Georgia Tech

PER @ GT

Education Research & Science Communication

Steven W. Tarr

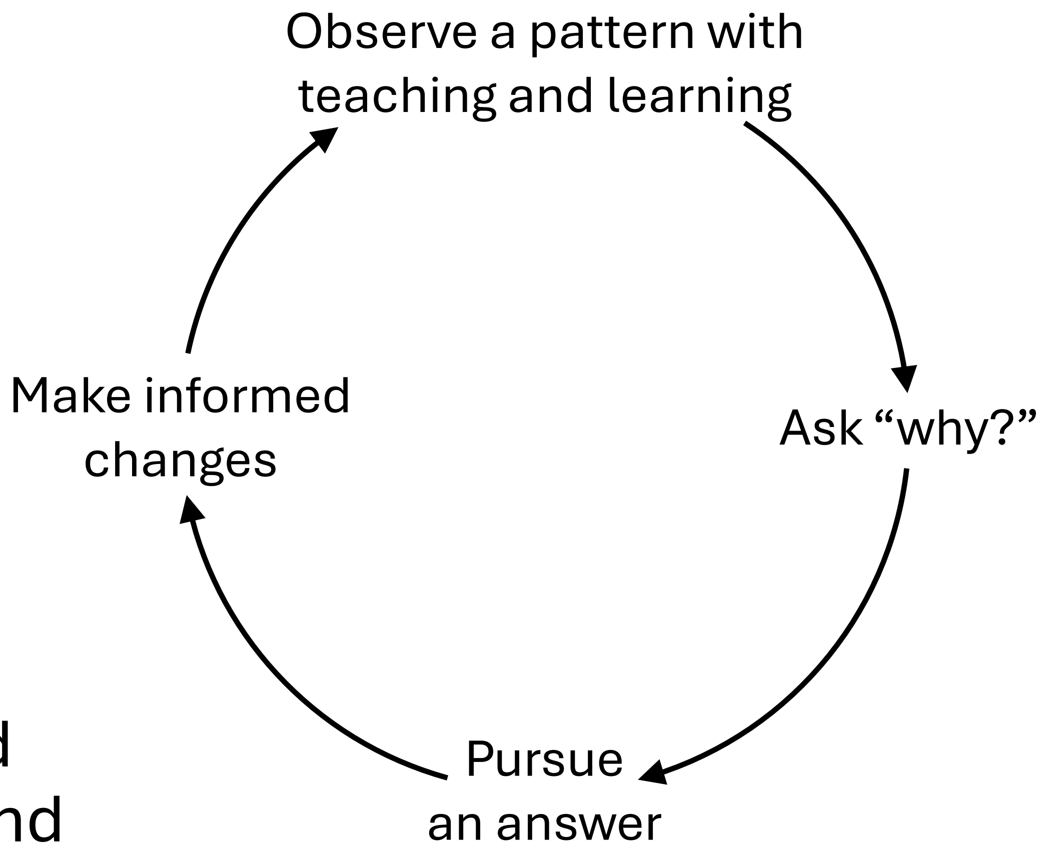
What is an "Education Researcher"? Is it different from an "Educator"?

Education Researcher	Both	Educator
• Your answers here	• Your answers here	• Your answers here

Education researchers approach teaching and learning like scientists.

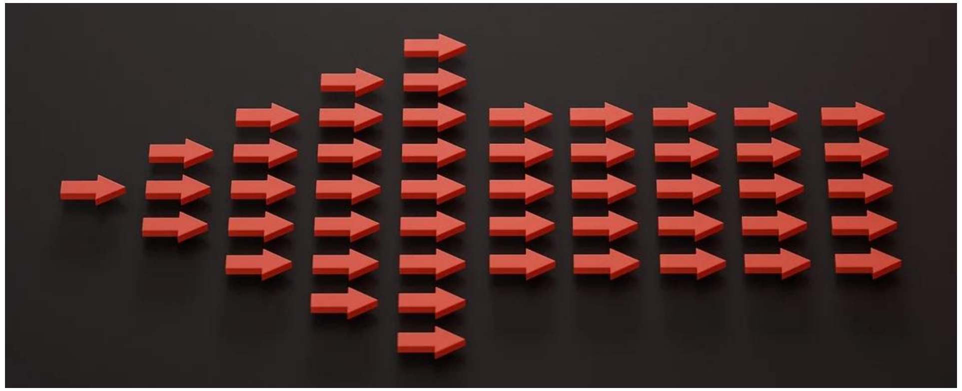
- What does it mean to be a **“good teacher”**?
  - Giving high grades?
  - Liked by students?
  - Lecturing like a wordsmith?
  - Teaching how I was taught?
- How do we know our students are **learning**?
  - We can’t go inside their minds.
  - Autonomy can lead to misaligned goals.
  - Behaviors can 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



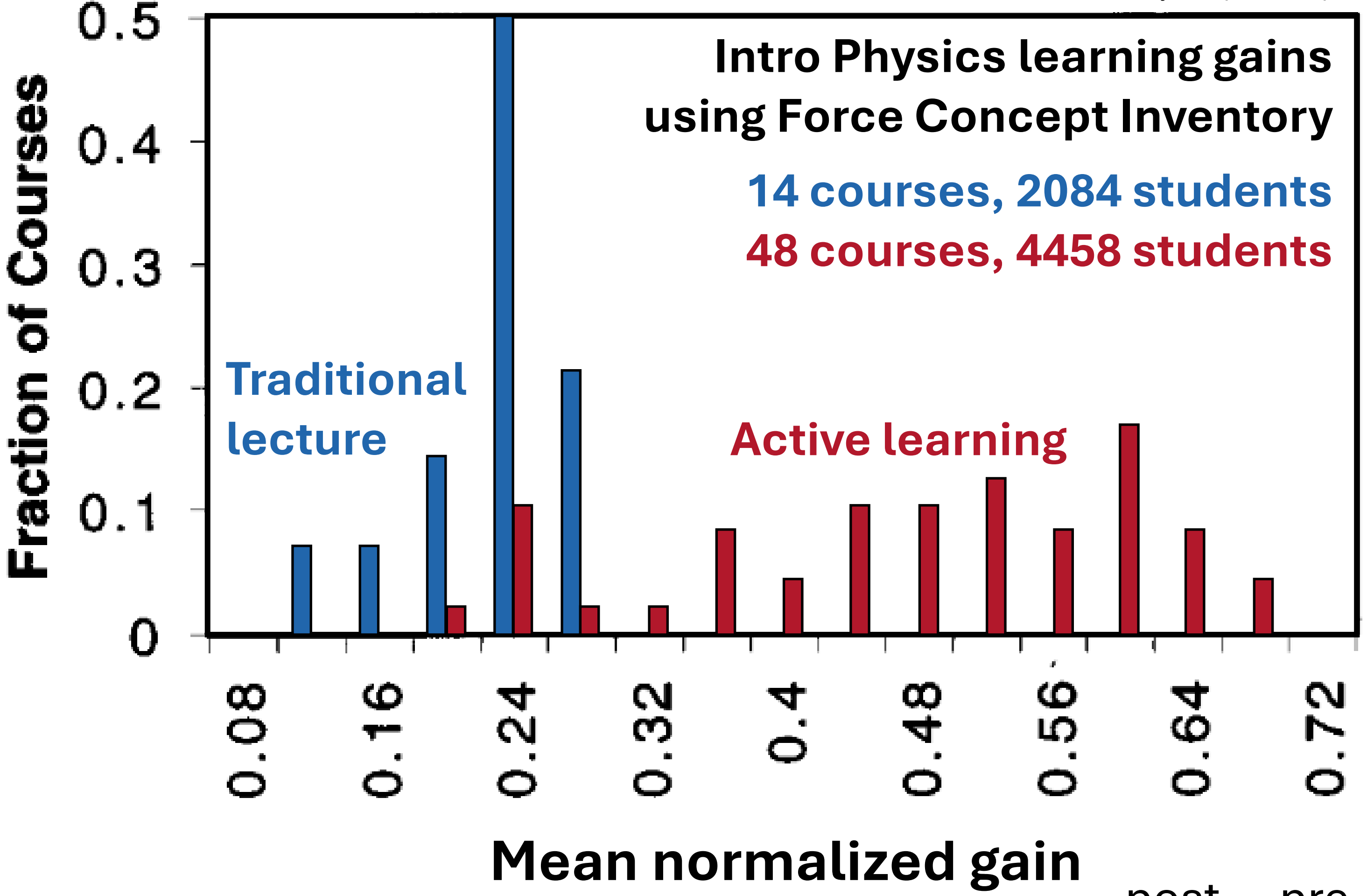
- Still, education research-based teaching methods **improve learning and retention** for students at **all ability levels** [McKagan, 2016].

- 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)

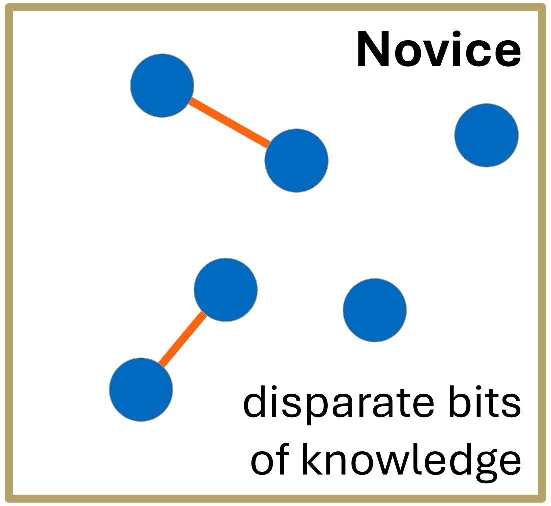


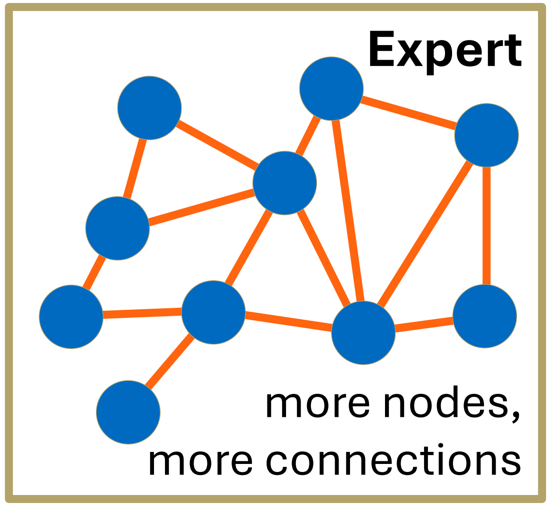
$$\text{normalized gain} = \frac{\text{post} - \text{pre}}{100\% - \text{pre}}$$

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

Students often…

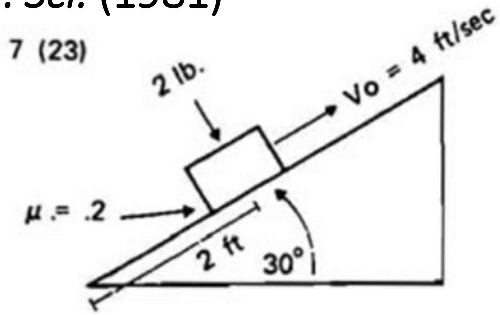
- **Know less** about a subject
- **Lack connections** between broad concepts
- **Organize** course content **differently**



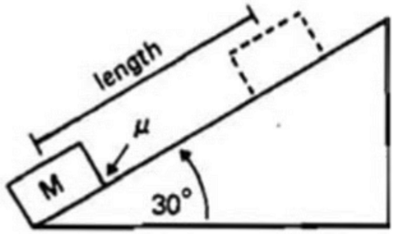


Chi et al., *Cogn. Sci.* (1981)

Problem 7 (23)



Problem 7 (35)



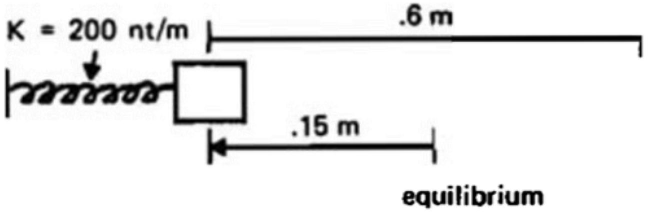
Novice 1: "These deal with blocks on an *incline plane*"

Novice 5: "*Inclined plane* problems, coefficient of *friction*"

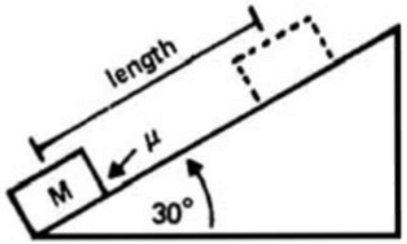
Novice 6: "Blocks on *inclined planes* with angles"

Novices categorize by **superficial** features.

Problem 6 (21)



Problem 7 (35)



Expert 2: "*Conservation of Energy*"

Expert 3: "*Work-Energy Theorem*. They are all straight-forward problems."

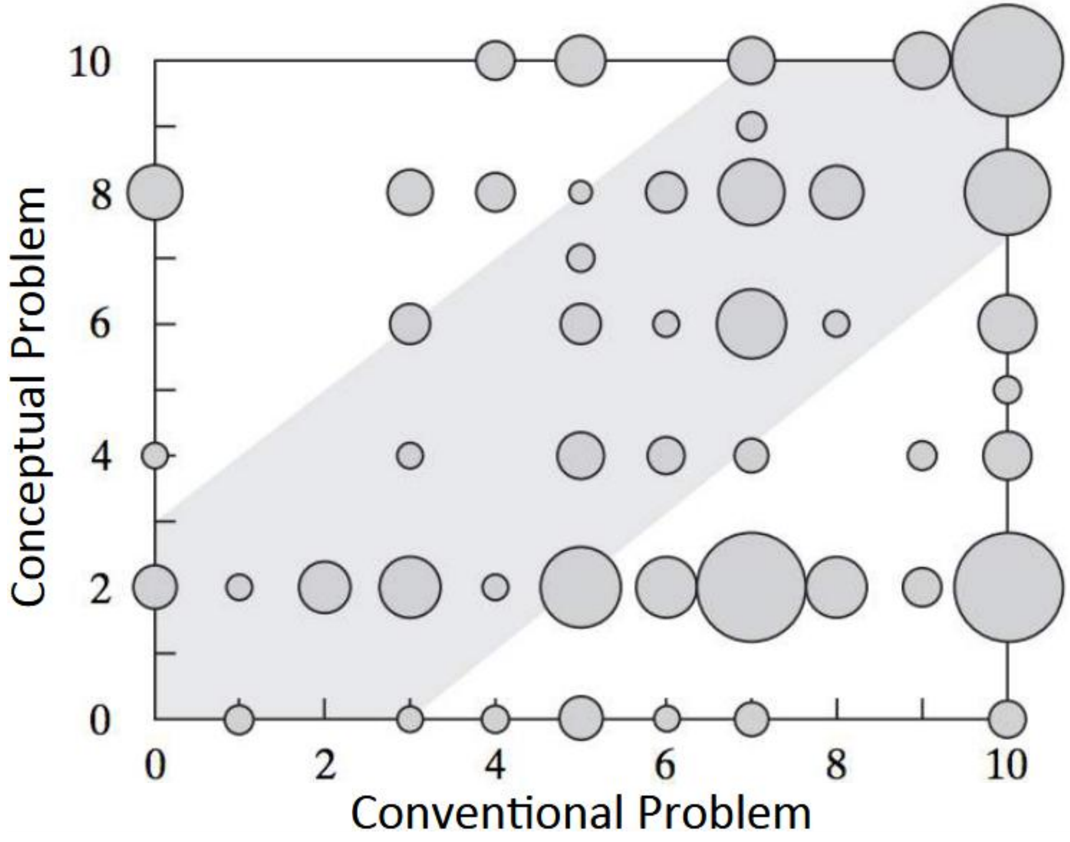
Expert 4: "These can be done from energy considerations. Either you should know the *Principle of Conservation of Energy*, or work is lost somewhere."

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].

Mazur, *Peer Instruction* (1997)



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

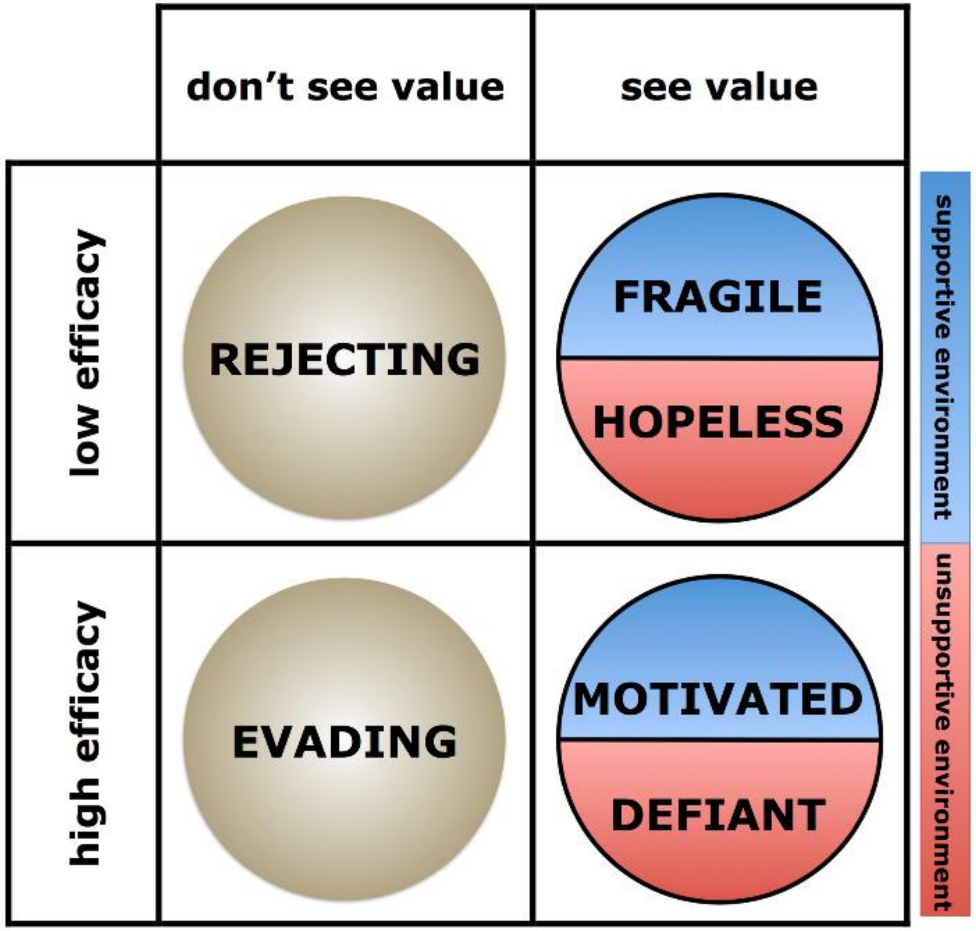
Contextual details about students, instructors, and course structure affect learning outcomes.

- 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].

Ambrose et al., *How Learning Works* (2010)



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.

AAPT PHYSICS EDUCATION® American Association of Physics Teachers® Enhancing the understanding and appreciation of physics through teaching

NATIONAL ACADEMIES Sciences Engineering Medicine

AUSTRALIAN LEARNING & TEACHING COUNCIL

IOP Institute of Physics

AIP American Institute of Physics

ABET Accreditation Board for Engineering and Technology

Swedish Council for Higher Education

AAPM AMERICAN ASSOCIATION of PHYSICISTS IN MEDICINE

J-TUPP JOINT TASK FORCE ON UNDERGRADUATE PHYSICS PROGRAMS

Oral and written media comprise a significant portion of classroom science communication.

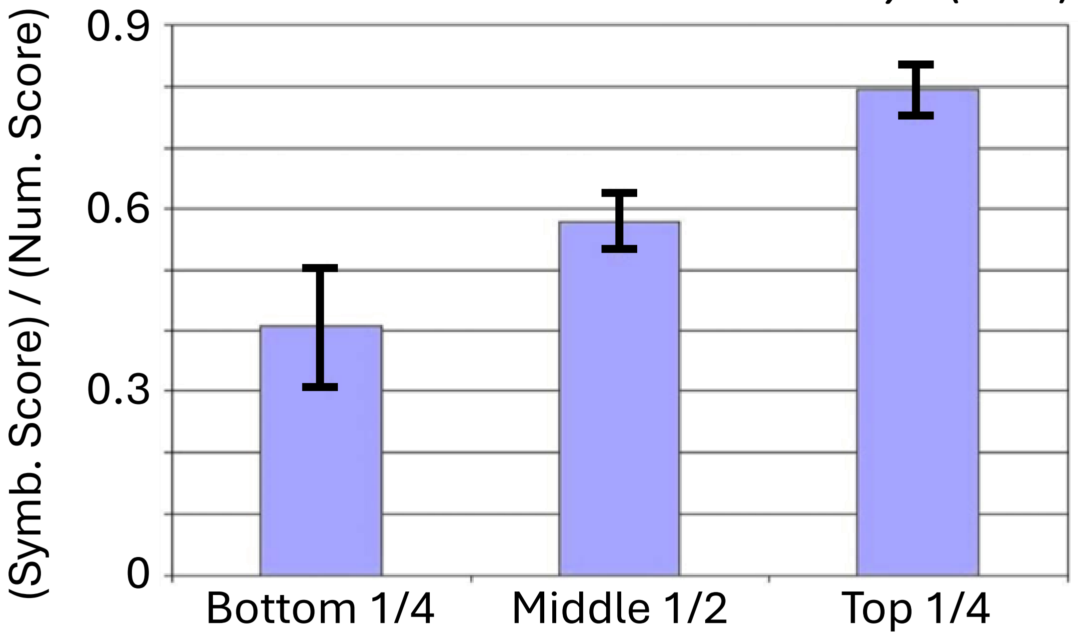
- Oral presentations help students develop effective **presentation, language, and research skills** [Aryadoust, 2015].
- Students view presentation assignments as **valuable despite** any associated **anxiety** [Grieve et al., 2021].
- Students and professionals agree that writing helps **refine scientific thought** [Hoehn & Lewandowski, 2020].

Presentation skills are broadly useful.

Translation between math and physics integrates quantitative and communicative learning goals.

- Students often **communicate** their present **understanding** to instructors through **problem-solving**.
- Mathematics and physics appear similar but approach numbers and symbols in **fundamentally different** ways [Torigoe, 2015].
- Novice physicists implicitly **assume** languages of math and physics are **interchangeable** [Torigoe & Gladding, 2011; Tuminaro & Redish, 2007].

Torigoe & Gladding, *Am. J. Phys.* (2011)



Introductory physics students perform worse on symbolic algebra-based physics problems than on equivalent numerical problems.

Peer-peer and peer-instructor interactions can improve science communication skills.

Erukhimova, @tamuphysastr, *YouTube* (2022)

- Informal peer **dialogues** during group problem-solving sessions **can improve learning** outcomes [Simpfendoerfer et al., 2024].
- Structured **feedback** from instructors can facilitate learning **on par with coursework** and exams [Hounsell et al., 2008].
- Progressively consumerist students have prompted instructors to adopt **new roles** as tutors, service providers, and entertainers [Wong & Chiu, 2019].

Instructors are creating increasingly performative science communication in the classroom with social media flair.

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

What made their lecturing the best?

