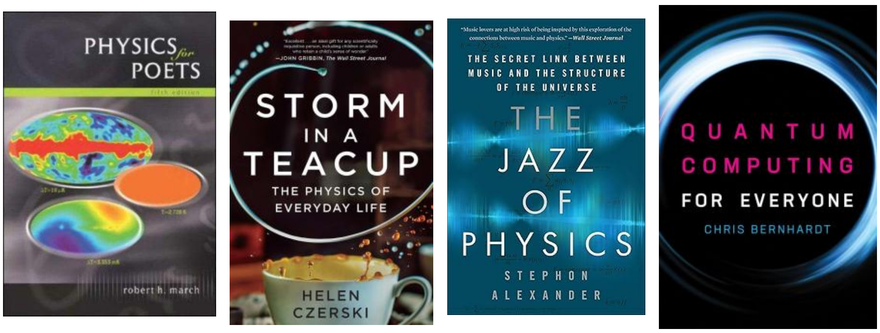
# Less Math, More Wonder

## Physics Courses for Non-Scientists




Jason Harlow

UNIVERSITY OF TORONTO
Downtown Campus

University of Guelph Physics Colloquium
Tuesday, November 18th, 2025 2:30 PM MACN 415

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# Outline of today’s talk

1. **Why** do we teach physics to non-scientists? What are the **goals**?
2. **History** of physics “breadth” courses since the 1970s
3. Active teaching techniques and **Assessing Students**
4. **University of Toronto** Physics Breadth Courses

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# What are physics breadth courses?

- At many universities, students must specialize in one or two disciplines, and they must also take a small number of courses **outside** their areas of specialization.
- So-called "breadth courses" serve to expose students to areas of knowledge and critical methods outside their primary area of study.
- **Physics** breadth courses could:
  - increase students' knowledge of physics concepts and ideas.
  - give students insight into how physicists think and approach problems.
  - cultivate a long-lasting appreciation of evidence-based methods of inquiry.

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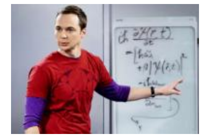
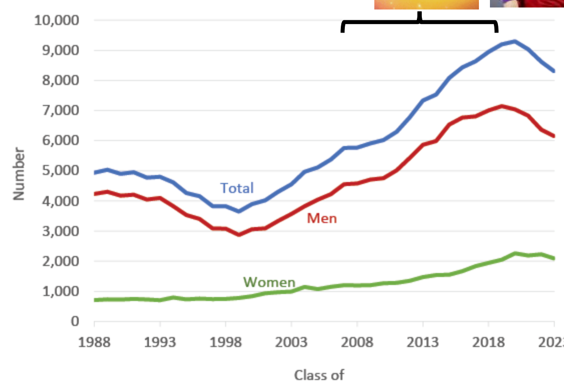
### USA: Number of BS degrees in Physics per year peaked in 2020

- In the 2023-24 academic year, U.S. institutions awarded 7,776 physics bachelor's degrees, marking the fourth consecutive year of decline.
- This downturn follows two decades of steady growth in the number of degrees conferred.
- The 2023-24 total represents a 16% drop from the all-time high of 9,296 degrees awarded in 2019-20.




Physics departments reported <1% of their physics bachelor's degree recipients in the class of 2023 identify as a gender other than man or woman.

AIP aip.org/statistics

https://www.aip.org/statistics/roster-of-physics-departments-with-enrollment-and-degree-data-2024

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# Popular breadth courses can significantly increase physics department enrolment

- There are three large breadth courses offered at U of T downtown campus:
- **The Magic of Physics** – fall 196 student enrolment cap, also offered in the summer to about 50 students
- **The Physics of Everyday Life** – winter 196 student enrolment cap, also offered in the summer to about 50 students
- **The Physics of Music** – winter - 330 student enrolment cap, online course with an in-person final exam.
- Over 800 students per year!
- Astronomy and Astrophysics more than doubles this: their cap for a "Contemporary Astronomy" equivalent is 2000 students per year!

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# Why should a non-science student study physics?

- "You know you can't enjoy a game unless you know its rules. Likewise, you can't fully appreciate your surroundings until you understand the rules of nature. Physics is the study of these rules, which show how everything in nature is beautifully connected. I enjoy physics, and you will too – because you'll understand it. If you get hooked and take a follow-up course, then you can focus on mathematical problems." – Paul Hewitt, author of Conceptual Physics

- "The complexity of today's technology is built on straightforward physical principles that govern modern materials, scientific processes, and physical devices. Students use this technology daily, but many are unaware of how and why its systems and devices work." – Niculescu et al 2000 Journal of Mathematics and Science

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# Why should a non-science student study physics?

