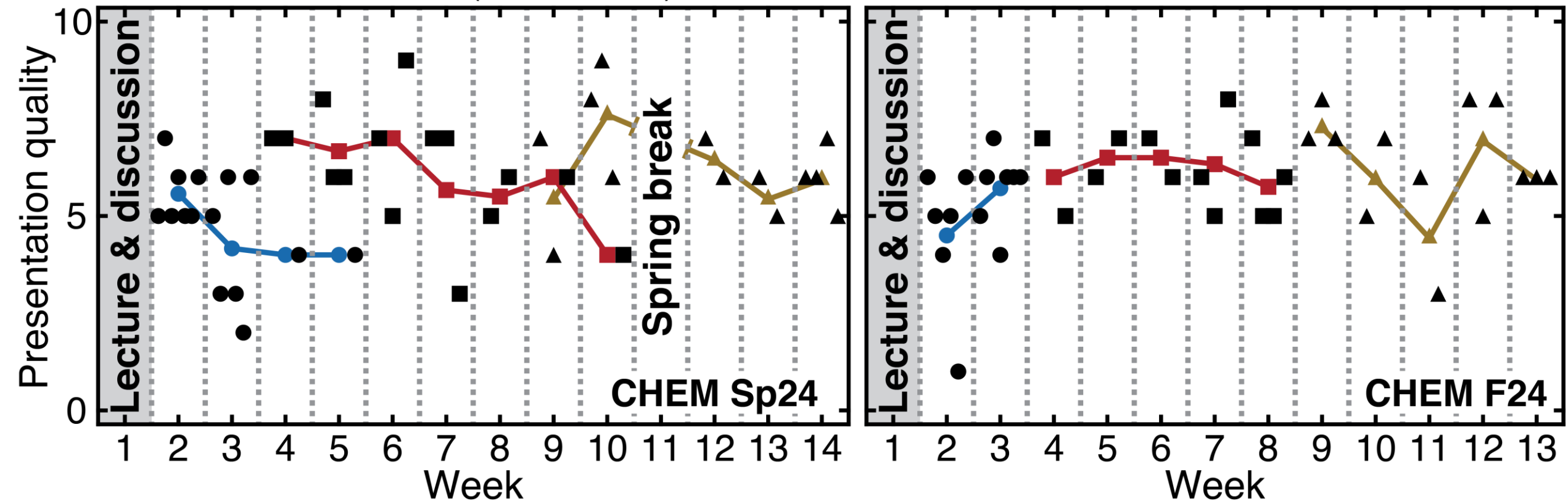
Research-based instruction helped Physics Seminar students significantly outperform earlier students.



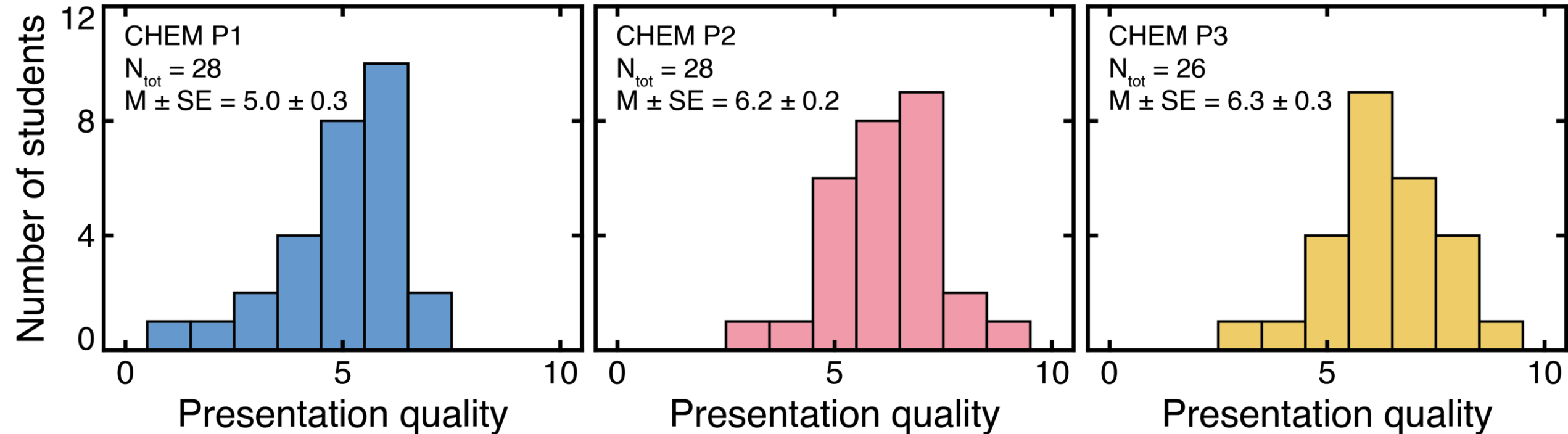
Statistical tests suggest that students who did receive research-based instruction significantly outperformed students who did not ($p < 0.001$).