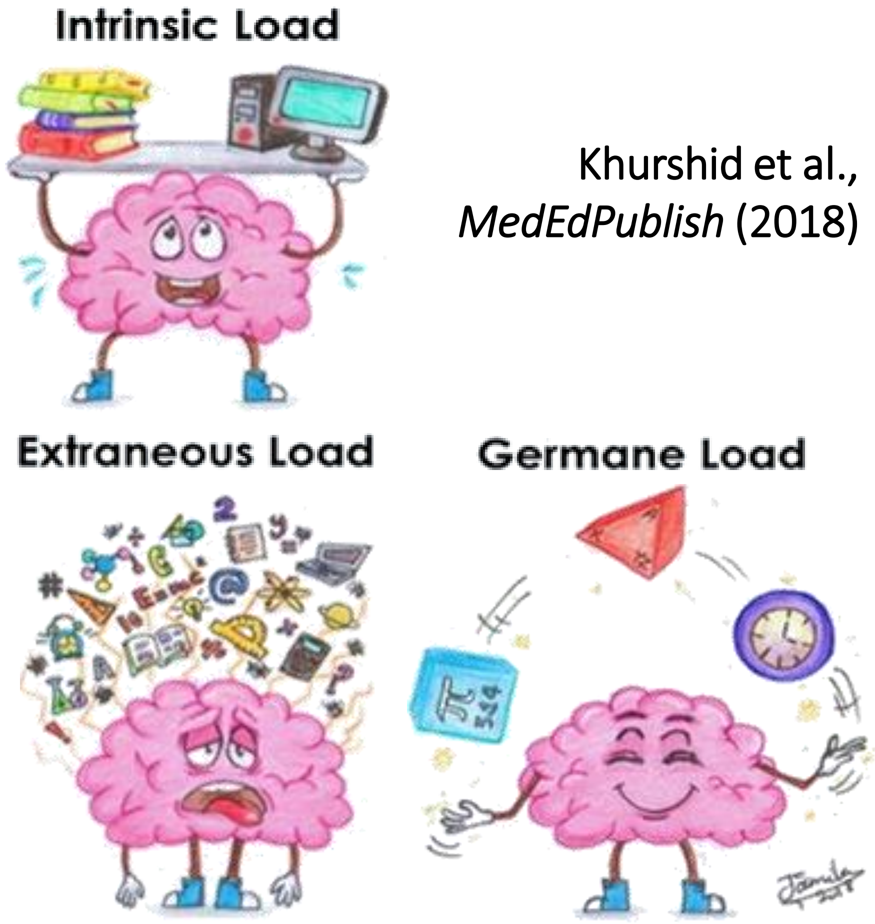
- Your answers here

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].
- **Other proposed theories** are less developed.
  - Integrative Model of Text-Picture Comprehension [Schnotz, 2002]
  - Grounded cognition model [Chen & Gladding, 2014]

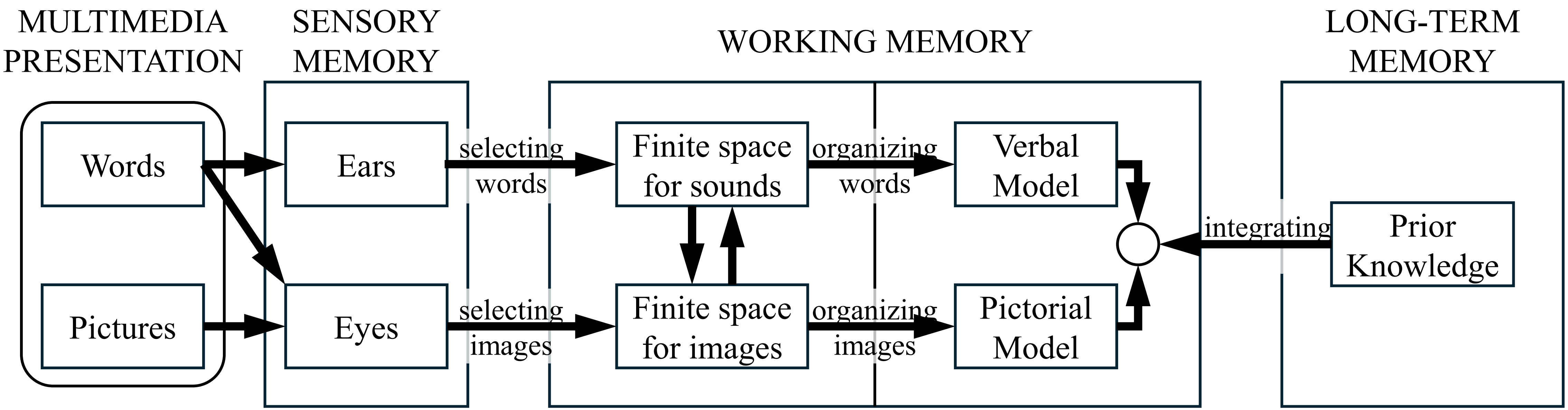


Khurshid et al., *MedEdPublish* (2018)

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

Successful multimedia is more than the sum of its parts.

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



Simultaneous sensemaking across **two channels**

Content curated to **avoid cognitive overload**

Active knowledge construction **guided** by a teacher

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**.

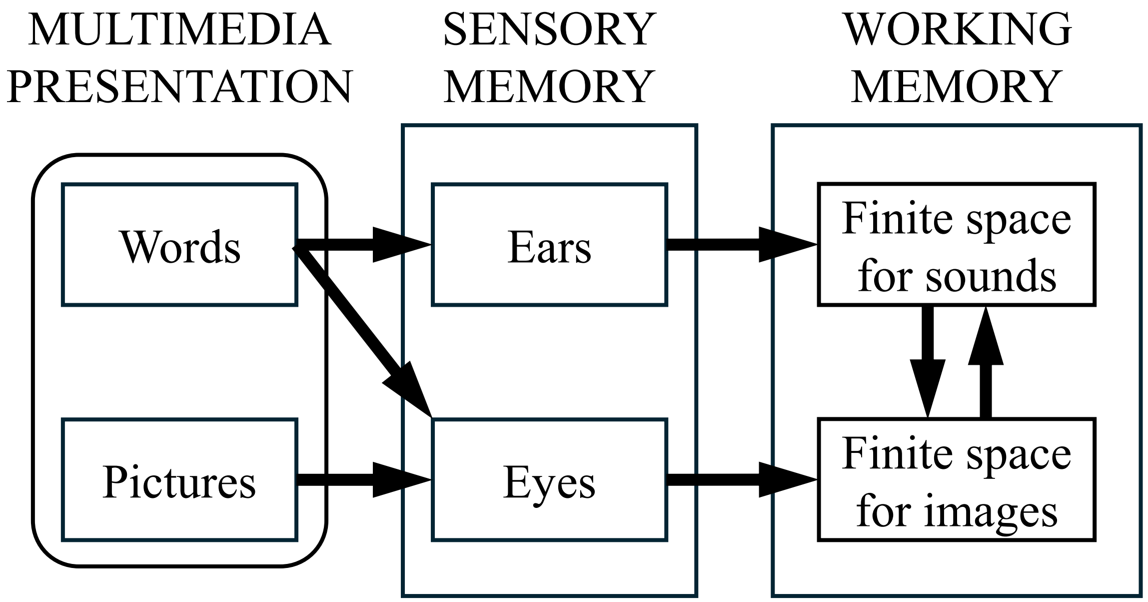
Coherence: Omit extraneous details.

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 et al., *J. Educ. Psychol.* (2001)

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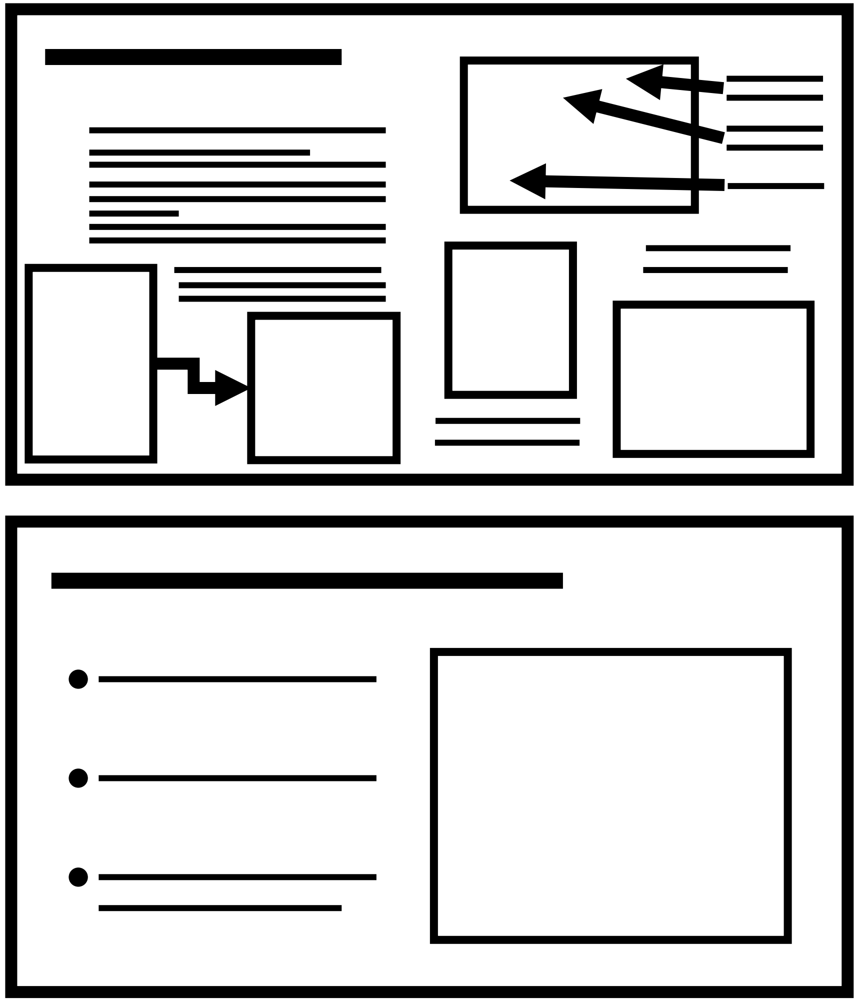


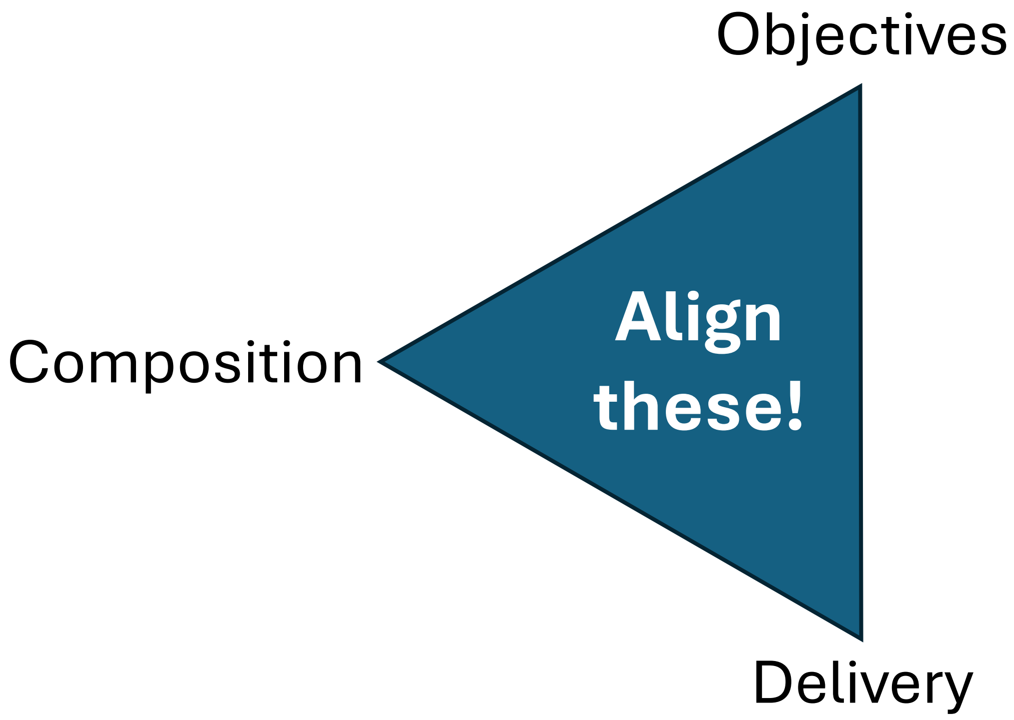
Overwhelming slide design hinders learning.

Design goals for instructional graphics depend on their intended medium.

Adapted from
Ambrose et al.,
How Learning Works (2010)

- Knowing how people learn from presentations helps us **design slides for learning**.
- Using **premade graphics** seems deceptively simple.
- **Different considerations** apply for other instructional media!
  - e.g., size constraints in printed media

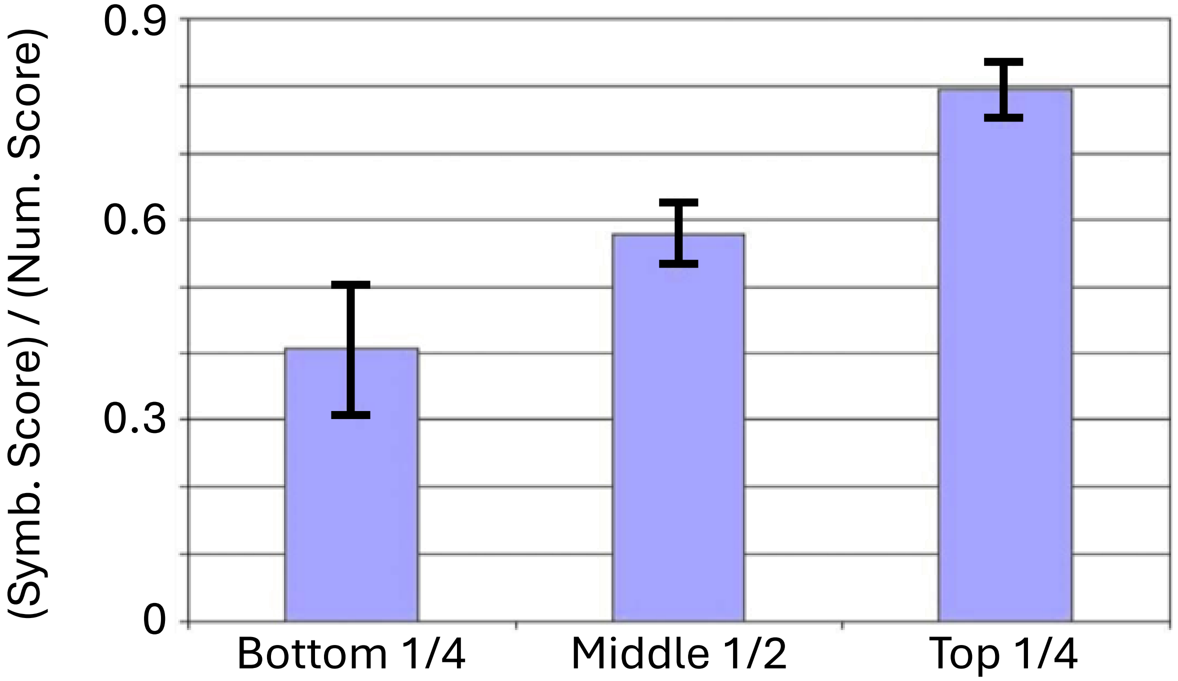
Presentation Design Triangle



Adapting graphics is necessary but easy.

- What can go wrong?
  - Mismatched content
  - Missing context
  - Illegible/unclear material
- Easy to fix with raw files or data…
  - …but we likely don't have them.
- Let's see some simple tricks to adjust premade graphics.

Torigoe & Gladding, *Am. J. Phys.* (2011)



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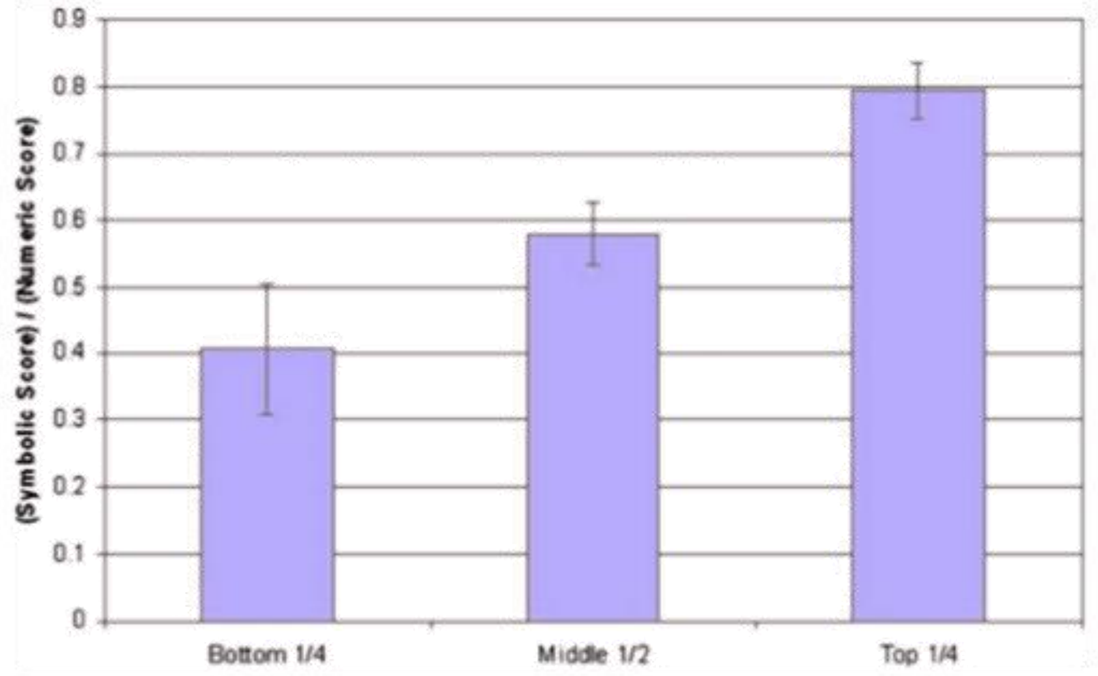


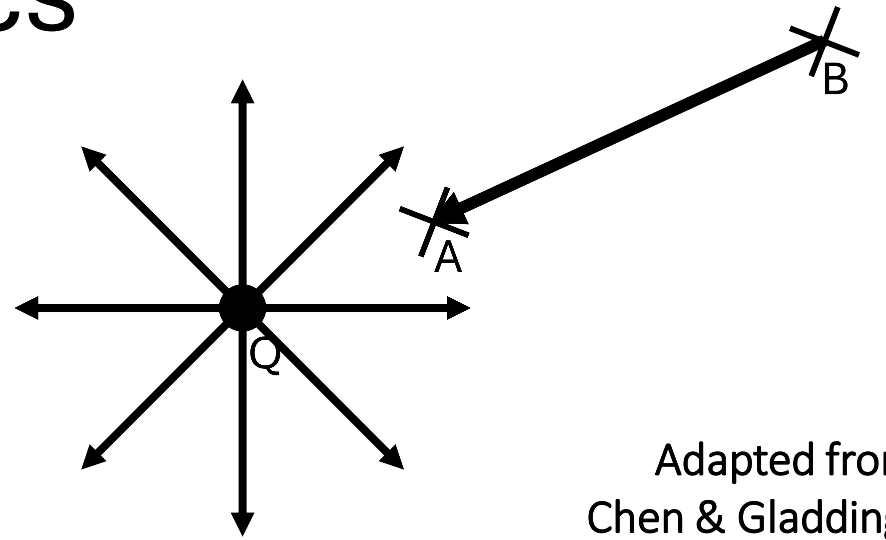
Fig. 1. Ratio of the symbolic version score to the numeric version score for different subgroups of the class averaged over two questions analyzed in Ref. 1. We interpret this ratio to represent the likelihood that the students who could solve the numeric version correctly would also solve the symbolic version correctly.

Consider designing simple graphics that leverage our spatial senses.

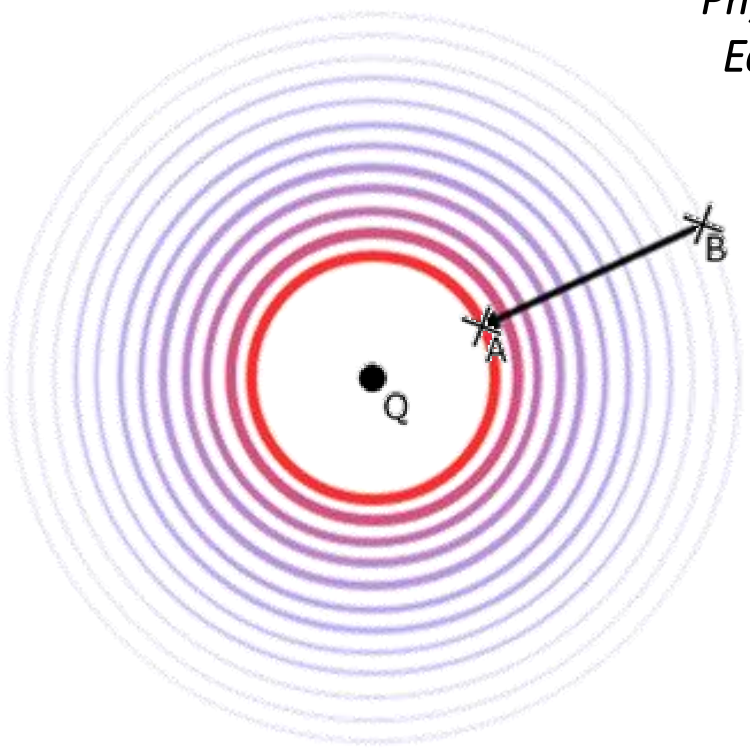
- More artistic freedom means **more freedom** to facilitate learning.

- **Align** abstract **content** with sensory-motor **perception** [Chen & Gladding, 2014].
  - e.g., Thick lines, saturated colors, typically perceived as “stronger”

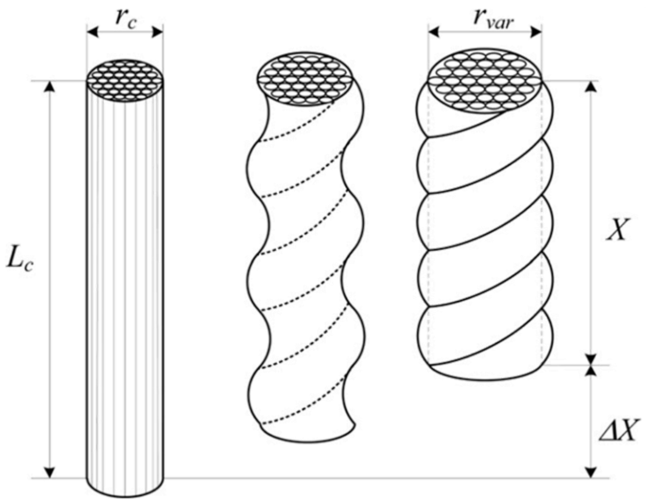
- No data? No problem! Make a **toy model**.