- "Every university in the country has the same dirty little secret: we are all turning out scientific illiterates, students incapable of understanding many of the important newspaper items published on the day of their graduation." – Hazen and Trefil NYTimes Magazine 1991

*Reaching for Science*

**LITERACY**

By Lynn Arthur Steen

http://www.steen-frost.org/Steen/Papers/91reaching-pub.pdf

A recent Harvard commencement provided just the right visual and symbolic context for the roving reporter who sought to understand what the graduates had learned. "What," the questioner asks, "causes the seasons?" One graduate after another answers with the poise that comes with an Ivy League education: "That's easy. The earth does not travel in a perfect circle, so in the winter it is further away from the sun." "Well then," persists our skeptical reporter, "why is it summer in the southern hemisphere when it is winter in the north?" "Um. . . ," comes the hesitant reply, as ivied assurance begins to evaporate. "I guess I never thought about that." In the midst of commencement, the emperor's graduation gowns vanish.

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# Why should a non-science student study physics?

- In the past few years, disbelief in science has been an issue of national news, especially during the COVID-19 pandemic, and the general public's attitudes towards science are often filled with misconceptions, leading to polarization in beliefs and mistrust of scientists.
- There are many inaccurate stereotypes of scientists that are pervasive in society as well, such as the "lone male white genius" trope.
- How has science education failed to address these beliefs, and what can we do to make a positive impact on students' attitudes towards science?

- Lewis et al 2022 Astronomy Education Journal https://arxiv.org/abs/2209.02852

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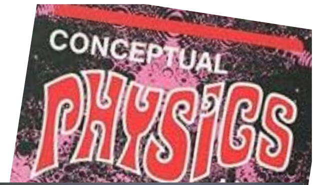
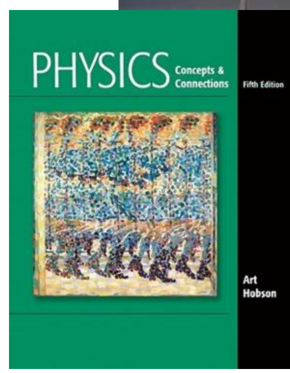
# "Magic of Physics": General First-Year Physics … without so much math




- When I go to a new dentist and they ask me what I do, if I say "I teach physics", they get angry and drill a little harder.
- But I think it's all the math they really hate!
- "Conceptual Physics" 1971 by Paul Hewitt is one of the first textbooks to focus on the ideas and using logical reasoning, and strongly de-emphasized the mathematics.
- In 1995 Art Hobson wrote "Physics Concepts & Connections" which had a stronger emphasis on Scientific Literacy and Modern Physics, and had a bit less of the classical curriculum *coverage* of Hewitt's book.

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# Demos, demos, demos!!!

- Students love demonstrations, and certain professors love doing them.
- Jearl Walker (pictured here) was a master physics demo guy and he wrote the book "Flying Circus of Physics".
- This teaching style choice lead to "Physics of Everyday Life" courses and "How things work"
- The idea is you start with the observation or the technology, and then you explain the physics behind it.

**How Things Work by Bloomfield**

<u>Table of Contents</u>

- Skating
- Falling Balls
- Ramps
- Seesaws
- Wheels
- Bumper Cars
- Spring Scales
- Ball Sports: Bouncing
- Carousels and Roller Coasters
- Bicycles
- Rockets and Space Travel
- Balloons

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## Students want less math.  But is that good?

- Clearly "Fundamentals of Physics" for physics majors has too much original problem solving for a humanities student to really master.
- Hewitt argues: "to the nonscience student, physics is enormously interesting, but paired with problem solving, the price of admission is too high for too many."
- Sobel (2009) responds with two objections:

1. Physics is inherently mathematical.  Without some math and numbers, we lose the storyline and important connections.
2. Every university student must have studied math for around 11 years as a child.  Why *can't* they do some math?

- One reason physics is so difficult is that we go too fast.
- An obvious solution is to pick a sub-topic, and focus on less material, but go deeper.

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## Special Topics: "Physics of…"

- Here you draw in the student with a specific topic they already think is interesting, and then teach physics around it.
- Almost every university has a popular Intro to Astronomy course that does this beautifully.