In Chemistry Seminar, presentation quality stays roughly constant per presentation type.

- Mini-seminars (4 min each)
- First Full Seminars (20 min each)
- ▲ Second Full Seminars (20 min each)
- Mean per week
- Mean per week
- ▲ Mean per week
- Instructional classes

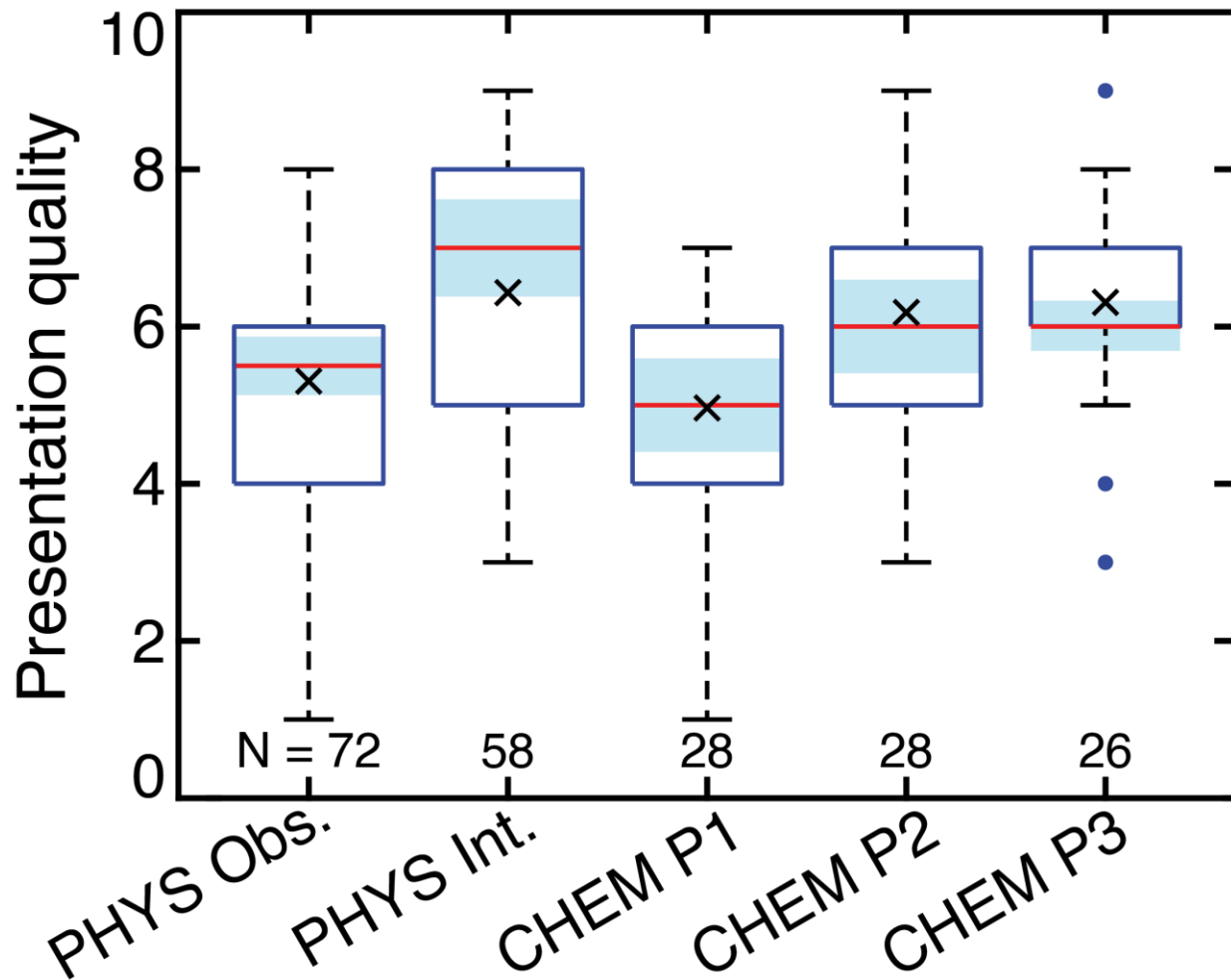