Adapted from Chen & Gladding, *Phys. Rev. ST Phys. Educ. Res.* (2014)



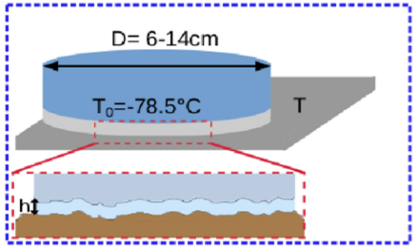
Theory

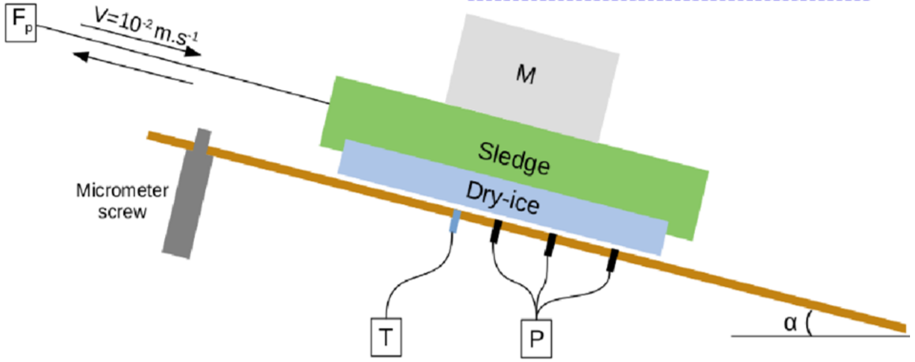


Gaponov et al., *IEEE/ASME Trans. Mechatron.* (2014)

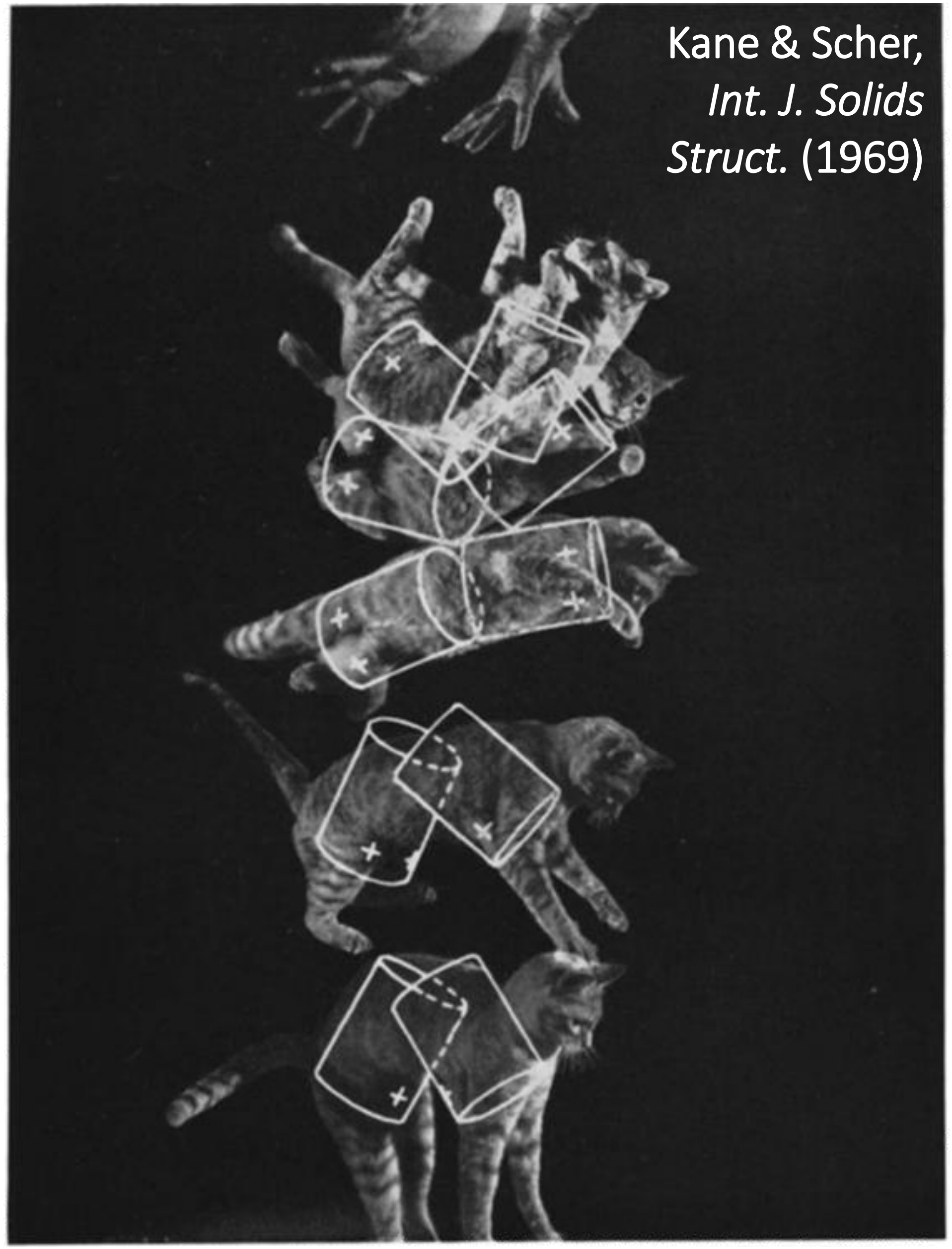
Apparatus

Parrenin et al., *Phys. Rev. E* (2021)



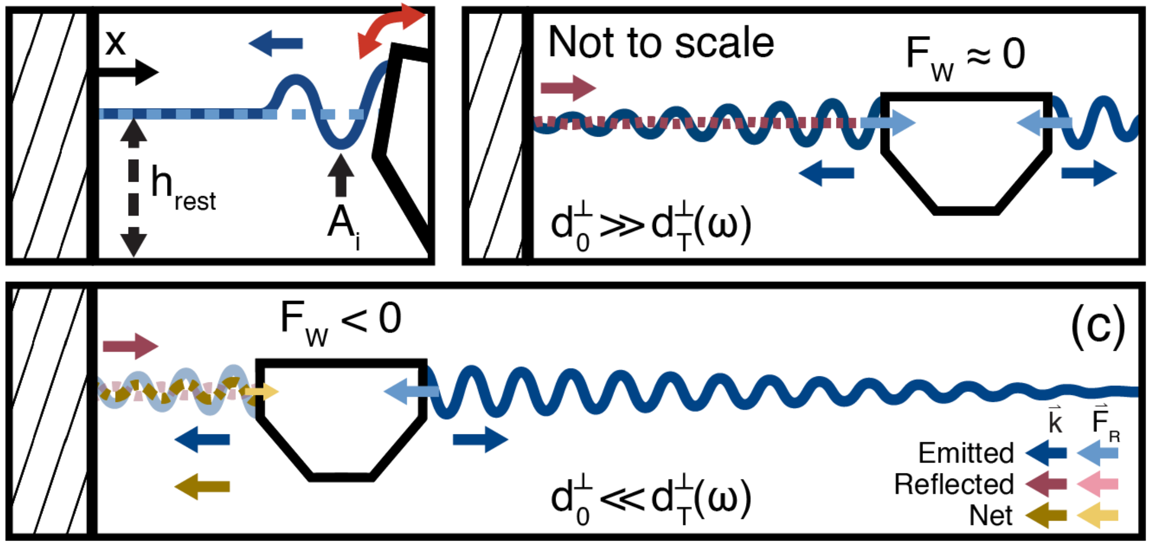


Experiment



Kane & Scher, *Int. J. Solids Struct.* (1969)

Result

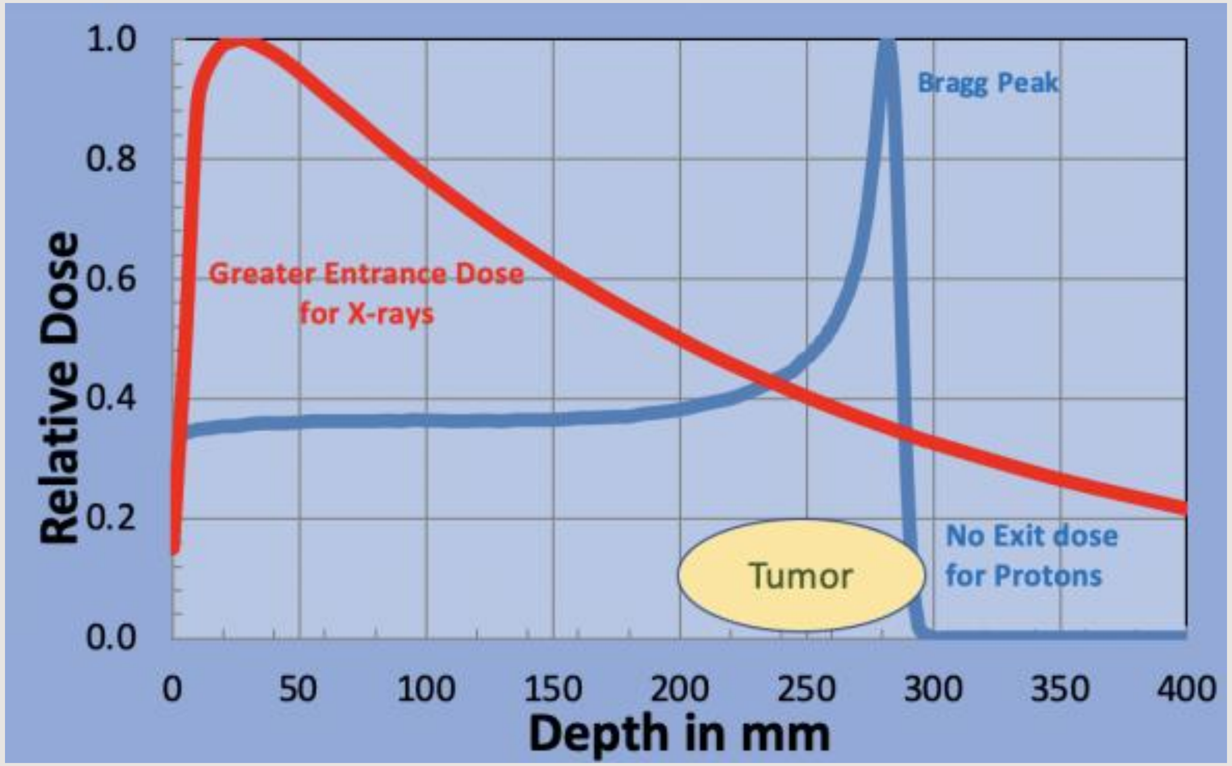


Tarr et al., *Phys. Rev. Lett.* (2024)

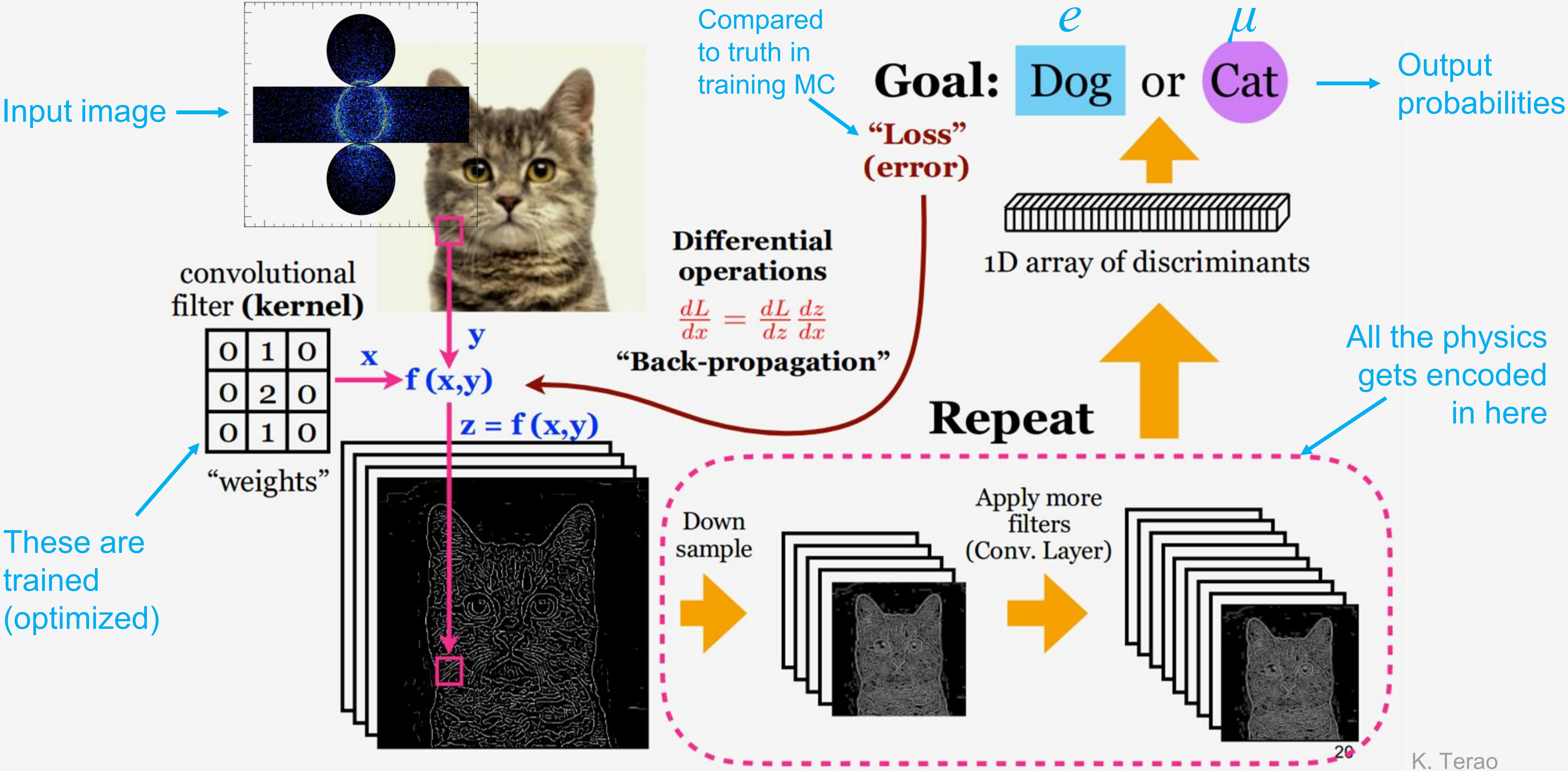
Let’s discuss some example slides from students who took PHYS 4602 before it included any instruction.

PROTON THERAPY VS PHOTON THERAPY

- Photon beam therapy, or traditional radiation, delivers an X-Ray beam as treatment to the patient
- The nature of proton energy loss ensures there is no exit dose
- Greater entrance dose for X-Rays
- In a comparative study by JAMA Oncology, patients treated with proton therapy were much less likely to experience severe side effects from treatment
- More research is necessary for a definitive conclusion



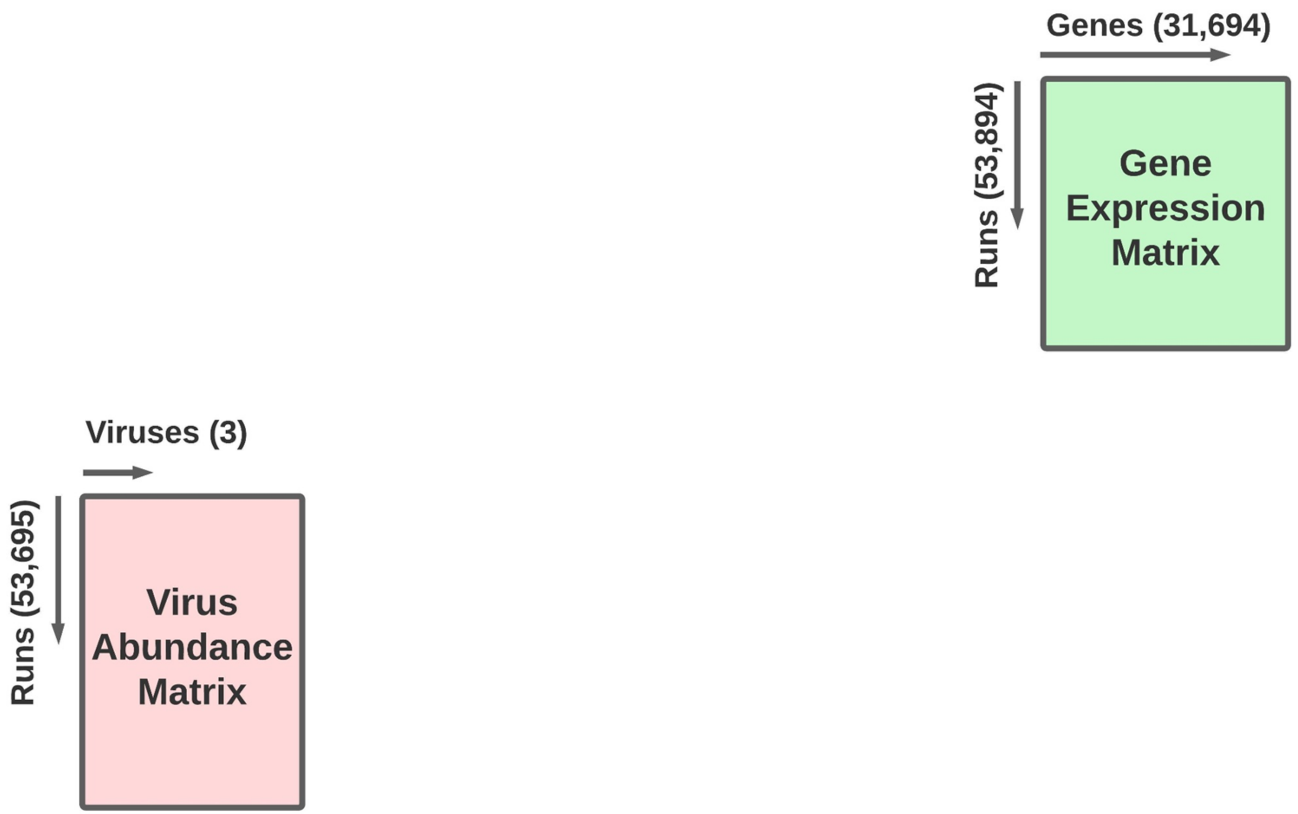
Crash Course in Deep Learning (CNN)



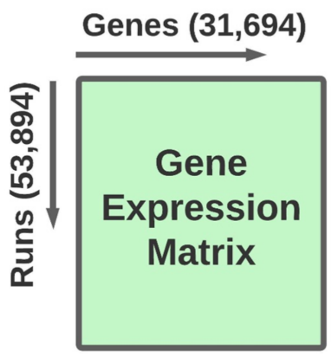
K. Terao

Machine learning workflow

Figure generated by Weights & Biases



Machine learning workflow



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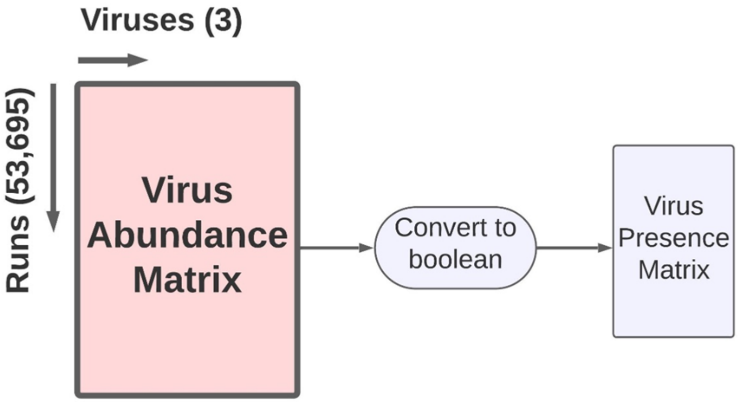

Machine learning workflow

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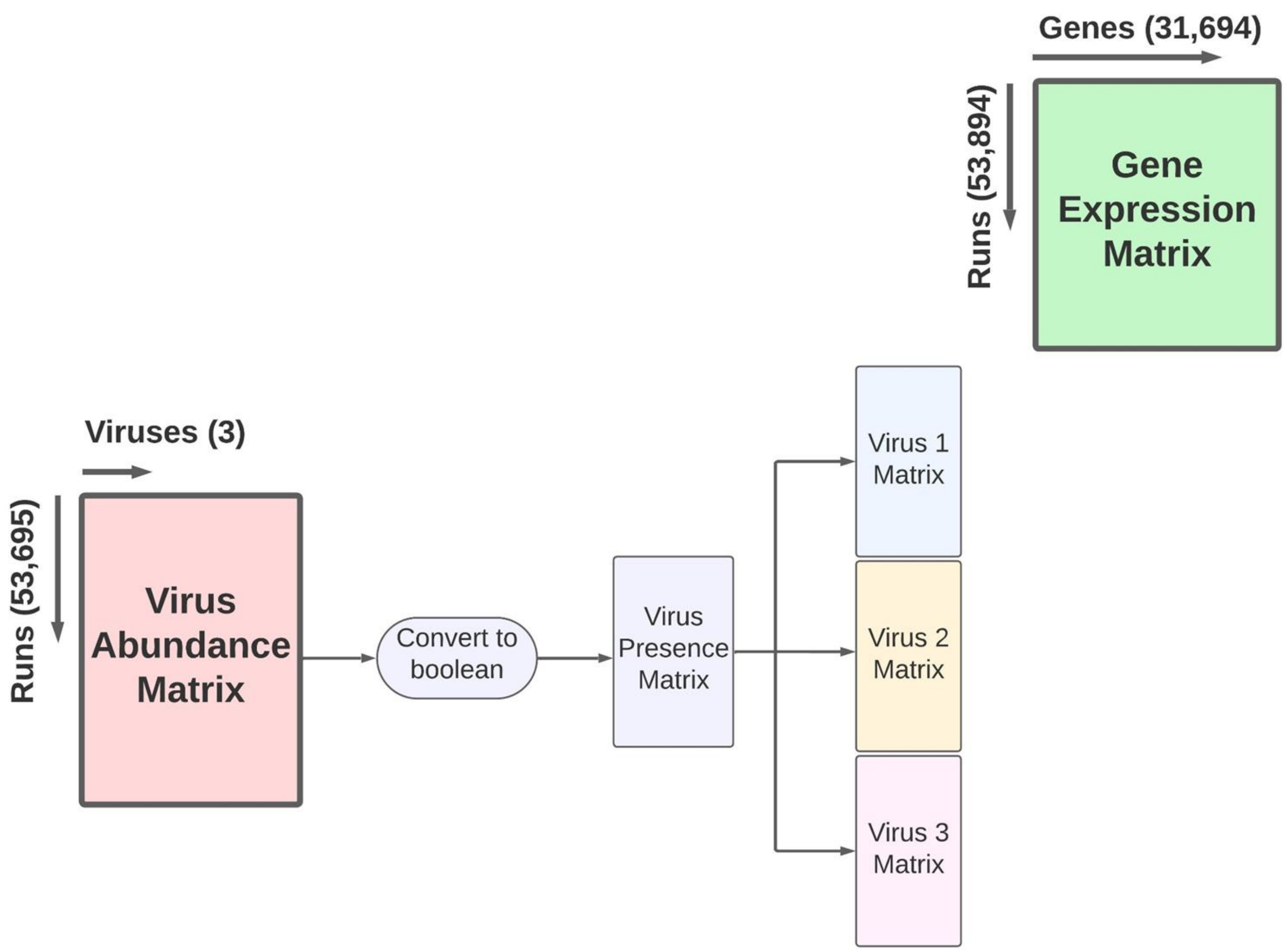

Machine learning workflow

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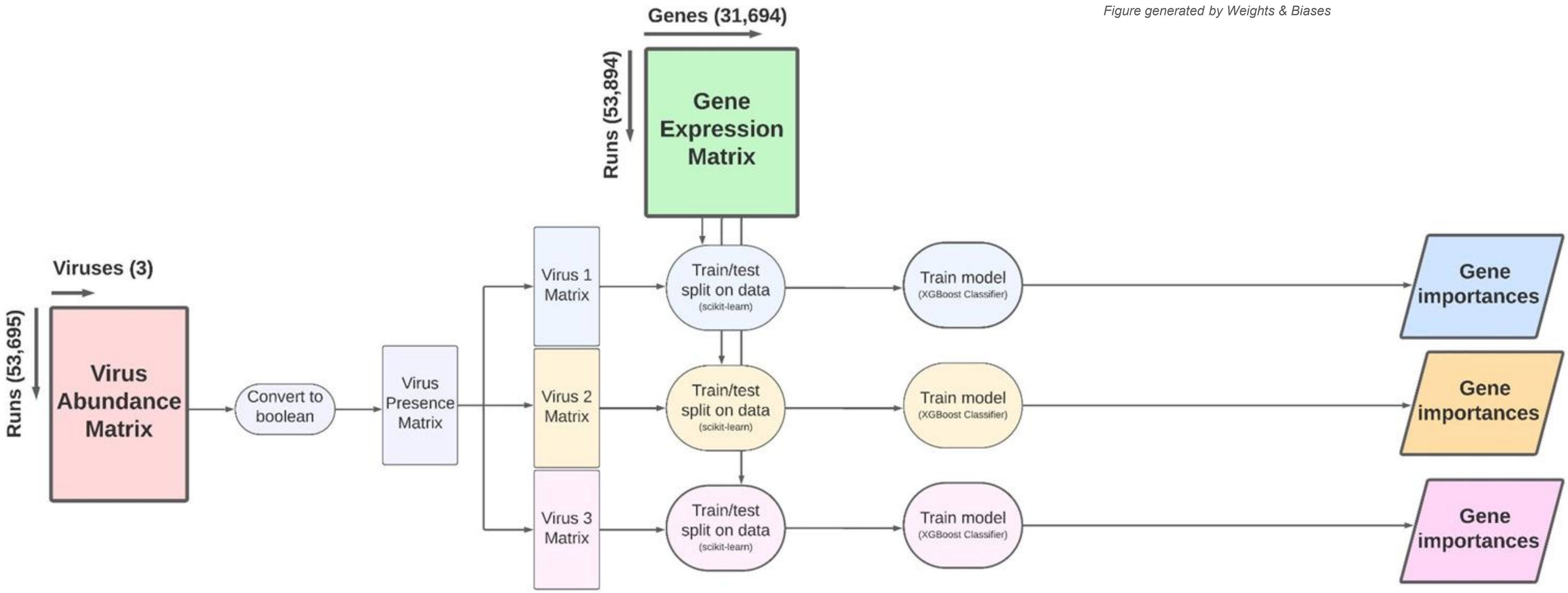