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## Special Audience: “Physics for…”

- *Physics for Future Presidents* is a book by Richard A. Muller. It’s physics topics he thinks the president of the USA should know. There are five parts:

1. Terrorism (ie 9-11)
2. Energy (oil vs. solar)
3. Nukes (weapons, also risks of nuclear energy)
4. Space (Satellites, the Moon)
5. Global Warming

- This was published in 2008 when Obama was running for president. These were hopeful times… Muller said in an interview that Michelle Obama had a copy of his book and she promised to give it to Barack.

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## Michael Sobel 2009 – Physics for the Non-Scientist: A Middle Way

- Question: How can we design assessments to avoid the shallowness of memorization yet lie within the capability of the *average* student?

**A Middle Way**

- Sobel proposes: *“that we design a course that does what most other college courses do, a course that asks students to learn what the teacher does in class, and what the teacher assigns in the text,* ***but nothing more.***
- *It will be a course that does* ***not*** *demand ingenuity, that does* ***not*** *demand that the student put together two ideas that they have previously used separately, that does* ***not*** *demand that the student be clever.*
- *The student sees a certain problem done in class, then tries three or four examples of the same problem with different numbers at home, and later has to do one on the exam.*
- *For a given subject or chapter, there might be four or five such problems, starting with a simple plug-in followed by more complicated examples.”*

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# Active Learning

- The main result of Physics Education Research is that what students learn depends on what the **students do**, not what the **teacher does**.
- Hake (1998) published a nice meta-study of FCI results and found the best gains were always in courses that had what he called “Interactive Engagement”:
- “designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors”
- It’s important, especially in large classes, to get students *talking to each other* about physics.

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# Student Response Systems

- i-Clicker Remotes. I used these from 2006-2016. I miss those days…
- Device-based apps or browser-based quiz systems:
  - Your LMS probably has a quiz function of some kind.
  - Top Hat
  - Poll Everywhere

School is boring – there is no other way to say it. Absorbing complex mathematical functions while staring at a powerpoint presentation is the least exciting way to spend 7 hours of your day. This may explain why 16% of US students are chronically absent from class.


- The problem I have with all of these systems is that I am sending my students to their phone or device in the middle of class.
- This creates a big **distraction** (as they check their notifications etc), and also creates a **less social atmosphere** – you are less likely to speak to your neighbour if your neighbour is looking at their phone – it's rude.



# Old-style paper daily mini-quizzes

- Each quiz question takes 2 to 5 minutes and is designed to get discussion going.
- Blank paper works for small classes, if you have lots of students you can use a blank form and scan into crowdmark or gradescope or something.
- I provide a big box of pencils, blank forms, and foldable voting cards, all of which I distribute at the start of each class.
- During class I present the questions via Powerpoint, and try to get discussion going. Students can fill out their "first guess" and "consensus view".
- At the end of each class I collect the filled-out forms, scan them into a system called [https://www.gradescope.ca/](https://www.gradescope.ca/) and award participation + accuracy points.

- See an 14-minute YouTube Video explaining the details of exactly how I do this in a class of 100 students here: https://youtu.be/Yh-J9OdSnxc

## Whiteboard activities

- In a class capped at 30 students I got a room with tables and distributed portable whiteboards.
- In-class activities involved some drawing and brainstorming on the whiteboard.
- "Vertical Learning"

$x = \frac{N}{N_{max}}$  $N = x \times N_{max}$

### Logistic Equation: You Try It!  Use: B = 3.2

- Remember, you must compute $x$, which is the number of mosquitos that hatch in a particular summer divided by $N_{max}$ = 200.
- So, for year 1, $x_1$ = 100/200 = 0.5
- Once you have calculated $x_2$, then the number of mosquitos born at the start of year 2 is 200 × $x_2$.
- Note: The number of mosquitoes should always be between 0 and 200.
- **USE YOUR WHITEBOARD!**
- I would like one Table Leader to describe how you found Year 2 Mosquito Population.
- A second Table Leader should describe how you found Year 3 Mosquito Population!

$$x_2 = Bx_1(1 - x_1)$$
$$x_3 = Bx_2(1 - x_2)$$
$$x_4 = Bx_3(1 - x_3)$$
$$x_5 = Bx_4(1 - x_4)$$

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## Hands-on Activities

1. Before you squeeze the bottle, try to predict what will happen when you to. How will squeezing the bottle affect the air bubble and the vial's position in the water? [No points for correctness, only effort.]