In Chemistry Seminar, student presentation quality improved significantly after the Mini-seminar.

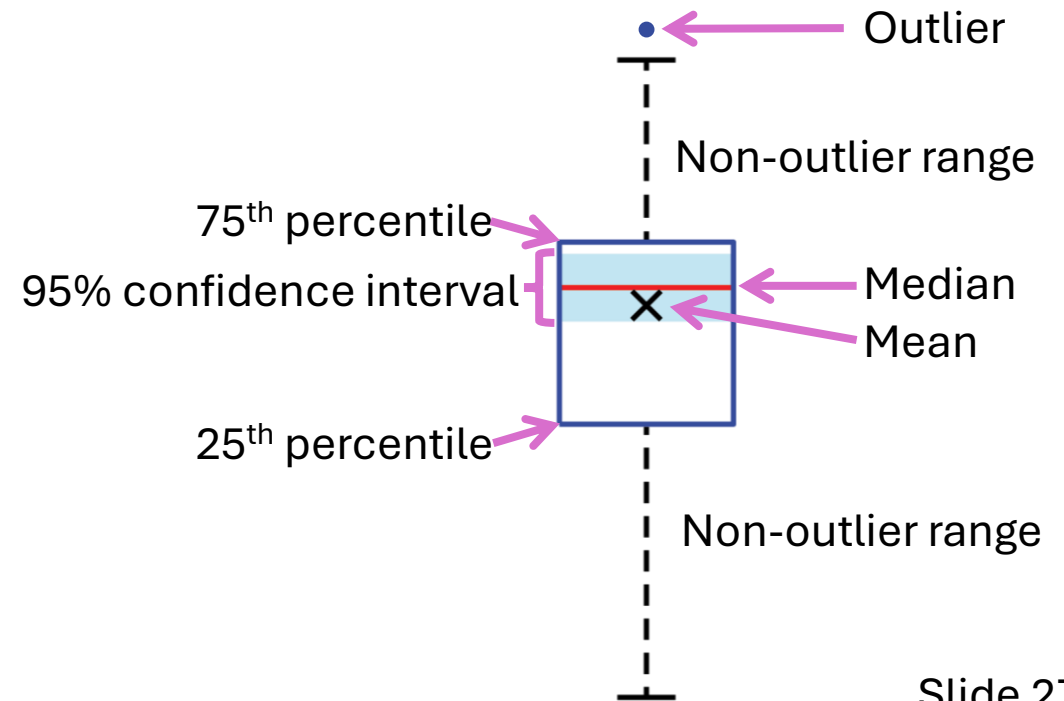


Statistical tests suggest that students improved significantly from the Mini-Seminar to the First Full Seminar ($p < 0.01$) but not from the First to the Second Full Seminar ($p = 0.48$).