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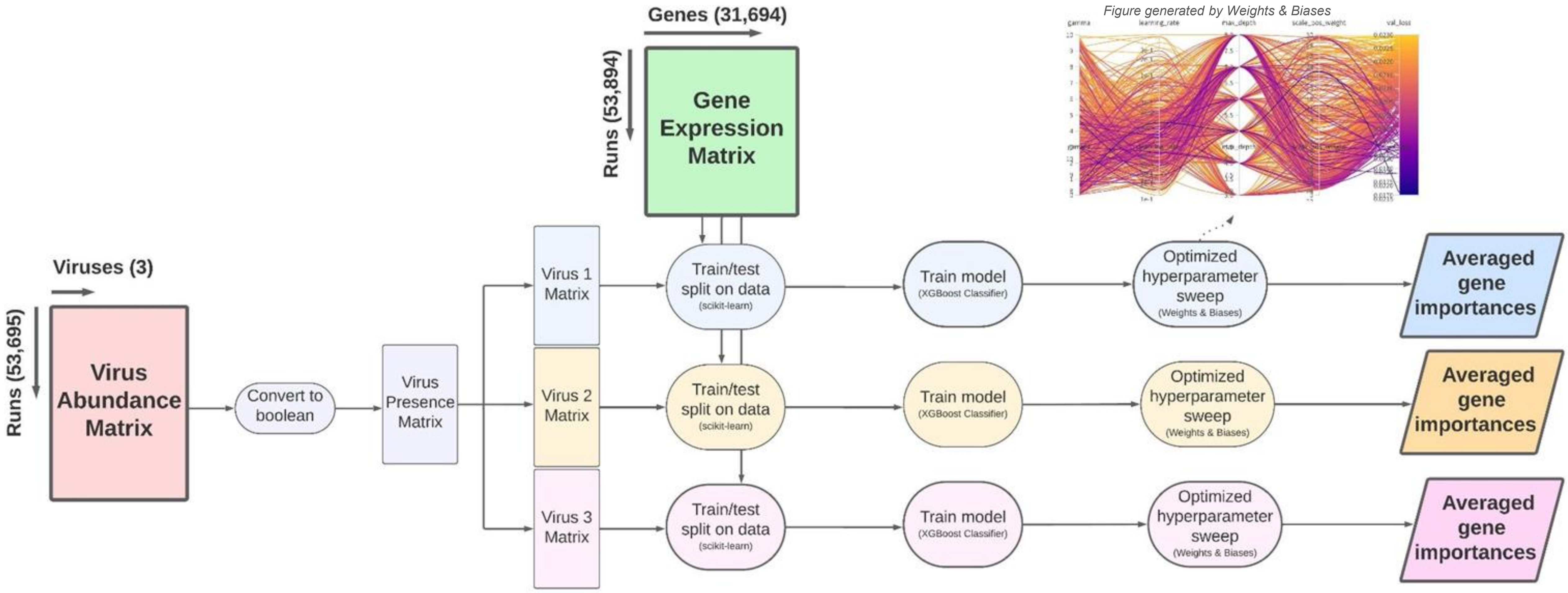

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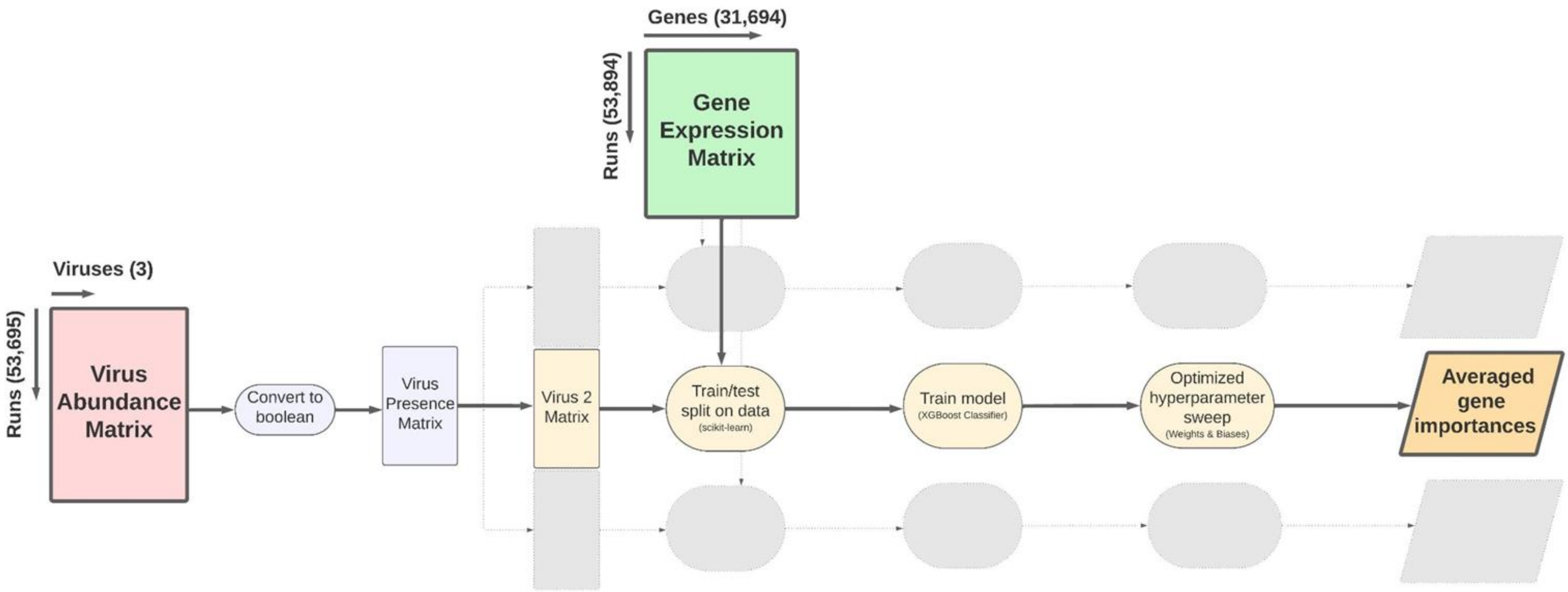
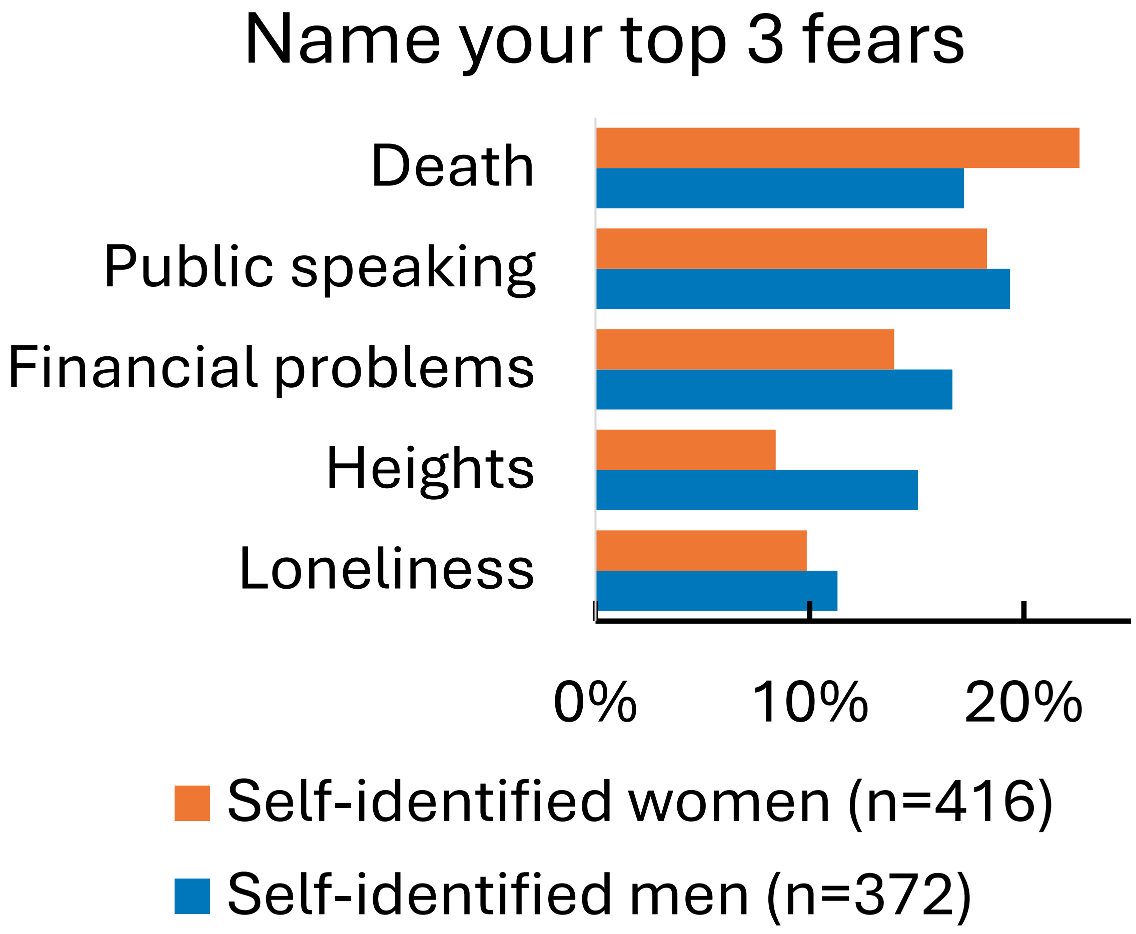
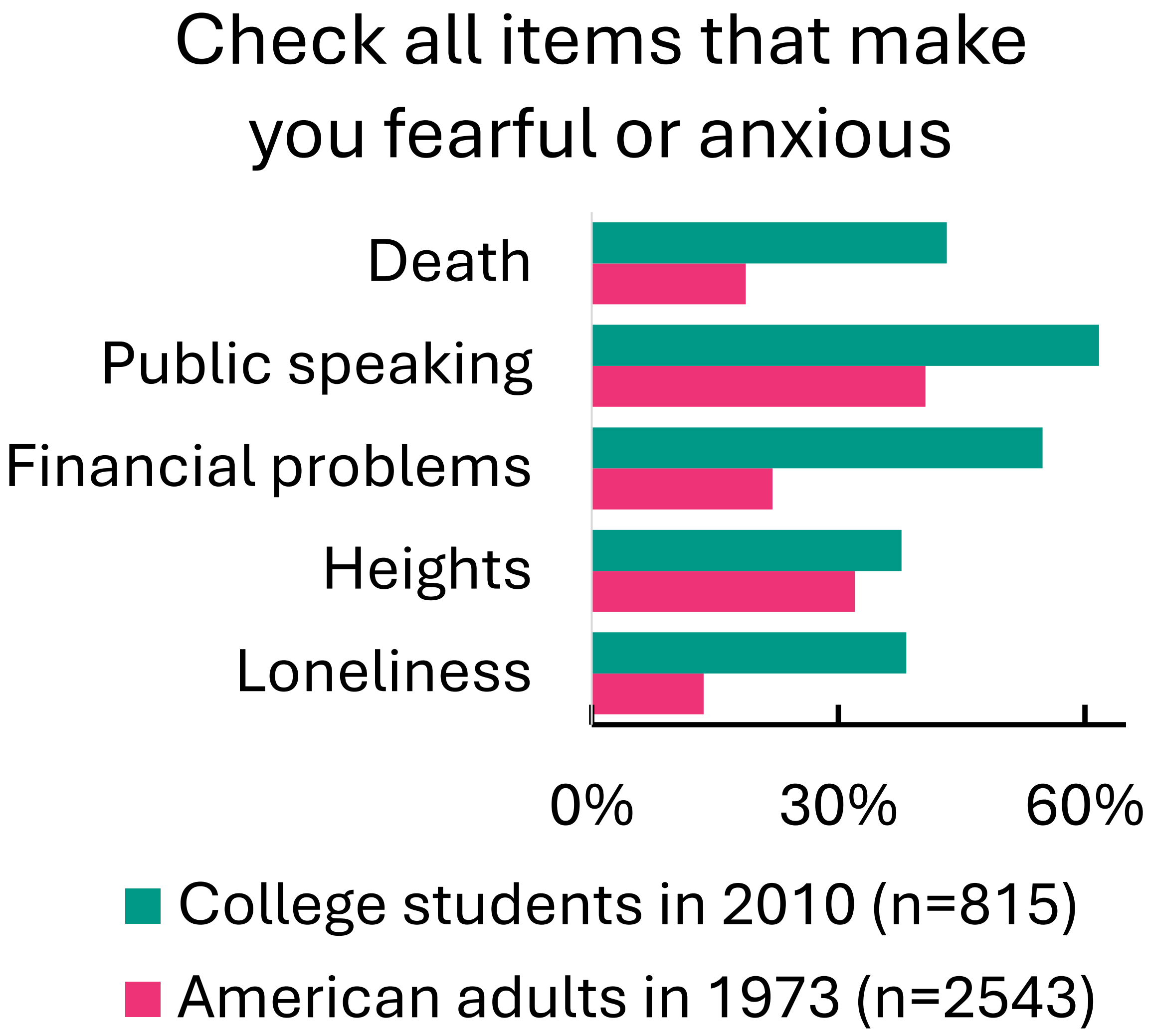


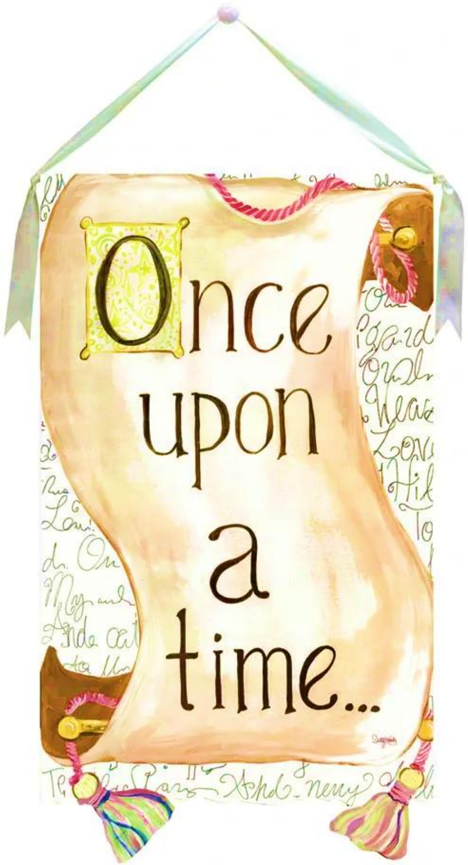
Public speaking ranks highly among common fears.

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





Novice public speakers often face 3 main challenges.



Organization

Delivery
(Verbal and nonverbal)

Anxiety

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, CHEM 4601 at GT
  - Succinctly restate goal(s) and take-home message.
  - Avoid abrupt endings and introducing new concepts.

First 2-3 slides, not counting title

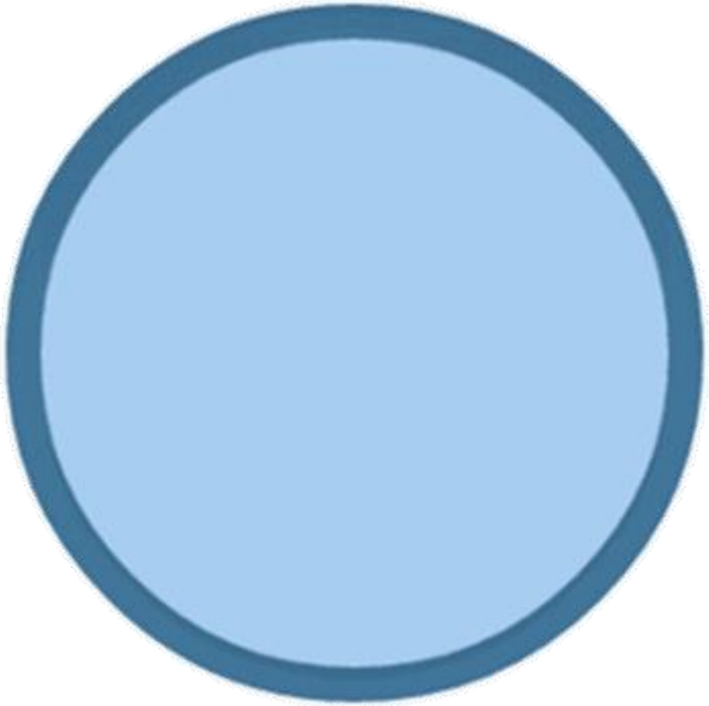
Conversations are more engaging than lectures.

- 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
  - Gestures
  - Facial expressions
  - 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.

BREAK

We'll continue in 5 minutes

TIME'S UP!

Georgia Tech

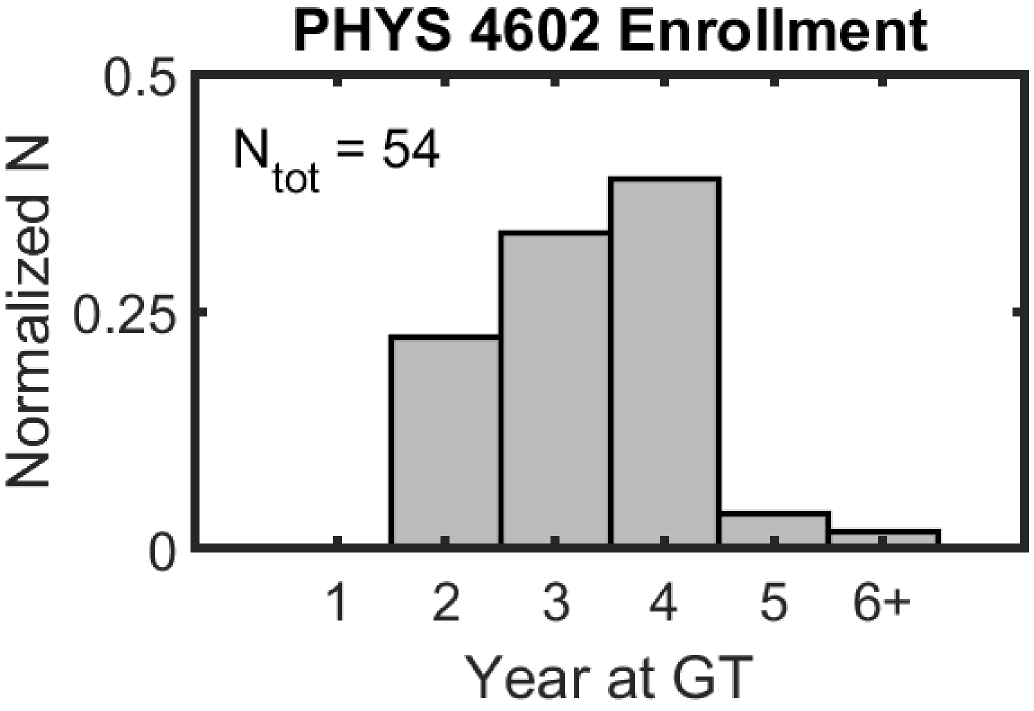
Students have dual roles in the physics and biochemistry communication courses at GT.

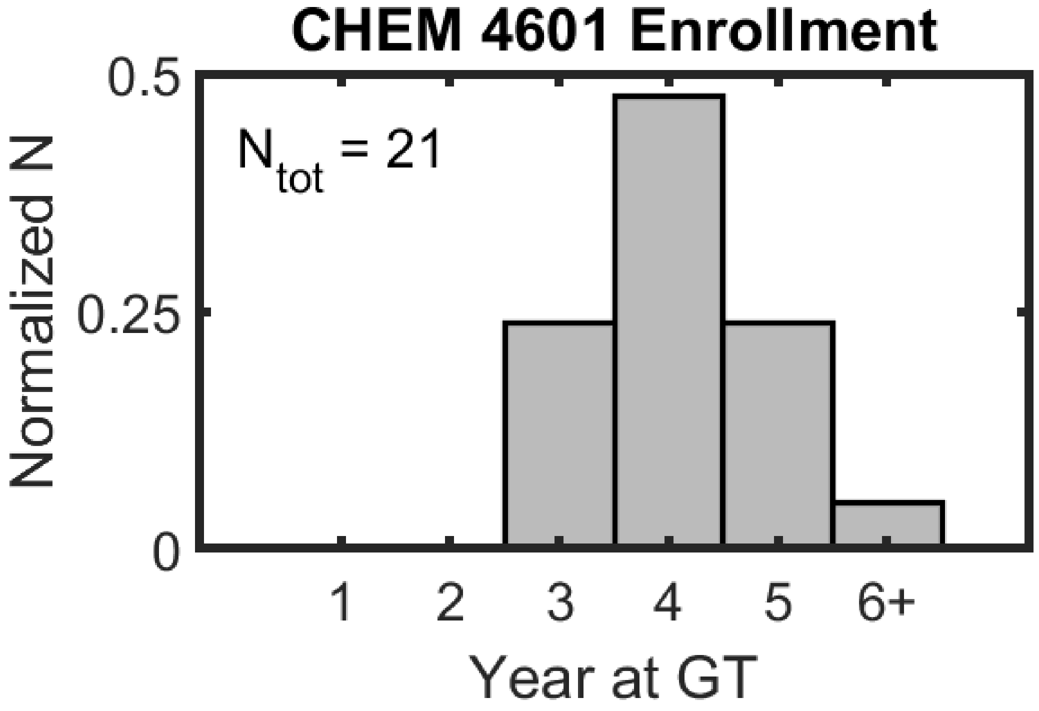
PHYS 4602 (1 credit hour)

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

CHEM 4601 (2 credit hours)

- Typical semesterly enrollment: 30-36
  - Two sections capped at 18 each
  - 48% 4th-years, skews older





Demographic information is limited to students who filled the survey.