2. Observe and describe the results of squeezing and releasing the bottle. Obtain your T.A.'s initials in the box when you have made a "working" Cartesian Diver.

Ask TA to sign here:

PHY205-H1S **Standing Waves on a String Part 1** Prof. Jason Harlow
Tutorial Worksheet #7 Physics, U of T

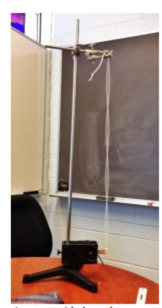
Name:__________ Signature:__________.
Name:__________ Signature:__________.
Name:__________ Signature:__________.
TA Name:__________ Tutorial Group Code:__________.

Please work in **teams of two or three students** to fill in the blanks in this worksheet. Each team should turn in **one** sheet for marking – it will be returned to the top person on the list in the next tutorial. All students in the team will receive the same mark.

The PASCO scientific WA-9857 String Vibrator drives a string or elastic cord to produce a standing wave. The string vibrator uses a coil-and-magnet design to vibrate a stainless steel blade, to which you attach an elastic cord today. The Alternating Current (AC) power supply plugs drives the string vibrator with a constant-frequency, constant-amplitude sine wave. The driving frequency equals the frequency of the mains power supply coming from the wall.

1. Stretch the cord vertically to a fixed length of about 70 or 80 cm. At the bottom it should be tied to the string vibrator. At the top it should go through a clamp which you can open and close using the thumb-screw. By pulling different amounts of slack cord past the top clamp, you can adjust the tension of the cord below. Observe the standing wave patterns that occur as you stretch the cord. Only certain amounts of tension will give a "good" pattern with a node at the string vibrator and nice, well defined "segments". A segment is an almond-shaped region with two nodes at the ends and an antinode in the middle. Note what happens to the number of segments as you increase the tension. Does **increasing** the tension cause the number of segments to **increase** or **decrease**?

2. What is the maximum number of good segments you can produce? What is the minimum number of good segments you can produce?



A set-up with 4 good segments.

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# Parlour Games

- Quantum cryptography

**Quantum Teleportation Game**
[Developed in part by U of T Professor Matthew Robbins, also associated with the Institute for Quantum Computing at the University of Waterloo.]

**Equipment:**
- Two identical paper sleeves
- Three “bit” coins, labeled 1 on one side and 0 on the other
- A binder-clip

3. **Sender:** What is the day number of your birth? (for example, if your birthday is January 14, your day number is 14):

________

4. Convert your day number to a 6-digit binary number (only 1s and 0s), and write it below. The first bit should be 0, since there are no day numbers more than 31. The second bit is the number of 16s, the third bit is the number of 8s, the fourth bit is the number of 4s, the fifth bit is the number of 2s and the last bit is the number of 1s. You can use the computer to search up a decimal to binary converter, if you wish. These bits are your **data**. The Verifier and Receiver should pretend that they do not know this binary number: [3 points for correct conversion of above]

____ ____ ____ ____ ____ ____

The following steps 2-5 will be repeated six times, one for each data bit above:

5. **Verifier:** Place two coins with the same side facing up (0,0 or 1,1) into the two identical sleeves. Clip the two sleeves together – still facing the same way – and toss them in the air to randomize which way is “up”! Give one sleeve (Near) to the Sender and the other (Far) to the Receiver, ensuring neither sleeve is flipped. These coins are now positively correlated.

6. **Sender:** Look at your data, and slip your coin into the envelope with the bit you wish to send up. Be careful not to flip the envelope. Also don’t look inside the envelope, and don’t let the others see you slip the coin in. Hand the envelope (now containing two coins) back to the Verifier.

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# Parlour Games

- Hawks Vs Doves game in Complexity course

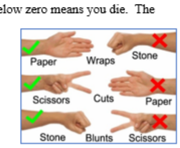
Name:________________________________ Date: ___________________

**PHY196 Emergence in Nature.** Class 19 Discussion Question.

Let’s play a game: Hawks Vs Doves Rock/Scissors/Paper

In each round, you will first select which kind of bird you are. You start with 100 health points. Then, you will stand up, take your score card, and have 6 battles with 6 different birds in the room, not at your table. Keep score after each battle. Going below zero means you die. The scoring is as follows:

- Dove vs Dove: play rock/scissors/paper. Winner gets +40 points, loser loses −10 points.
- Hawk vs Hawk: play rock/scissors/paper. Winner gets +50 points, loser loses −100 points.
- Dove vs Hawk: Hawk always wins +50, Dove loses nothing.