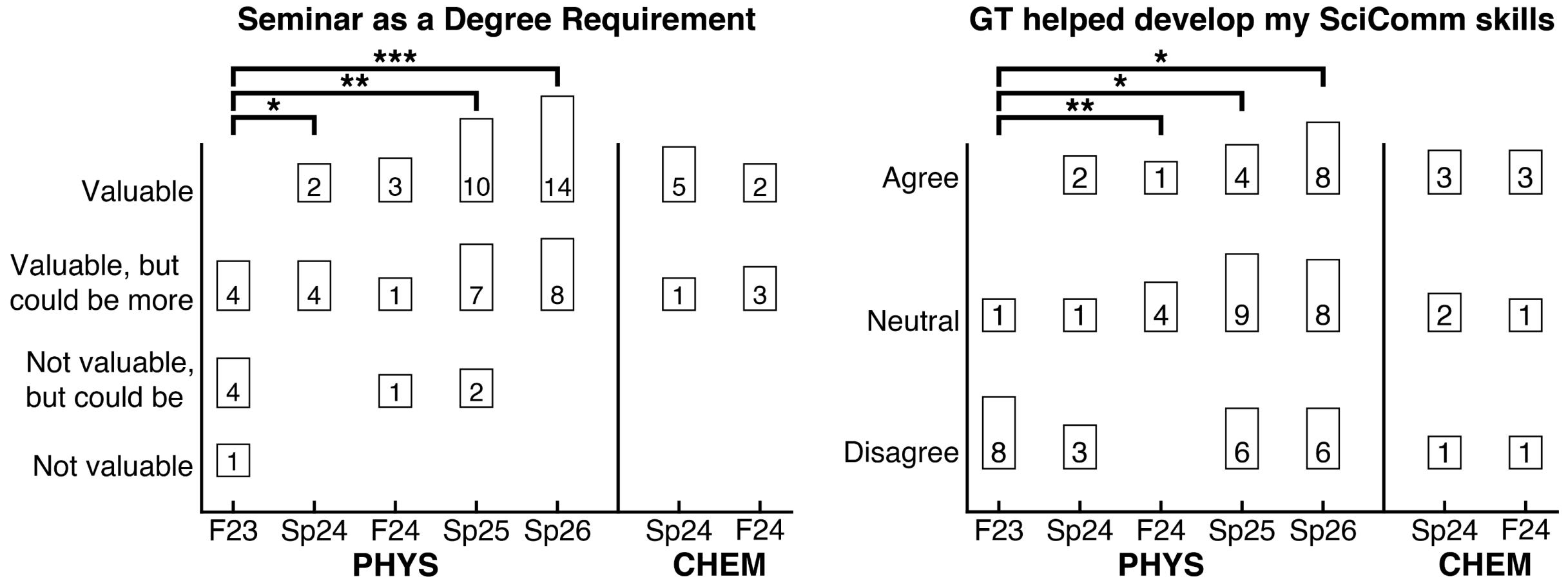
There are a variety of methods that teachers can use to help significantly improve student presentation skills.



Research-based instruction in Physics Seminar helped students deliver presentations with **comparable quality** to those by students with **multiple rounds of practice & feedback** in Chemistry Seminar.



Revising Physics Seminar had cascading positive effects on students' beliefs about their time at Georgia Tech as a whole.



* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

There are no research-validated standards for science communication **yet**.



Slide 29 of 29

- How can we support student success if we don't always understand what success means?
 - Remember, course **context and climate** matter!
 - Even without scientific consensus, **many** communication **tools work**.
 - **Study** the literature hard but **your classroom** harder.
- Ongoing **changes** to Physics Seminar **are working**.
 - Improved presentation quality as measured by CTML ($p < 0.001$).
 - Improved student attitudes toward Physics Seminar ($p < 0.001$) and learning science communication at GT ($p < 0.05$).
- **Teach like a researcher!**

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For group information,
visit <https://per.gatech.edu/>