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

PHYS 4602 (1 credit hour)

- Typical semesterly enrollment: 40-50
  - One uncapped section
  - 39% 4^{th}-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

CHEM 4601 (2 credit hours)

- Typical semesterly enrollment: 30-36
  - Two sections capped at 18 each
  - 48% 4^{th}-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**."*

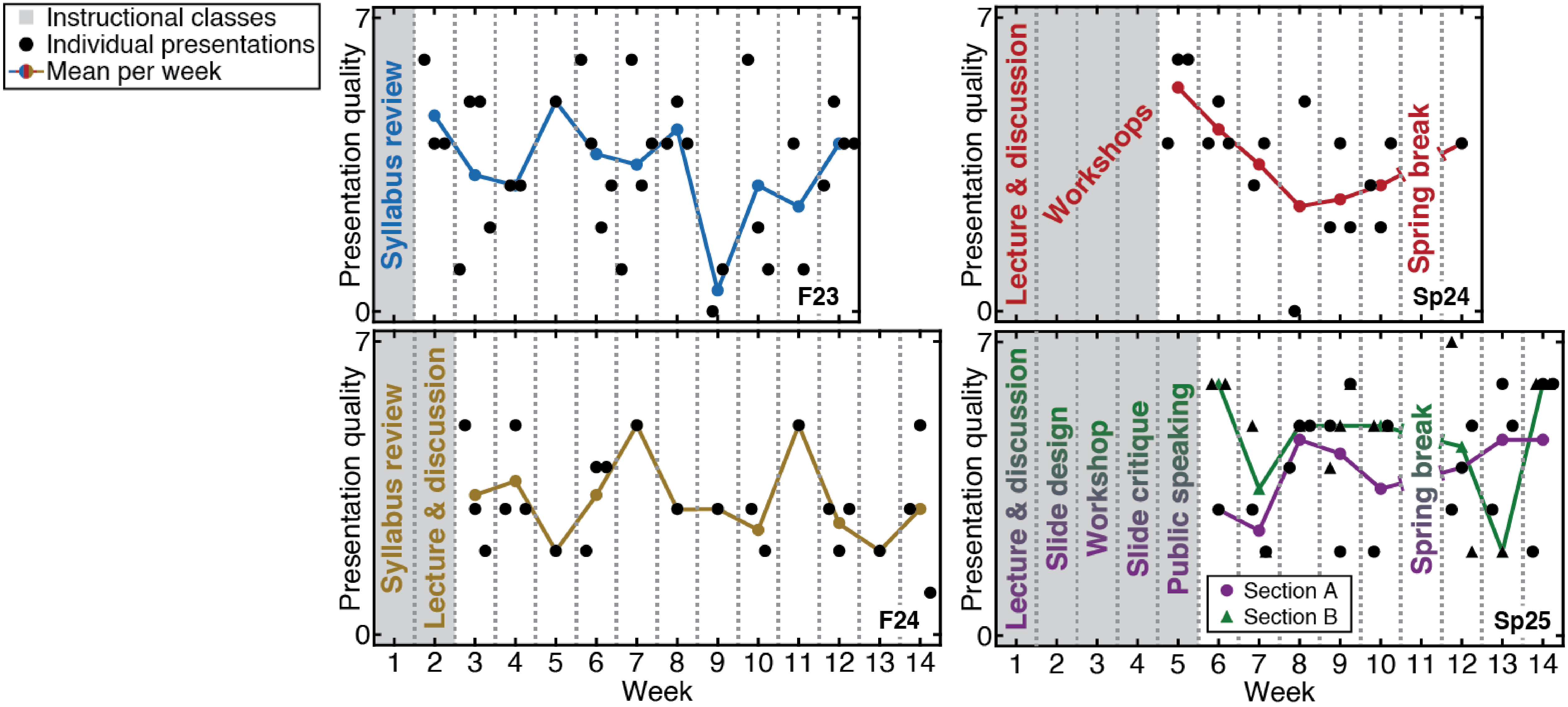
PHYS Sp25 students praised many aspects of research-based instruction but still saw room for improvement.

- PHYS Sp25: W1 Intro to science presentations, W2 Slide design, W3 Presentation workshop, W4 Slide critique, W5 Public speaking

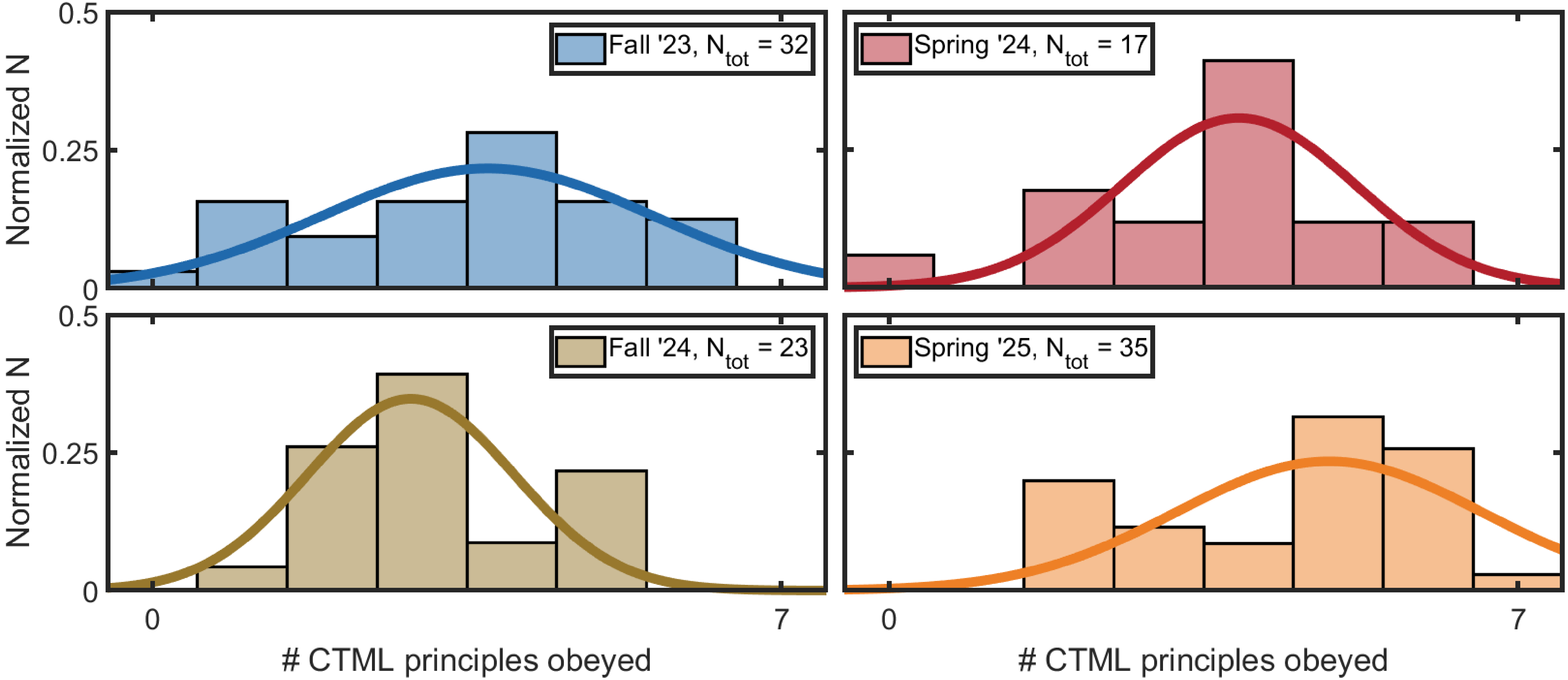
Tally	Intro	Slide Design	Workshop	Slide Critique	Public Speaking	Ambiguous
Positive	1	9	4	1	5	5
Mixed	0	1	1	1	1	4
Negative	0	0	1	4	0	1

- Students appreciated **learning** slide design **guidelines** (e.g., animations, text and graphic usage) and **practicing implementation** with the hands-on activity.
- Students found the workshop **useful for building** their slides and getting **feedback**, though some felt it was too soon to focus on slide specifics.
- Students were **frustrated** by critiquing one key slide because it led to **irrelevant feedback** built on **incorrect assumptions** about the broader presentation.
- Students embraced the speaking challenge as **initially scary but very helpful**. Some requested more feedback and exposure to further build confidence.

In PHYS 4602, presentation quality remains roughly constant throughout semesters regardless of intervention.



Research-based instruction helped PHYS 4602 students in Sp25 significantly outperform earlier students.



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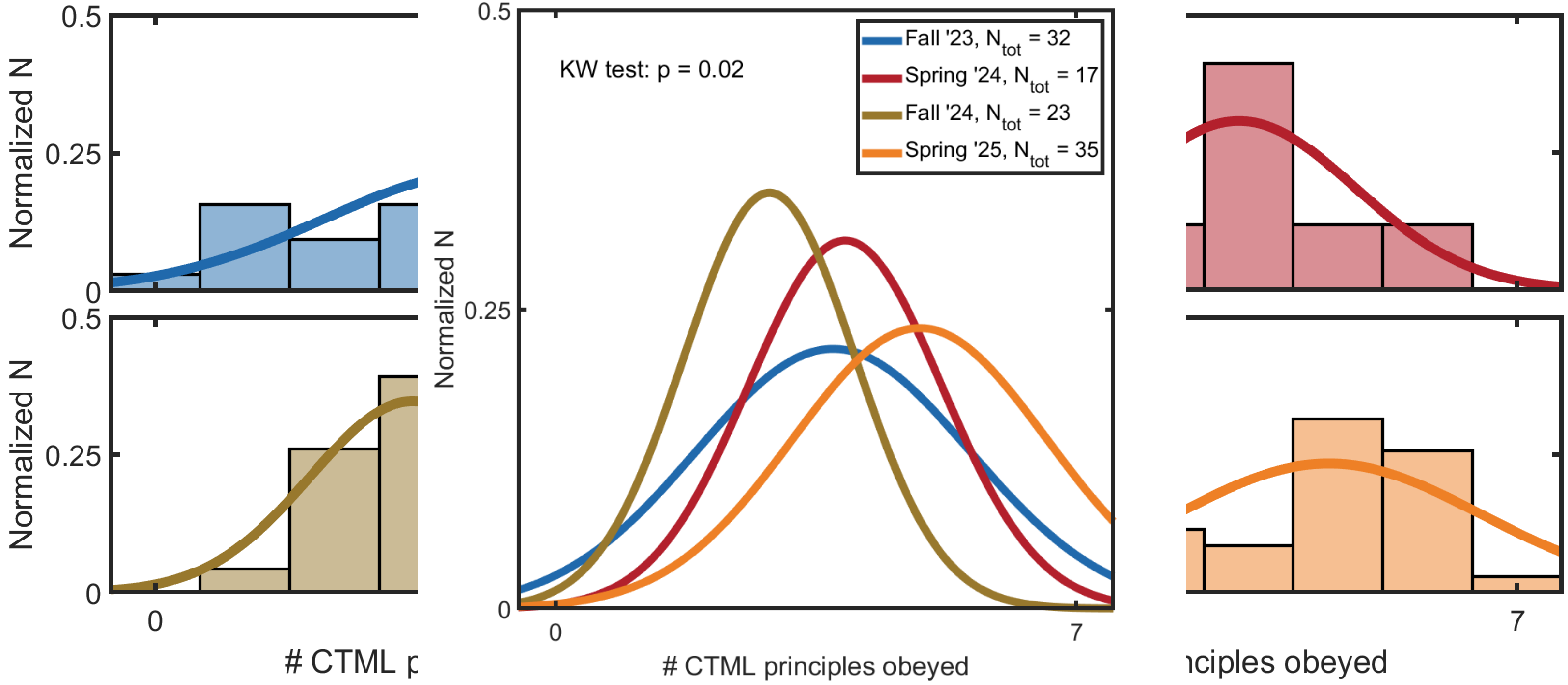

One-sided Mann-Whitney U tests with Bonferroni corrections suggest that Sp25 students outperformed F23 ($p < 0.05, |z| = 2.25$) and F24 ($p < 0.01, |z| = 2.89$) students but not Sp24 students ($p = 0.15, |z| = 1.65$).

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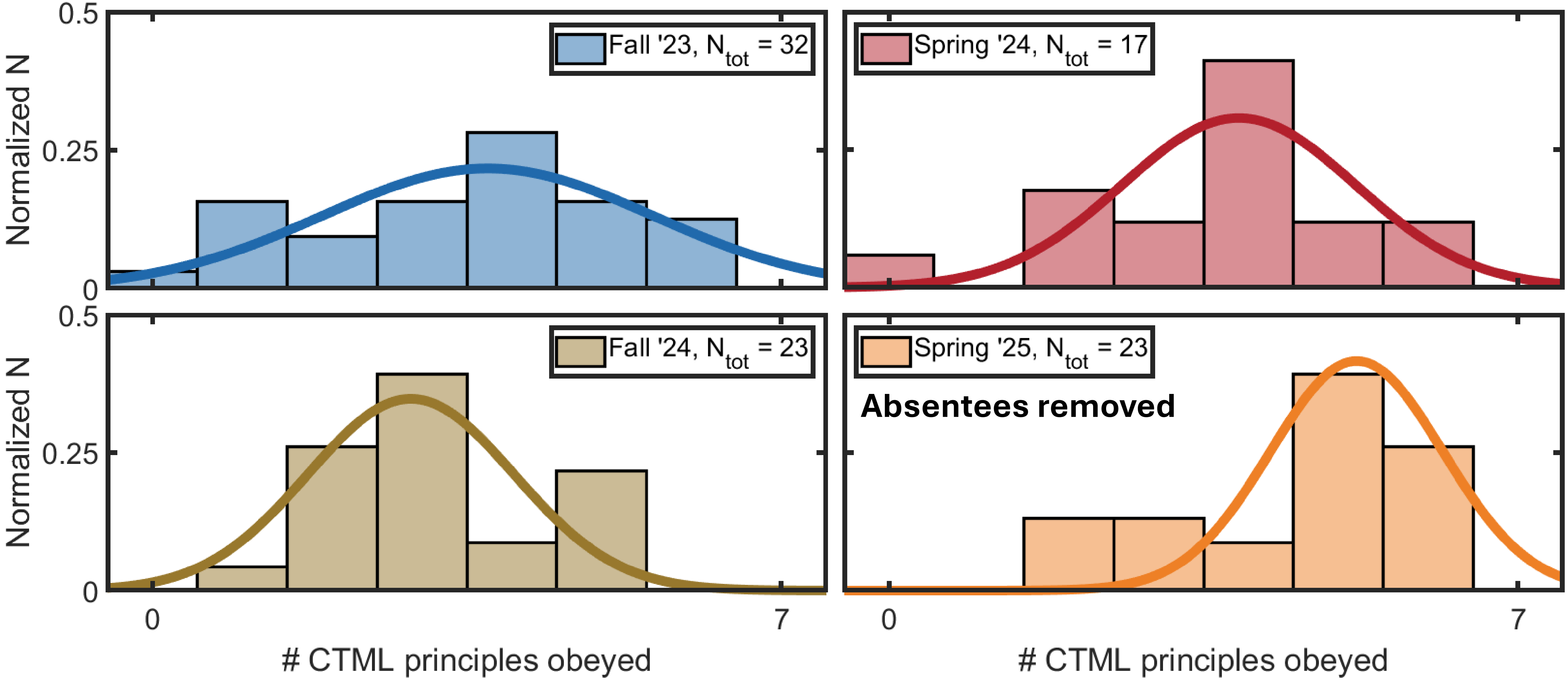

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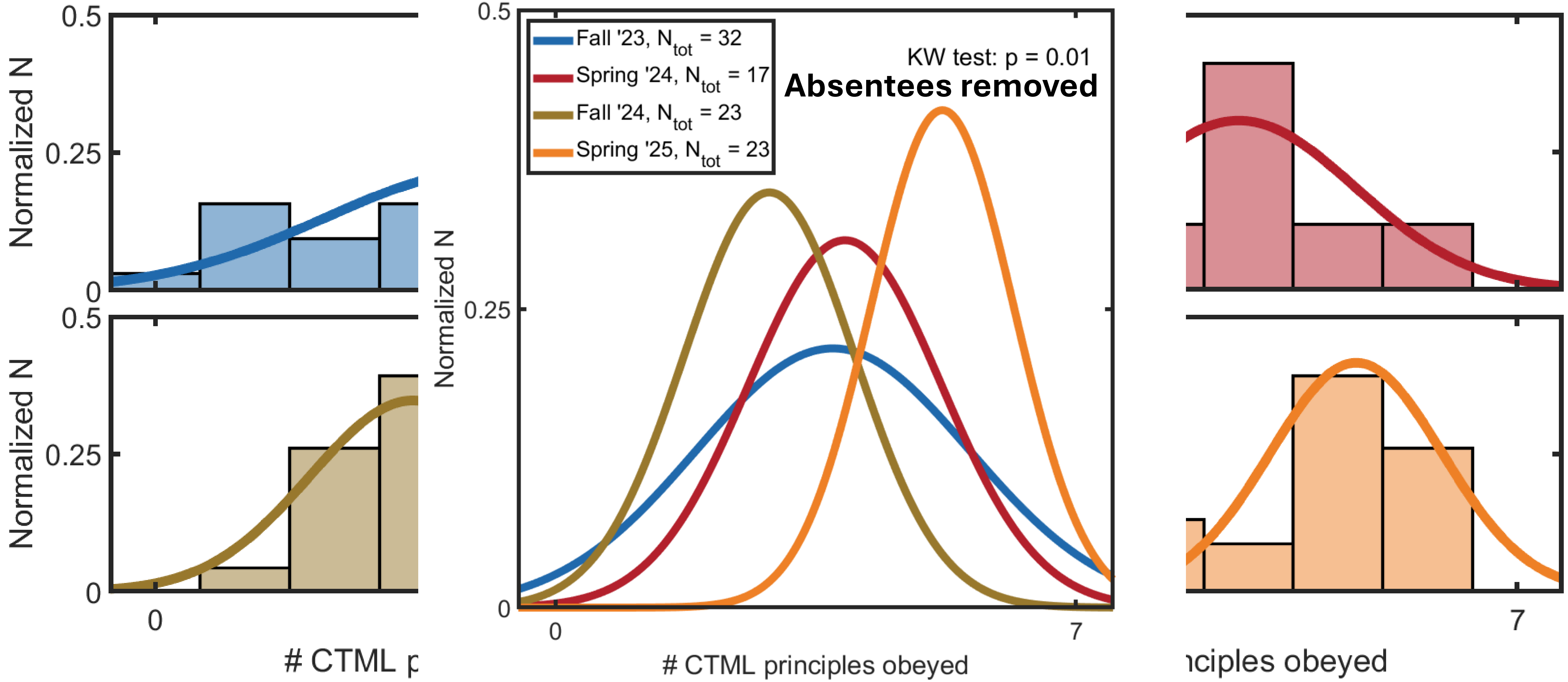
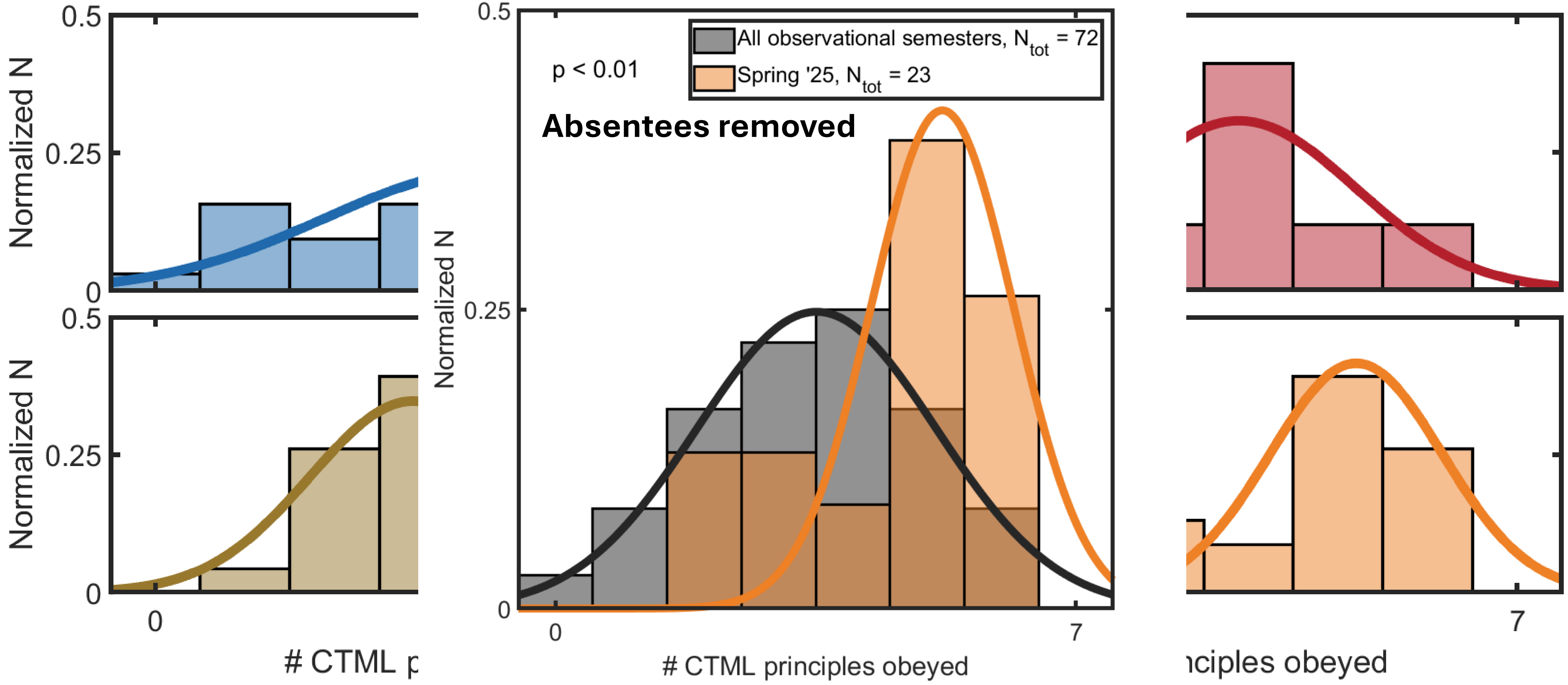


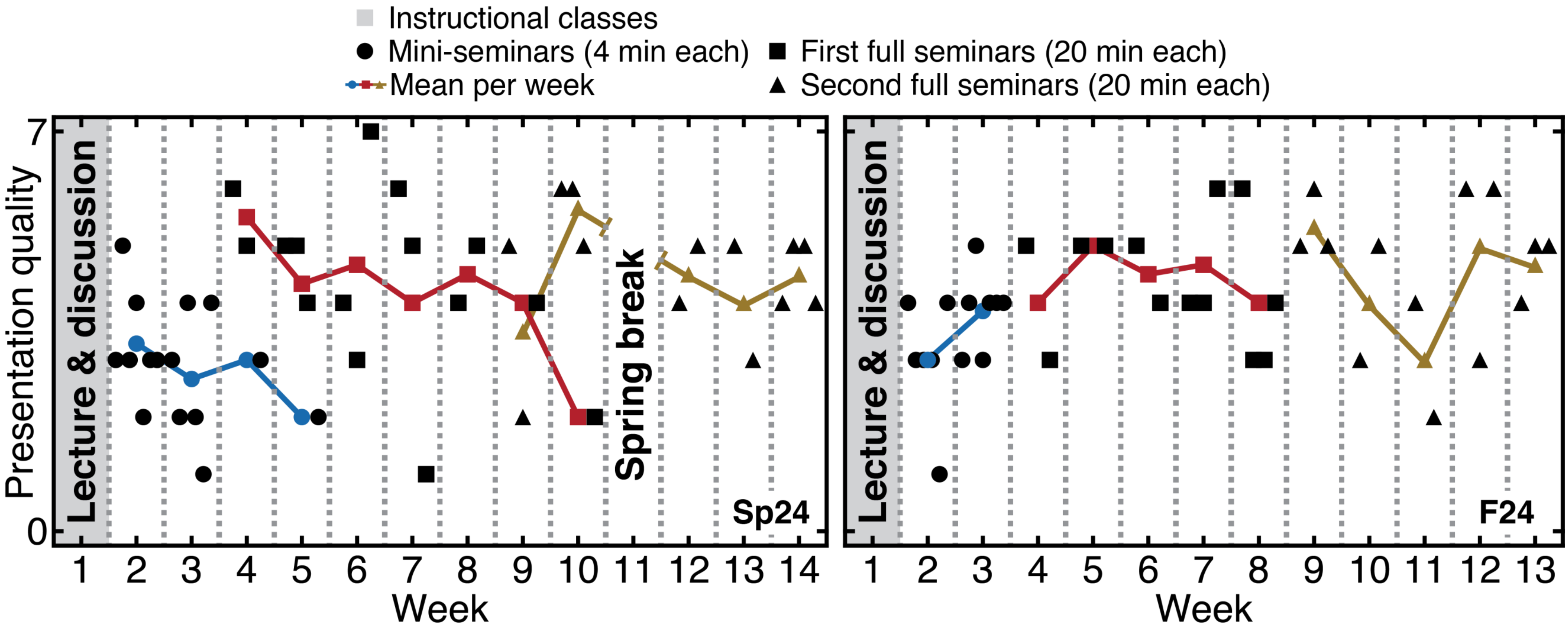
One-sided Mann-Whitney U tests with Bonferroni corrections suggest that Sp25 students outperformed F23 ($p < 0.05, |z| = 2.35$) and F24 ($p < 0.01, |z| = 3.12$) students but not Sp24 students ($p = 0.09, |z| = 1.89$).