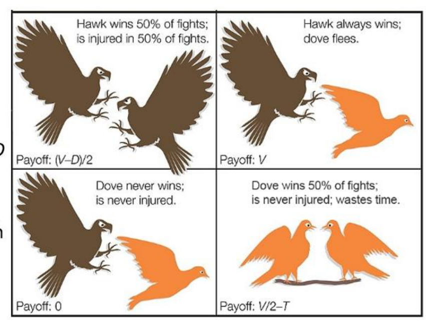

ROUND ONE: Everyone is a dove.

Your role is:__DOVE_____

| Battle number | Result: Win/Loss | Change +/− | Total score (must be greater than 0) Initial: 100 |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | Final Score: |

## Game Theory: Hawks and Doves

- You can model the situation by assigning “points” to the disputes over food.
- The food is worth $V$ points, $V = 50$, for example.
- Losing a fight costs the loser $D$ points, $D = 100$ for example.
- Running away costs nothing.
- Doing a little dance costs both birds $T$ points, $T = 10$ points.

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## Does all of this work?

- Physics education researchers have created several surveys to measure students' beliefs about physics, and science in general.
- Colorado Learning Attitudes About Science Survey (CLASS) asks students to respond to 42 statements on a five point scale from A:'strongly disagree' to E:'strongly agree'.
- When physicists answer, 36 of the statements elicit strong consensus.
- Student responses to these 36 statements can be scored to quantify how expert-like or novice-like their attitudes are.
- Such surveys are usually given as a pre- and post-test to measure the "gain" or change in students' beliefs over the course of a semester.
- More recently, Watson et al (2025) at the University of Alberta have developed the Augustana Interdisciplinary Scientific Literacy Evaluation (AISLE) which tests not only attitudes but ability to reason scientifically.

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## Examples of CLASS statements

1. A significant problem in learning physics is being able to memorize all the information I need to know.
2. To understand physics I discuss it with friends and other students.
3. It is important for the government to approve new scientific ideas before they can be widely accepted.

- Experts tend to agree with 2, and disagree with 1 and 3.

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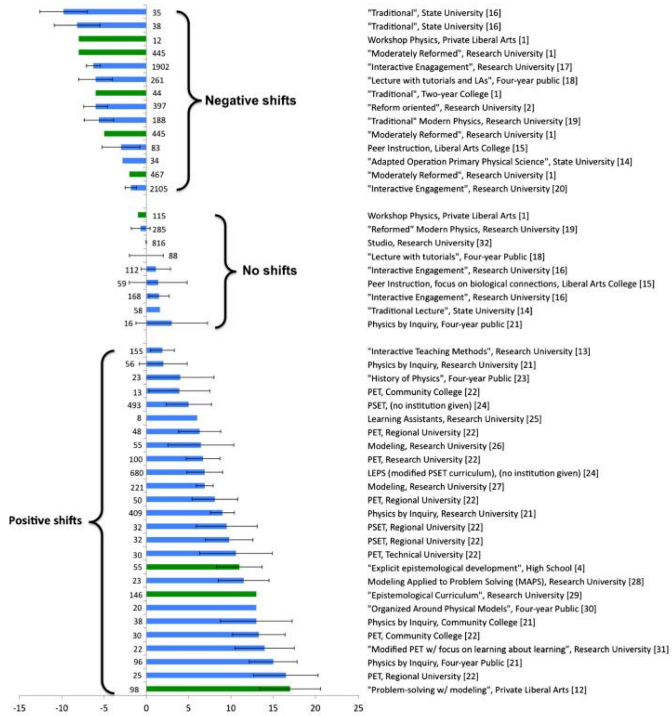
# Does all of this work?

- Madsen et al (2015) synthesized the results of 24 studies using CLASS.
- Many traditional physics courses cause students to have negative shifts in attitudes.
- Strongest gains come when labs, and peer instruction, and modeling instruction were included.
- Also, smaller class size helps.






# In-person testing

- Old-fashioned in-person testing is vital for individual accountability – no devices except for a calculator, perhaps.
- It's good if the midterms and final exam total to 75% of the course mark.
- The other 25% is "unsupervised" in the sense that they have access to their devices.