Research-based instruction helped PHYS 4602 students in Sp25 significantly outperform earlier students.

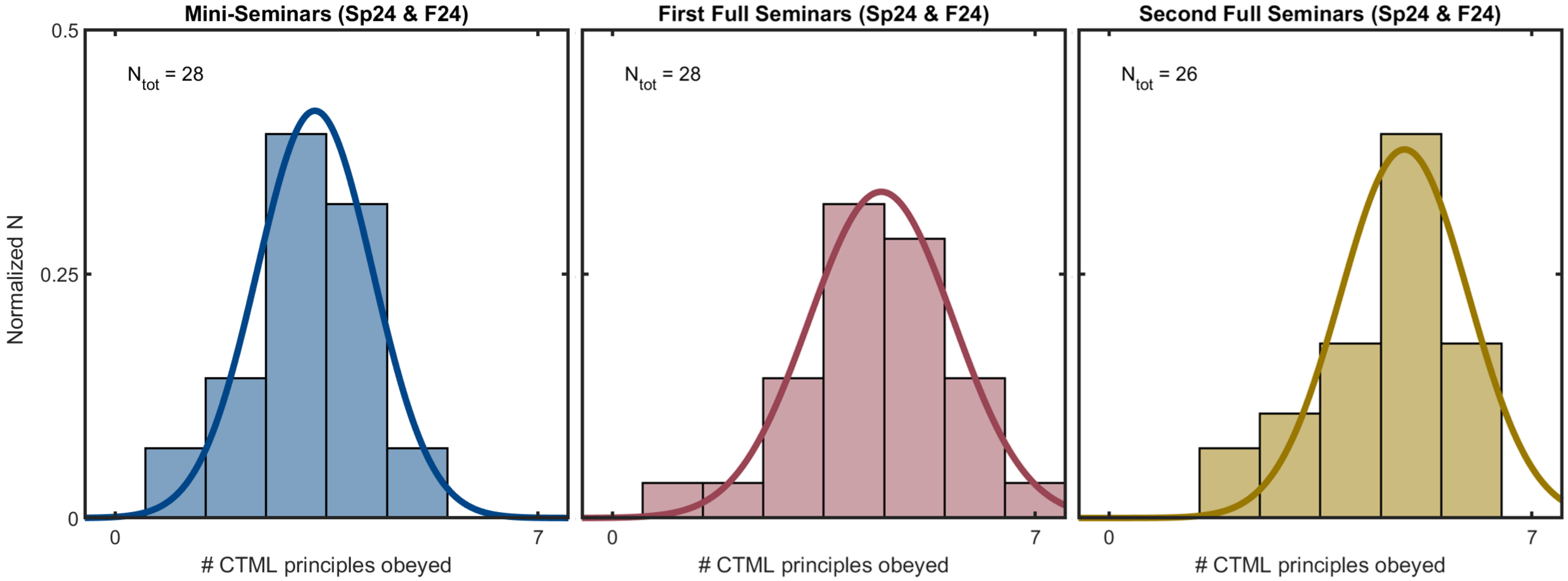


One-sided Mann-Whitney *U* test suggests that students who did received research-based instruction outperformed students who did not ($p < 0.01, |z| = 3.02$).

In CHEM 4601, presentation quality stays roughly constant per presentation type.

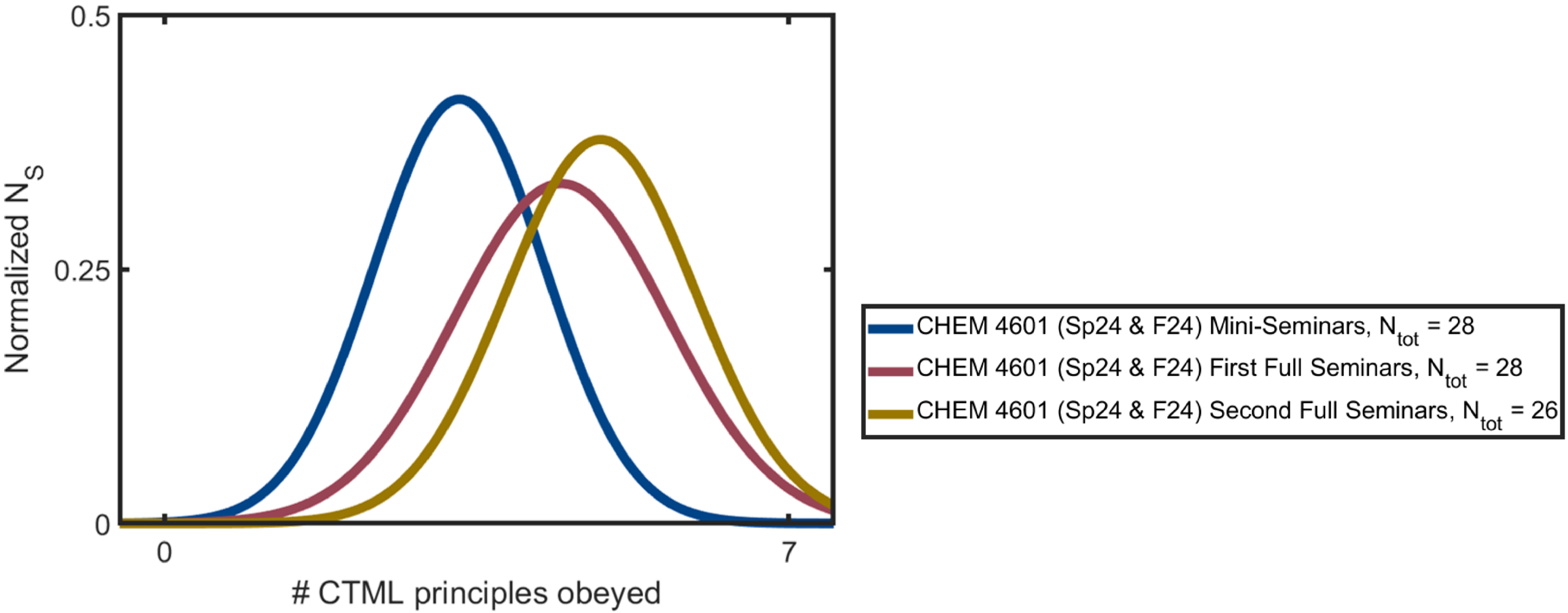


In CHEM 4601, student presentation quality improved significantly after the Mini-Seminar.



One-sided Mann-Whitney *U* tests suggest that students did improve from the Mini-Seminar to the First Full Seminar ($p < 0.001, |z| = 3.51$) but not from the First to the Second Full Seminar ($p = 0.25, |z| = 0.66$).

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



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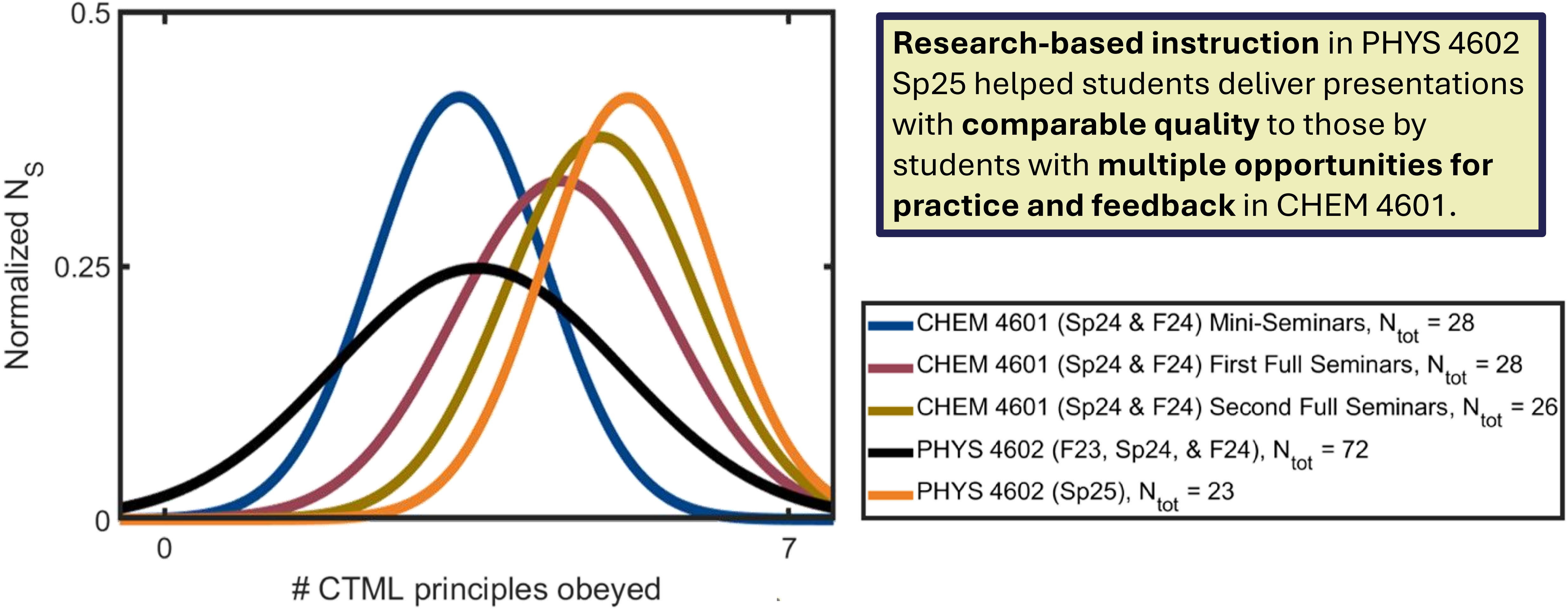
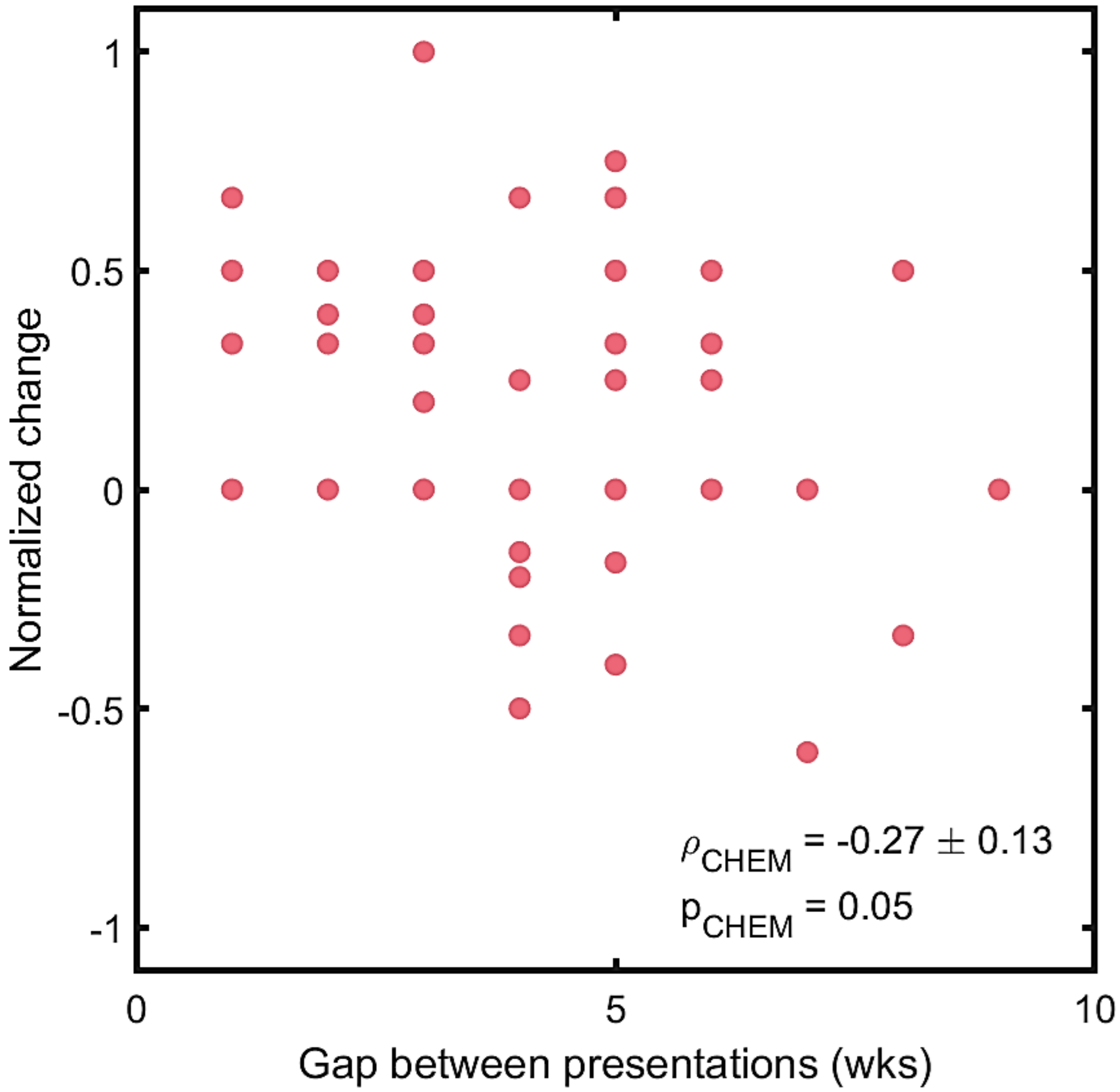


Research-based instruction in PHYS 4602 Sp25 helped students deliver presentations with **comparable quality** to those by students with **multiple opportunities for practice and feedback** in CHEM 4601.

One-sided Mann-Whitney *U* tests suggest that students did improve from the Mini-Seminar to the First Full Seminar ($p < 0.001, |z| = 3.51$) but not from the First to the Second Full Seminar ($p = 0.25, |z| = 0.66$).

Random assignment of presentation dates may disadvantage students who receive large gaps between presentations.

$$\text{Normalized change} = \begin{cases} \dfrac{\text{post} - \text{pre}}{100\% - \text{pre}}; & \text{post} > \text{pre} \\ \dfrac{\text{post} - \text{pre}}{\text{pre}}; & \text{post} < \text{pre} \\ \text{drop}; & \text{post} = \text{pre} = 100\% \text{ or } 0\% \end{cases}$$



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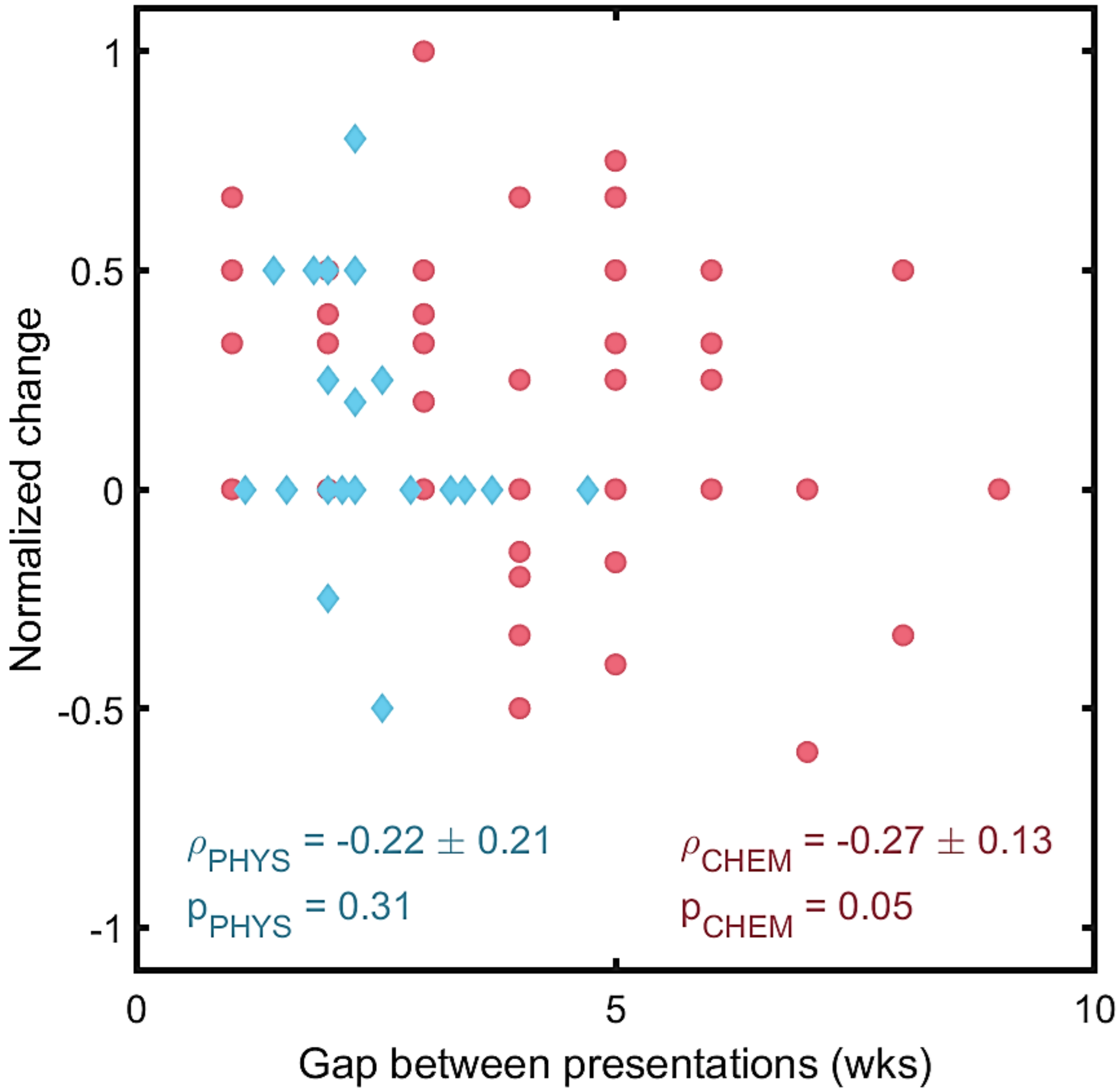
- (PHYS 4602 F24) Recorded presentation redo **due within 2 weeks** of in-class presentation.
  - Often minimal change in quality
  - Inconclusive trend in time
- Factors **other than time** between presentation dates **may be relevant**.



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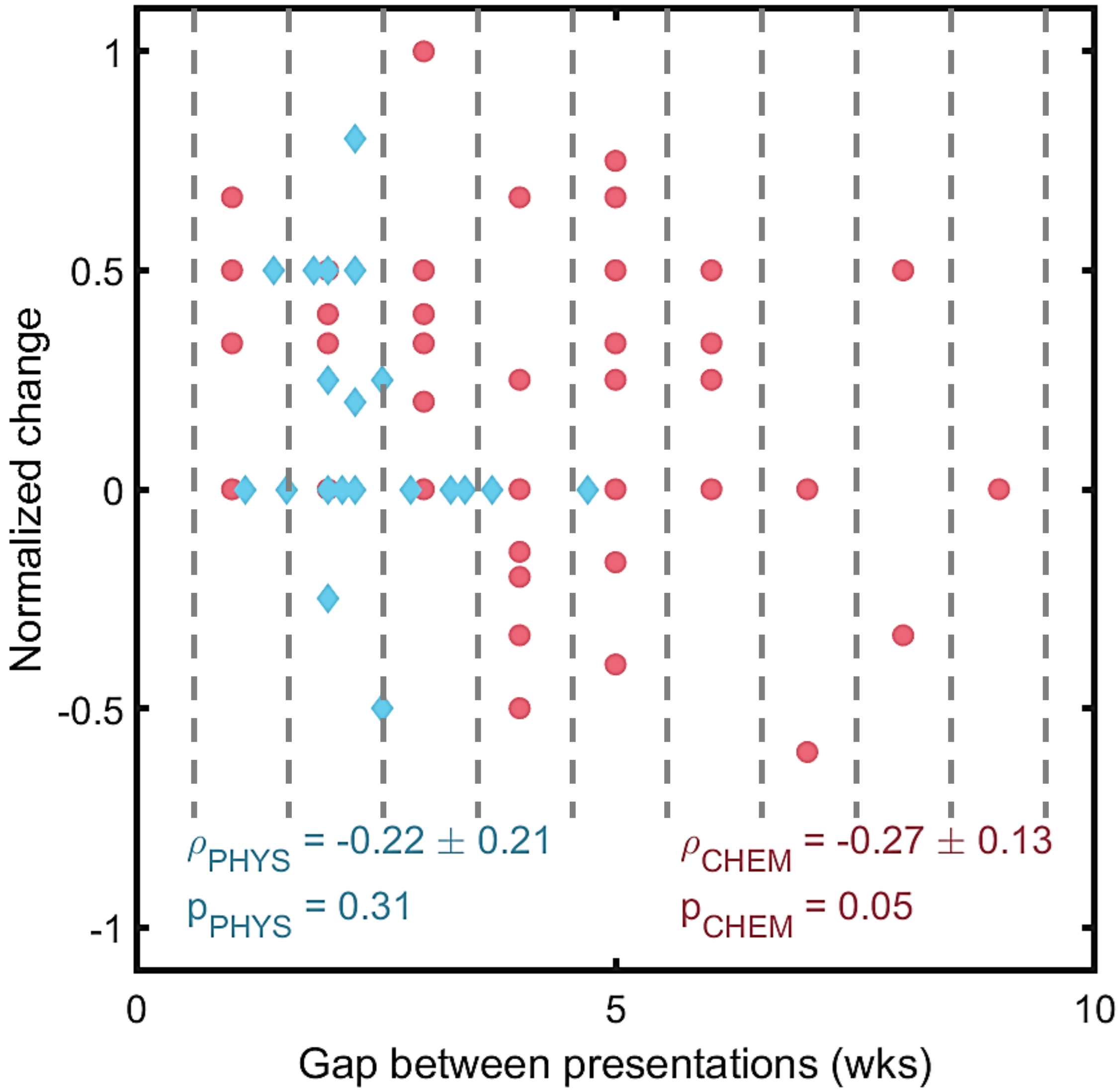

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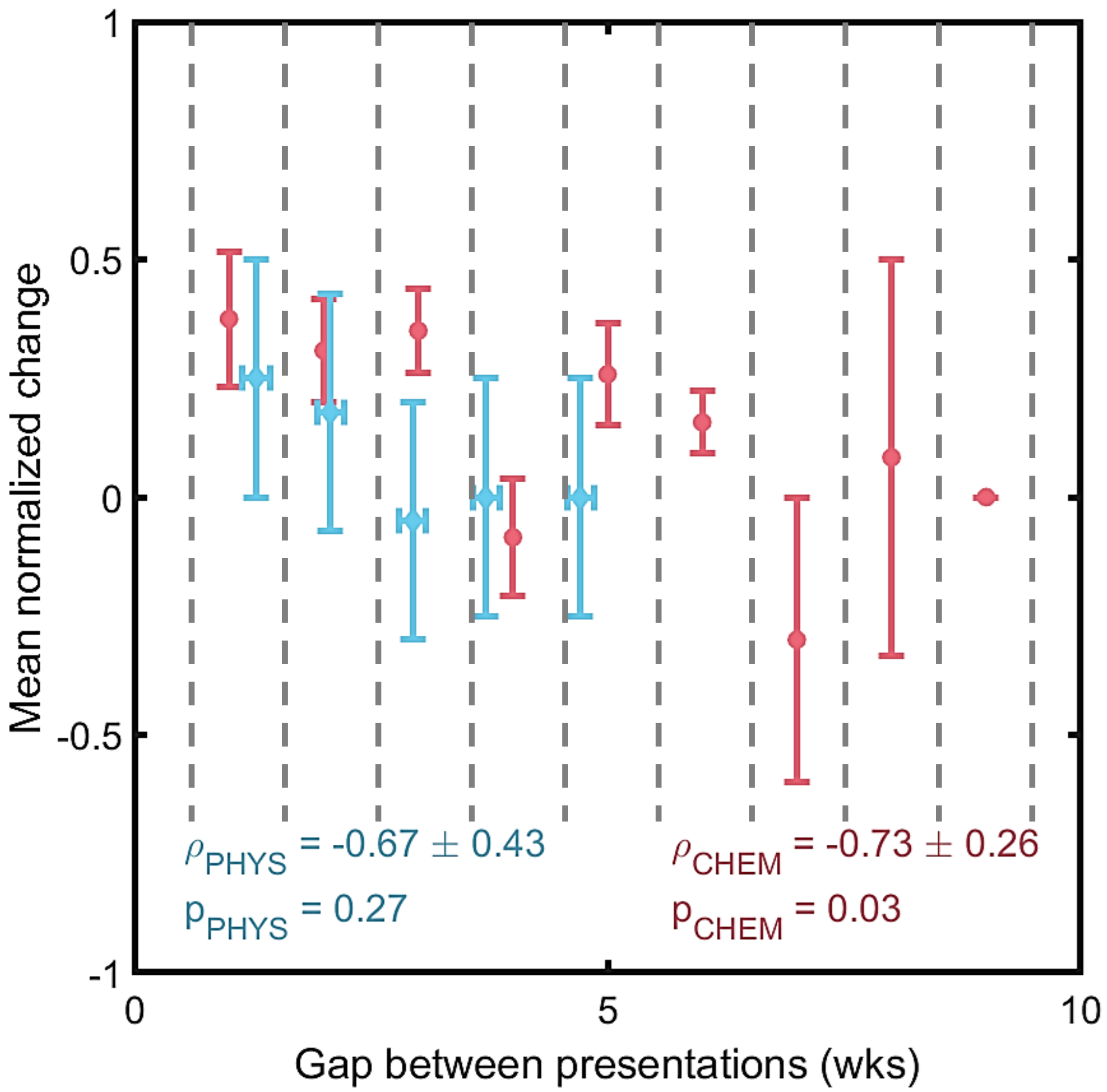

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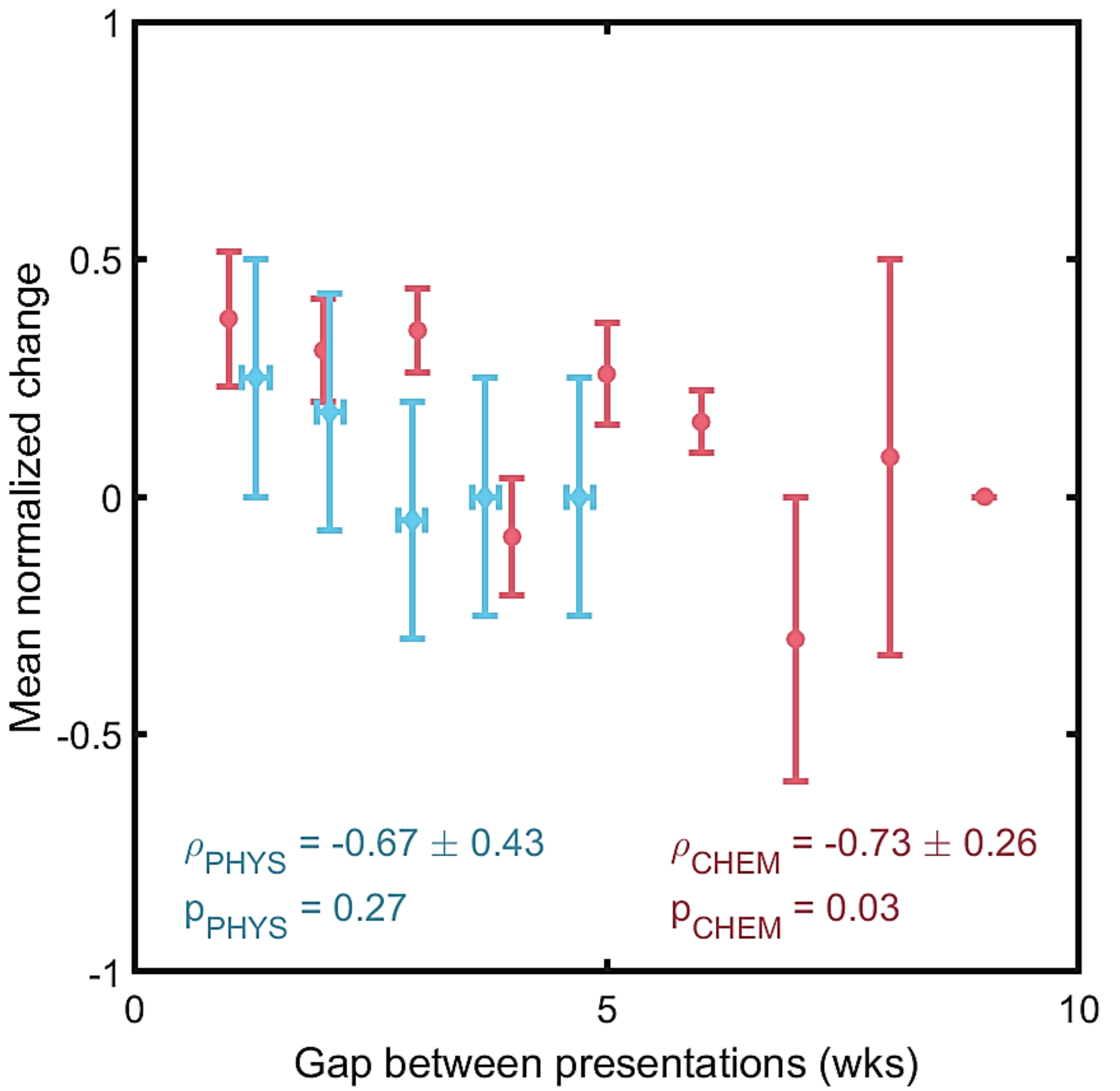
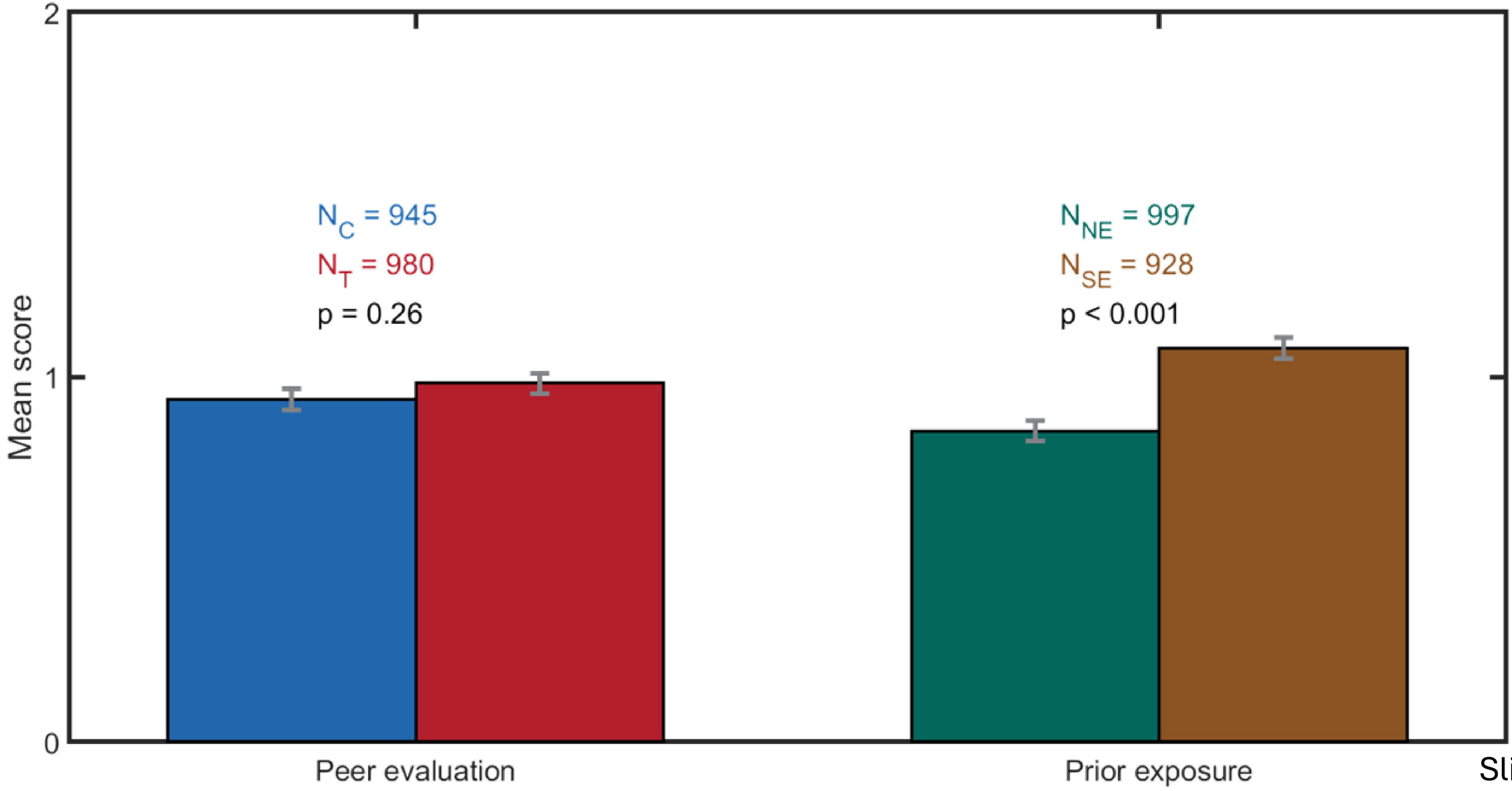


Across PHYS 4602 semesters, student quiz performance is linked more to prior exposure than in-class reflection.

Rubric: Full credit = 2 / Partial credit = 1 / No credit = 0



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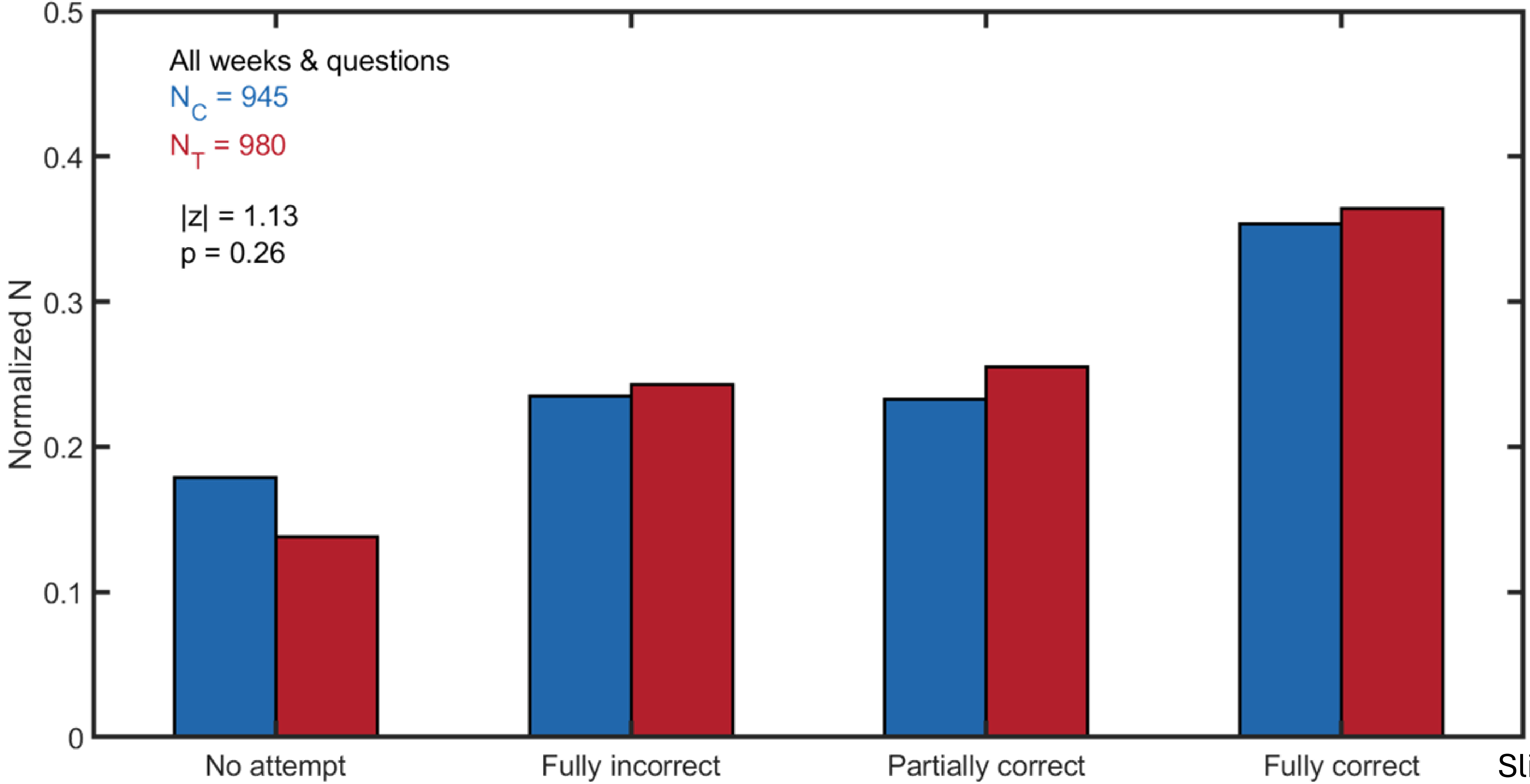

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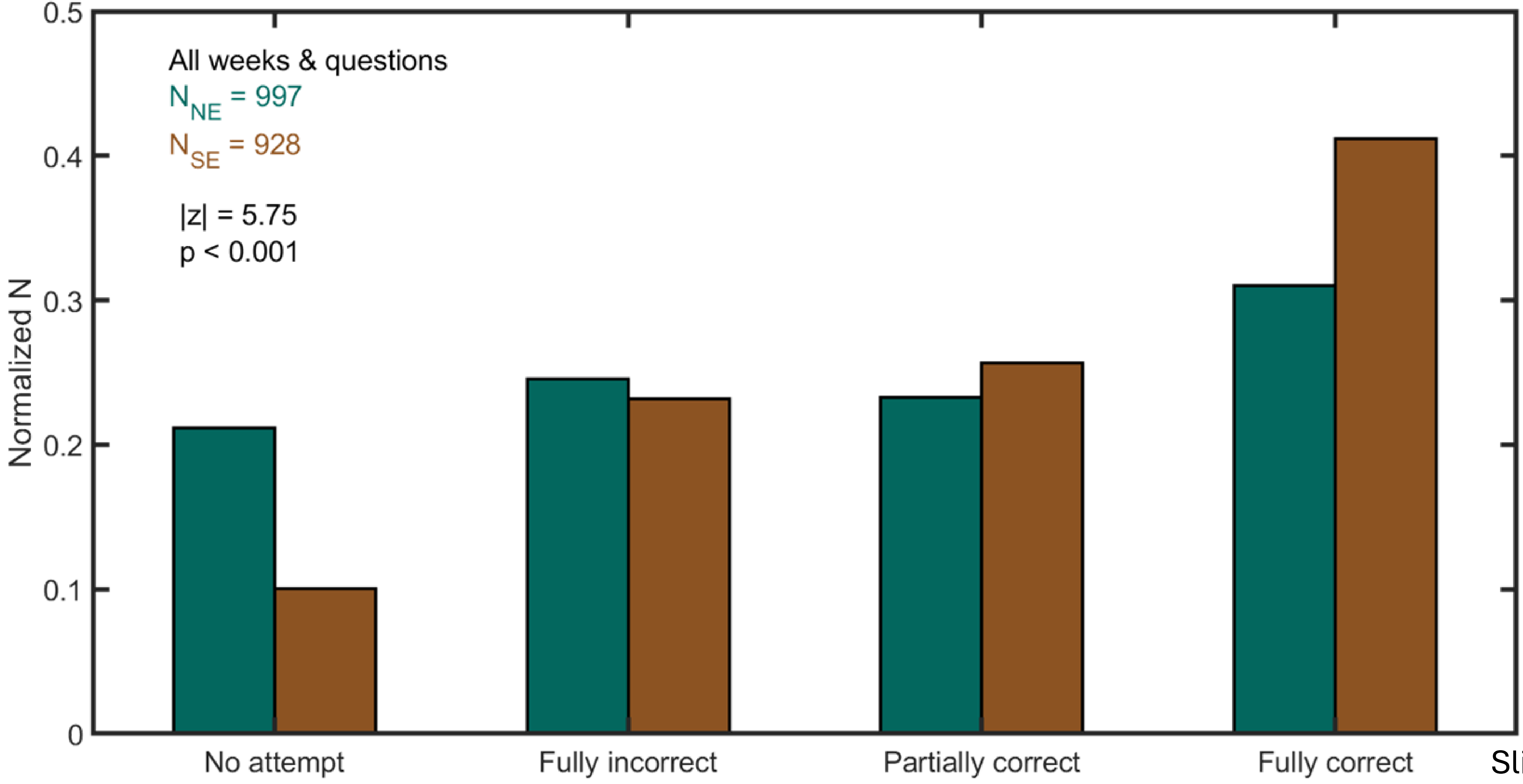


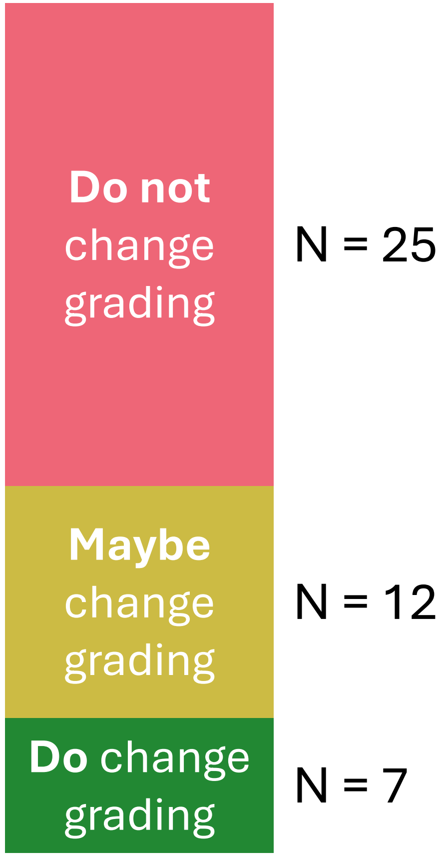
Some students found writing peer evaluations to be helpful but rarely engaged in self-reflection.

Positives

- Students believe they **paid better attention** to presentations because they knew they needed to comment later.
- **Completion-based** grading promotes honesty and relieves stress.
- (CHEM) Students appreciated the time to **internalize** public **feedback** and identify presentation strengths and weaknesses.
- (CHEM) Though some found their own reflections repetitive and tedious, they also felt the **repetition might be helpful.**

Negatives

- (CHEM) Many admitted that they **don't refer back** when preparing and instead expect to have learned simply by writing it down.
- (PHYS) **Few** students used the peer evals as a **springboard for introspection,** instead filling the forms as a quid pro quo.
- (PHYS) Many hoped for varied, actionable critiques and were **disappointed** that they mostly **received standardized platitudes**.
- (PHYS) Most felt the **prompts were too positive and specific** and would have preferred space to write general comments.



Students largely opposed the suggestion of grading peer evals on merit.

Across PHYS 4602 semesters, students learn slightly more from presentations that follow certain CTML principles.

m: # presenters
n: # quiz submissions

Sub 0: Corresponding presenter did not follow the principle
Sub 1: Corresponding presenter did follow the principle

d: Effect size
d_{lit}: [Mayer, 2021]

Multimedia Design Principle	m_0	m_1	n_0	n_1	d	d_{lit}
Coherence: Omit extraneous, seductive details.	56	51	1047	878	$0.12^{**} \pm 0.05$	0.86
Signaling: Visually guide learners through content organization.	68	39	1305	620	$0.14^{**} \pm 0.05$	0.70
Redundancy: Avoid text that is redundant with narration or images.	75	32	1379	546	$-0.15^{**} \pm 0.05$	0.72
Spatial Contiguity: Place corresponding slide contents nearby.	29	78	436	1489	-0.053 ± 0.054	0.82
Modality: Complement graphics with narration, not text.	41	66	801	1124	0.075 ± 0.046	1.00
Personalization: Use a conversational, informal style.	44	63	835	1090	$0.46^{***} \pm 0.05$	1.00
Embodiment: Augment instruction with dynamic expression.	36	71	667	1258	$0.094^{*} \pm 0.048$	0.58

$^{*}\, p < 0.05; ^{**}\, p < 0.01; ^{***}\, p < 0.001$

- CTML studies rarely occurred in the classroom.
  - Prerecorded, heavily scripted presentations
  - Presentations lasted under 2 min; 8-10 s per slide
  - Psychology Subject Pool at UCSB
- Large intrinsic cognitive load in this course may reverse Redundancy principle.
  - PER emphasizes multiple overlapping visual representations [Opfermann et al., 2017].

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

- 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 PHYS 4602 **are working**.
  - Improved presentation quality as measured by CTML ($p < 0.01$).
  - Improved student attitudes toward PHYS 4602 ($p < 0.01$) and learning science communication at GT ($p < 0.05$).

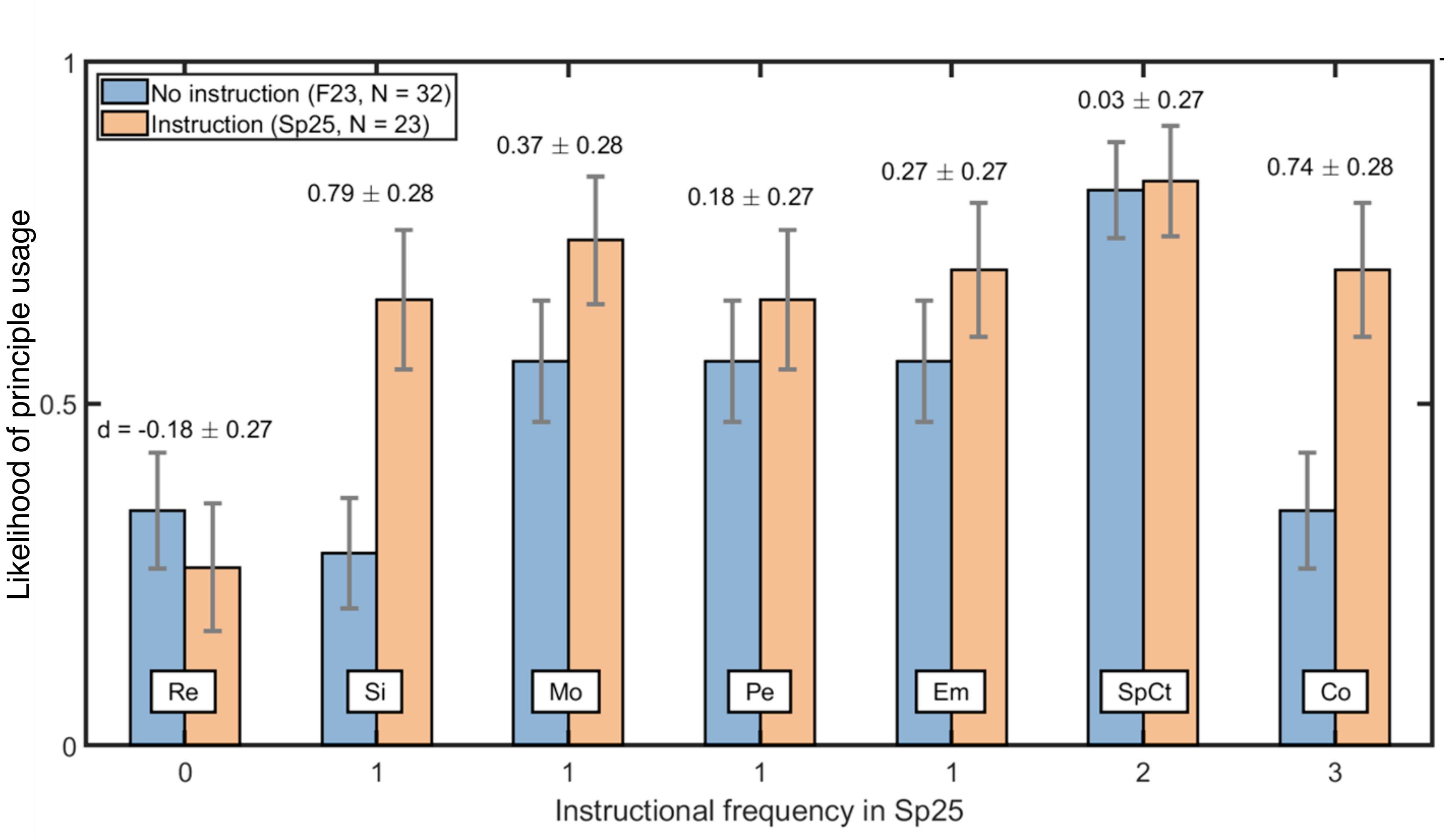
- **Teach like a researcher!**

Presenter: Steven W. Tarr
steventarr@gatech.edu

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

<table>
<tr><th></th><th>Fall ’23
(Prof. 1)</th><th>Spring ’24
(Prof. 2)</th><th>Fall ’24
(Prof. 3)</th><th>Spring ’25
(Prof. 2 & Tarr)</th></tr>
<tr><td>Structure</td><td colspan="3">1 section, no enrollment cap</td><td>2 sections capped at 24</td></tr>
<tr><td>Instruction</td><td>0 instructional days</td><td>4 instructional days</td><td>1 instructional day</td><td>5 instructional days</td></tr>
<tr><td rowspan="3">Presentation schedule</td><td>4 presentations/class</td><td colspan="3">3 presentations/class</td></tr>
<tr><td>Self-selected dates</td><td>Randomly assigned dates</td><td>Self-selected dates</td><td>Randomly assigned dates</td></tr>
<tr><td colspan="2">1 presentation/student</td><td>1 live, 1 recorded /student</td><td>1 presentation/student</td></tr>
<tr><td>Instructor feedback</td><td>Posted to Canvas</td><td>Delivered privately</td><td>Emailed (Tarr bcc’d)</td><td>Delivered live</td></tr>
<tr><td rowspan="2">Peer feedback</td><td>None</td><td colspan="3">Peer evaluations returned the following week</td></tr>
<tr><td></td><td></td><td></td><td>Tarr: Live peer feedback</td></tr>
<tr><td>Peer eval version</td><td colspan="2">First iteration</td><td colspan="2">Second iteration (at Prof. 3’s request)</td></tr>
<tr><td>Quiz questions</td><td colspan="2">Students submit 3–4 “content” & “application” questions</td><td colspan="2">Students submit 2 uncategorized questions</td></tr>
</table>

Instructional frequency alone does not account for which items Sp25 students outperformed earlier students.



Multimedia Design Principle

Coherence (Co): Omit extraneous, seductive details.

Signaling (Si): Visually guide learners through content organization.

Redundancy (Re): Avoid text that is redundant with narration or images.

Spatial Contiguity (SpCt): Place corresponding slide contents nearby.

Modality (Mo): Complement graphics with narration, not text.

Personalization (Pe): Use a conversational, informal style.

Embodiment (Em): Augment instruction with dynamic expression.

Across semesters, student quiz performance decreases significantly for early presentations on full class days.

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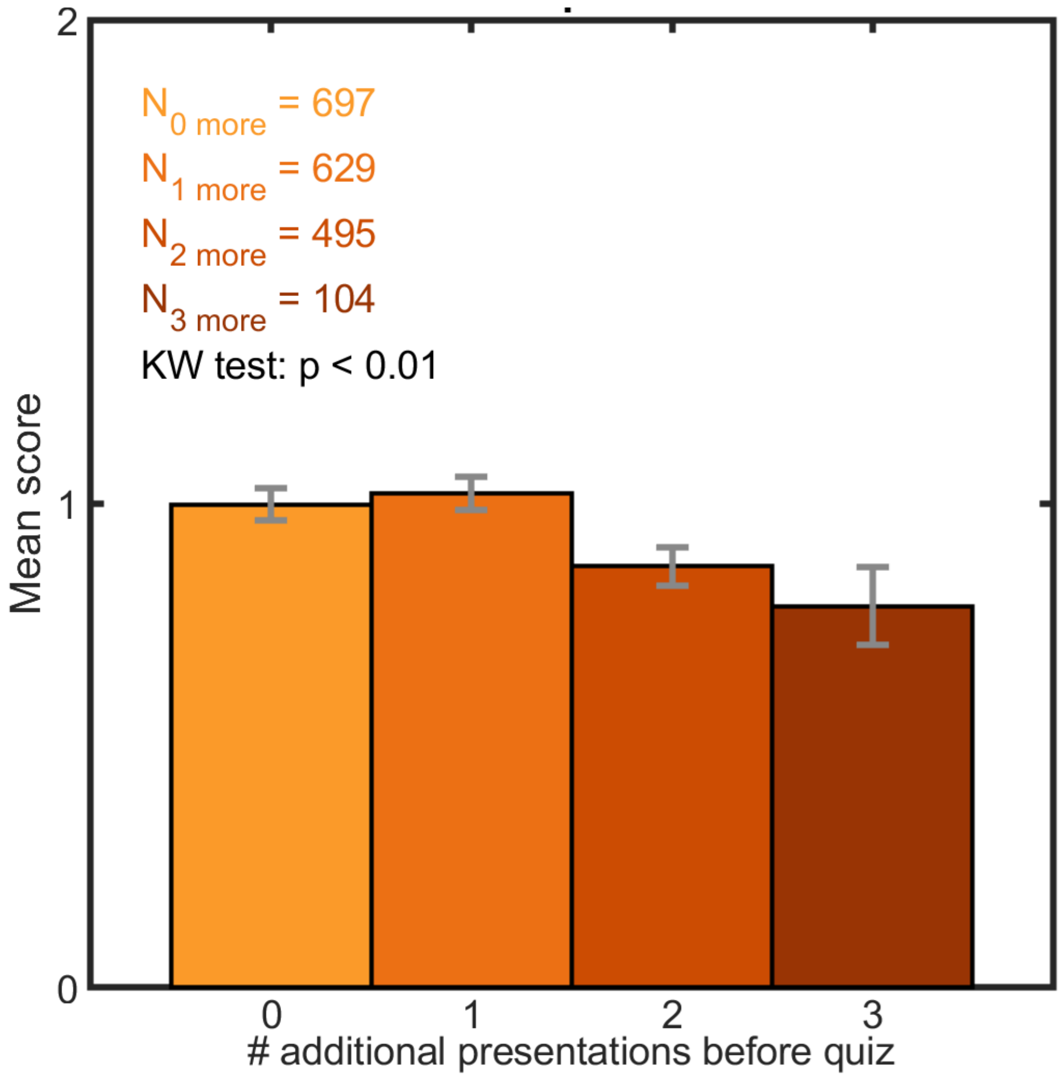

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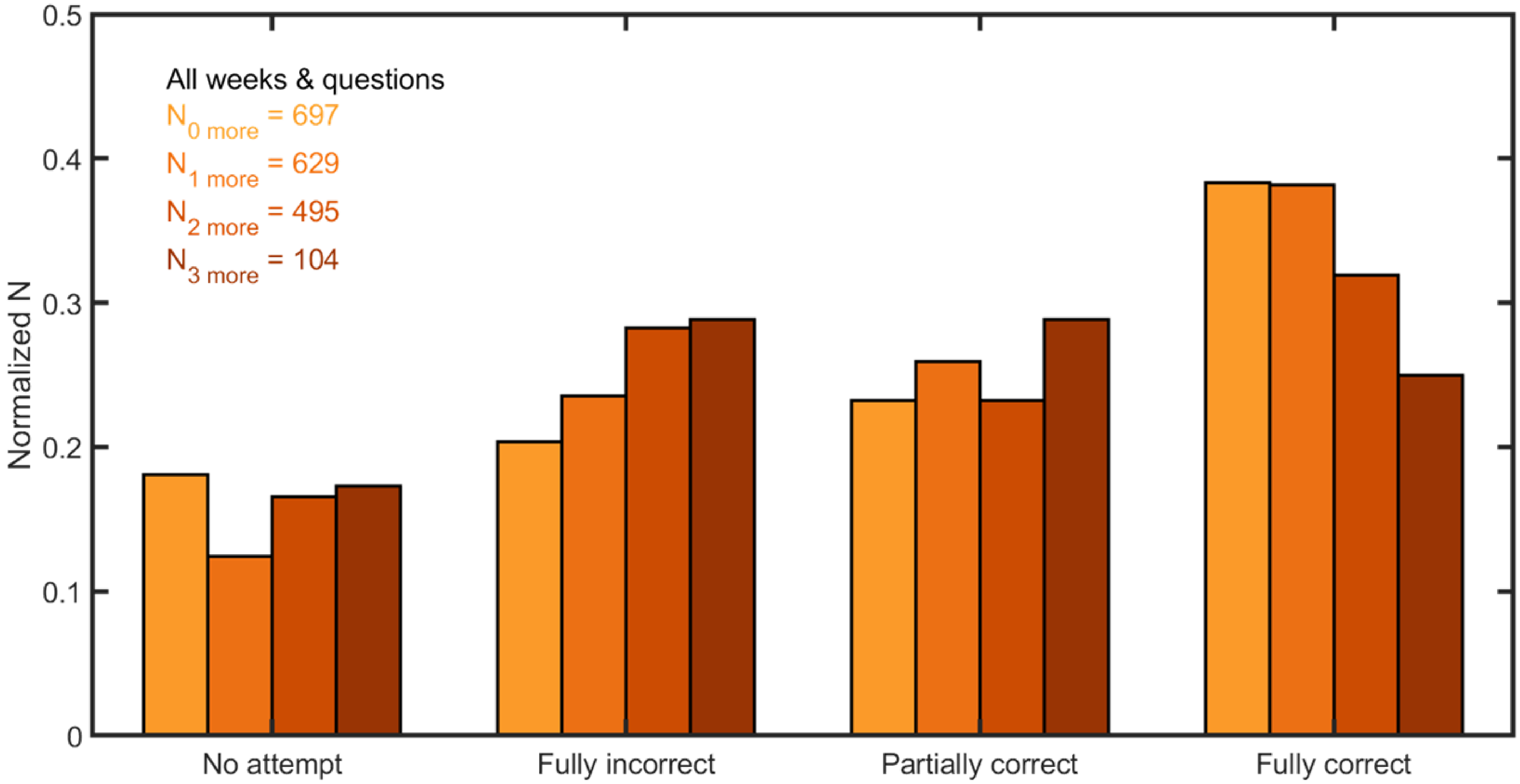

Consenting students participated in semi-structured interviews (36% in PHYS 4602, 39% in CHEM 4601).

PHYS 4602 (39 interviews)

- **Self-identified gender:**
  - 9 women, 27 men, 3 non-binary
- **Progress at time of PHYS 4602:**
  - 2 second-years, 17 third-years, 18 fourth-years, 2 fifth-years
- **Timing of PHYS 4602:**
  - 9 from F23, 6 from Sp24, 5 from F24, 19 from Sp25

CHEM 4601 (11 interviews)

- **Self-identified gender:**
  - 6 women, 5 men
- **Progress at time of CHEM 4601:**
  - 2 third-years, 8 fourth-years, 1 fifth-year
- **Timing of CHEM 4601:**
  - 6 from Sp24, 5 from F24

Steps taken to prepare a presentation are mostly uniform. Time spent per step varies with experience.

- **Reasons for topic choices** included academic and career **goals**, past or present **research**, (PHYS) **audience** engagement, and (CHEM) health issues in the **family**.
  - Some had given talks on chosen topics before, though these were **often informal**.
- Common preparation trends with **highly varied time** distribution:
  - Reading thoroughly, taking notes, and extracting key data
  - Writing slide text and incorporating visuals
  - Practicing delivery with friends, family, or significant others
  - (PHYS) Iterating slide contents for timing and audience comprehension
  - (CHEM) Outlining the presentation for narrative flow
- (PHYS) Students took **varied approaches** to developing **key questions**.
  - Some refined their key questions alongside their presentation materials.
  - Others found it easier to understand their questions after designing slides.
- (CHEM) Students rarely changed their preparation process.
  - **Seven** students kept the **same** preparation process for all presentations.
  - **Two** significantly **changed** their preparation process.
  - **Two** claimed the process **both** stayed the same and changed.

Some PHYS 4602 students found writing and reading peer evals to be helpful; many found the forms too restrictive.

Treatment & Control Peer Eval Questions

1. Check one box per row: (4-pt Likert, needs improvement to very impressive)
   - T. Presentation (1.) content & (2.) quality
   - C. Presentation (1.) audibility & (2.) legibility
2. Have you encountered the presentation topic before? If so, please specify.

3T. List two content items you learned or felt were presented well.

4T. List two techniques the presenter used that contributed to the presentation quality.

3C. Briefly describe your level of engagement throughout the presentation.

4C. Could you summarize this talk to someone who missed class today?

- Students believe they **paid better attention** to presentations because they knew they needed to comment later.
- **Few** students used the peer evals as a **springboard for introspection,** instead filling the forms as a quid pro quo.
- Most felt the **prompts were too positive and specific** and would have preferred space to write general comments.
  - Similarly, many hoped for varied, actionable critiques and were **disappointed** that they mostly **received standardized platitudes**.

CHEM 4601 student beliefs: Reflecting on presentations improves attention span and personal presentation skills.

Full Seminar Reflection Questions

1. What good presentation skills did you observe from today's speakers?
2. What areas for improvement in the presentations did you observe?
3. What biochemistry did you learn?
4. Have you encountered the presentation topic before? If so, please specify.
5. Please indicate your opinions by checking one box per row: (5-pt Likert, strongly disagree to strongly agree)
    1. Before this presentation, I understood the biochemistry content (i.e., proteins, nucleic acids, carbohydrates, lipids) in this paper.
    2. Before this presentation, I understood the biochemistry methodology in this paper.

- Students believe they **paid better attention** to presentations because they knew they needed to comment later.
- Students appreciated the time to **internalize** Prof. 4's public **feedback** and identify presentation strengths and weaknesses.
    - Many admitted that they **don't refer back** when preparing and instead expect to have learned simply by writing it down.
- Though some found their own reflections repetitive and tedious, they also felt the **repetition might be helpful.**

PHYS 4602 students believe peer evaluations are best graded on completion due to their subjectivity and time constraints.

- **Eighteen** students **disapproved** the notion of **grading peer evals on content**.
  - Challenging to assess subjective answers
  - Exacerbates existing time limitations
  - Concerns of embellishing for credit rather than being honest
  - Disapproval of faulting students for an inability to comment on some presentations
  - Genuine interest in peers' work regardless of assessment
- **Five approved** grading peer evals on content.
  - Improve engagement and feedback quality.
- **Eleven** expressed views **in the middle.**
  - "It would encourage us to be more thorough and dedicated to our responses, but at the other time, it just puts less emphasis on us actually paying attention to the presentation…. If instead I have to focus on, 'Oh, well they used good pictures, I like the graphics here,' then I'm losing a little bit of how they delivered that information."

CHEM 4601 students believe grading reflections on completion is ideal.

- **Seven** students **disapproved** the notion of **grading reflections on content**.
  - Increased stress and pressure
  - Challenging to grade subjective answers
  - Concerns of embellishing for credit rather than being honest
- **Two approved** grading reflections on content.
  - “On the reflections being graded, I think that'd be fair, honestly. I don't put too much effort into my reflection knowing that it's graded on completion. If I was graded a little bit more harshly, I think I might put a little bit more effort into it. I don't know if I would actually get more out of it, but I'd certainly put more time in.”
- **One** said **both** options make sense.
  - The class would be more stressful, but she would pay a little bit more attention.
- **One** explained how to grade on content, but **did not take a stance**.
  - A content-based reflection grade must account for students’ spoken feedback.

Students are split between completion-based and merit-based grading largely due to the PHYS 4602 course structure.

- **Eleven** students **disapproved** the notion of **grading presentations on merit**.
  - Existing pressures sufficiently motivate effortful presentations.
  - With only one chance, detailed grades punish students who lack prior experience.
  - High-quality feedback and student development can exist without grades.
- **Ten approved** grading presentations on merit.
  - Improve learning with greater motivation.
  - Emphasize the importance of science communication skills.
  - Punish poor effort and quality.
  - Align PHYS 4602 with the typical classroom experience.
- **Sixteen** expressed views **in the middle.**
  - A detailed rubric should account for prior experience.
  - Presentations should primarily be graded on completion with 10-30% graded on merit.
  - Multiple presentation opportunities are needed.
- **One** explained how to grade beyond completion, but **did not take a stance**.

CHEM 4601 students believe grading mini-seminars and reflections on completion is ideal.

- **Nine** students **disapproved** the notion of **grading mini-seminars on content**.
  - Increased stress and pressure
  - Not enough time to prepare or perform
  - Contradicting the assignment's purpose(s):
    - Quick feedback for the first full seminar
    - Exposure to public speaking
- **One approved** grading mini-seminars on content.
  - "Even though it's shorter, it's a different way of doing science communication that's not any more significant or less significant, and so I would consider that to be something that I would consider to be beneficial to be graded."
- **One** said **both** options make sense.
  - There is not enough time to demonstrate the skills expected for the full seminars. Instead, focus on breaking down and explaining one figure to an audience.

CHEM 4601 students believe the full seminar rubric is fair and helpful.

Full Seminar Rubric Criteria

1. Opening (0, 3, 4, 5 pts)
2. Introduction (0, 7, 8, 9, 10 pts)
3. Experiments (0, 5, 7, 9, 10 pts)
4. Data/Results (0, 5, 7, 9, 10 pts)
5. Conclusions (0, 2, 3, 4, 5 pts)
6. Delivery (0, 7, 8, 9, 10 pts)
7. Q&A (0, 5, 7, 9, 10 pts)
8. Flow (0, 11, 14, 15 pts)
9. Slide Quality (0, 11, 12, 14, 15 pts)
10. Timing (0, 7, 8, 9, 10 pts)

Total Points: 100

- Students **overwhelmingly approved** of the full seminar rubric and how Prof. 4 handled both in-class and written feedback.
  - "I think it's fair.... I'm just surprised that we were graded on the design and the layout of the slide and how we're presenting..., but I can't say that I don't like it.... And it has helped me and how well [*sic*] I am at public speaking now and how confidently I can present things."
- Some students noted their **uneasiness** with the rubric, as they are **used to** courses that emphasize scientific **content over communication** skills.
- Some felt that Prof. 4's **feedback is harsh**, especially on going overtime, accounting for room lights, or making all fonts large enough.
  - Many still acknowledged that the rubric is fair overall and that Prof. 4 is **not a harsh grader**.

PHYS 4602 students have mixed perspectives on Georgia Tech's contributions to their development of SciComm skills.

- **Seven** students indicated that **GT was important** in the development of their science communication skills.
  - GT experiences **outside of class** (e.g., research, internships, extracurriculars) were **paramount**.
  - PHYS 3201/2 w/ Prof. 5, GT 1000 w/ Prof. 6, & PHYS 2213 w/ Prof. 7 were also valuable.
- **Seventeen** students indicated that **GT was not important.**
  - The courseload at GT, physics or otherwise, **neither emphasizes** communication skills **nor builds** on prior experiences.
  - Instructors use presentations to **test content awareness** and largely **overlook presentation skills**.
  - PHYS 4602 is the **only substantive experience** and is **insufficient** in scope and practice opportunities.
- **Fifteen** students expressed views **in the middle.**
  - Although GT provides a **foundation**, students must do significant **personal work**.
- Bonferroni-adjusted post-hoc pairwise comparisons detect **statistically significant** differences ($p<0.05$) between student attitudes across years.
  - Negative outlooks on GT were significantly more common in F23 than either F24 or Sp25.

CHEM 4601 students believe Georgia Tech contributes to student development of SciComm skills, but rarely through coursework.

- **Six** students indicated that **GT was important** in the development of their science communication skills.
  - Three said they had **never** been exposed to science presentation skills **until CHEM 4601.**
  - Two cited TA training, extracurriculars, research, and observing professors as their main sources of development, but also expressed contentment with **CHEM 4601 as a means of formalizing** what they learned.
  - One said GT's role was **building a content knowledge base** to draw from during future science communications.
- **Two** students indicated that **GT was not important.**
  - One expressed **dissatisfaction** with the degree's **emphasis on lab reports** and **de-emphasis on presentation skills**.
  - One **decried assignments** as contributing to skill development rather than application and discussions with friends.
- **Three** students expressed views **in the middle.**
  - One said that although GT provides a **foundation**, students must do a lot of **personal work** to get anywhere near GT's expert speakers.
- **Four** students with negative views on GT's impact (2 not, 2 middle) were **discontented** that most presentations in courses are **end-of-semester projects graded with platitudes** rather than meaningful feedback.

Students want to cover presentation skills in their physics degree and see a path for PHYS 4602 to meet that need.

- Students **mostly agreed** that **PHYS 4602 is useful** but also hope for more.
  - **Fifteen** students said PHYS 4602 is **valuable** for students pursuing a physics degree.
  - **Sixteen** students said PHYS 4602 is **valuable,** but it **could be better**.
  - **Seven** students said PHYS 4602 **could be valuable,** but it **presently is not**.
  - **One** student said PHYS 4602 is **not valuable**.
- Ongoing **changes** to the course **are improving** student beliefs.
  - Bonferroni-adjusted post-hoc pairwise comparisons detect **statistically significant** differences ($p<0.01$) between student attitudes toward the course in **F23 and Sp25.**
- Many mentioned possible further improvements:
  - **Fourteen:** Moving the course **earlier** in the degree
  - **Eight:** Adding **more presentations** and opportunities for feedback
  - **Eight:** Adding **more instruction** on elements of successful presentations
  - **Five:** Improving the **value** for students with prior presentation **experience**

Student beliefs: CHEM 4601 is a valuable and useful experience that enhances their chemistry degree.

- Students **overwhelmingly agreed** that **CHEM 4601 is useful** and successfully develops science presentation skills.
  - **Seven** students said CHEM 4601 is **"definitely valuable"** for students pursuing a chemistry degree.
  - **Four** students said CHEM 4601 is **"probably valuable,"** but it depends on students' post-degree plans.
  - **Five** students (3 definite, 2 probably) mention using this course as preparation for their future graduate programs.
- Students **appreciated** having a **structured, low-stakes** way of learning and practicing information delivery, use of visuals, and public speaking.
- Some mentioned possible improvements:
  - **Four:** Moving the course **earlier** in the degree
  - **Two**: **Expanding** beyond biochemistry
  - **Two**: Easing an **overly critical** feedback style
    - However, **two** others cited the toughness as **helpful**
  - **Two**: Incorporating example presentations that **better match** the CHEM 4601 seminar styles
  - **One**: Providing more explicit, concise guidelines and templates for **poster** design