## Writing Assignments

- Research papers in the age of Generative AI are problematic.
- If you tell students not to use GenAI, some won't, and these honest students will be at a disadvantage.
- I do not believe it is possible to catch and prosecute a student for using GenAI. You can never prove it, as it is "original". Services like Turnitin.com do not work.
- It is depressing to pay a Teaching Assistant for 30 minutes to read and mark an essay that was "written" in 15 seconds using one ChatGPT prompt.

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## Writing Assignments: Suggestions

- Have them build something real, make a video showing it – I have each student create their own musical instrument using things around the house. Then they write about that video.
- Have them write about a hands-on activity or experiment, as opposed to web-based research.
- Some instructors explicitly allow use of AI to generate a first draft. Ie: "Use ChatGPT (or another AI) to generate a draft explanation of [physics concept]. Then revise the draft by (a) correcting errors, (b) adding real-life applications, (c) providing your own reflective commentary."
- Some instructors interview each student about their paper – 15 minute "oral exams" to discuss their paper.

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## Writing Assignments

- University of Calgary has a web-site called "Maximizing Learning with Effective GenAI Prompt Writing".
- The idea is to actually teach them how to write using AI – for example, instruction on the practice of writing prompts.
- According to Oppenlaender et al. (2023), "prompt engineering is iterative and interactive — a dialogue between humans and AI in an act of co-creation."

| Initial Prompt | Improved Prompt |
|---|---|
| "Explain the universe." | "Provide an overview of the Big Bang theory and its significance in understanding the origin and expansion of the universe." |

| Initial Prompt | Improved Prompt |
|---|---|
| "What are the causes of climate change?" | "List and explain in 10 sentences, the primary human-induced factors contributing to climate change, including the impact of carbon emissions and deforestation? Use lay terms". |

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# *Big* Breadth courses at U of T Physics

- There are three unlimited-enrolment breadth courses offered at U of T downtown campus, each of which draws about 300 students per year:
- PHY100 – **The Magic of Physics** – survey of classical + modern physics, 250 students per year
- PHY205 – **The Physics of Everyday Life** – Conceptual course using everyday objects (cars, weather, appliances, etc.) to teach underlying physics, 250 students per year
- PHY207 – **The Physics of Music** –oscillations, waves, hearing, musical scales, instruments, digital audio, 330 students per year.
- We use the “200” numbers, even though these are open to first years and have no prerequisites, because U of T limits the number of 100-series courses that can contribute to graduation requirements.

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# *Small* Breadth courses at U of T Physics

- Faculty of Arts and Science requires every department to offer three “seminar-style” first-year courses which must limit to 25 students. We offer:
- PHY196 – **Emergence in Nature** – chaos in nonlinear systems, spontaneous pattern formation
- PHY197 – **Modern Physics for the Curious** – relativity, quantum physics, unification forces, string theory, and big bang cosmology
- PHY199 – **Dark Matter and Dark Energy are the New Black** – the hypotheses of dark matter and dark energy, and the debates about what might really be going on.
- We also teach ENV238 **Physics of the Changing Environment** to about 40 students per year, as part of the School of the Environment.

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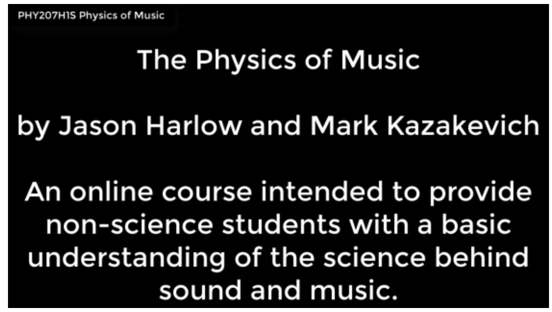
# The Physics of Music

- This was the first online course taught in physics at U of T. I started developing it in 2016 and first taught it in 2018.
- I couldn't find a good textbook that incorporated "A Middle Way" of math and doing practice, while not going too deep.




- So I wrote a textbook; it is not yet published but it is my original content (with a coauthor), and is offered mainly in an online interactive format.
- 12 chapters, each with full colour figures and animations, interactive examples, end-of-chapter questions with complete solutions and problems with no solutions provided (Instructors Guides available). There are over 70 "lecture videos" also provided.
- It will also soon be available as a big black and white PDF – about 350 pages. I've printed out the first 5 chapters if you're interested.

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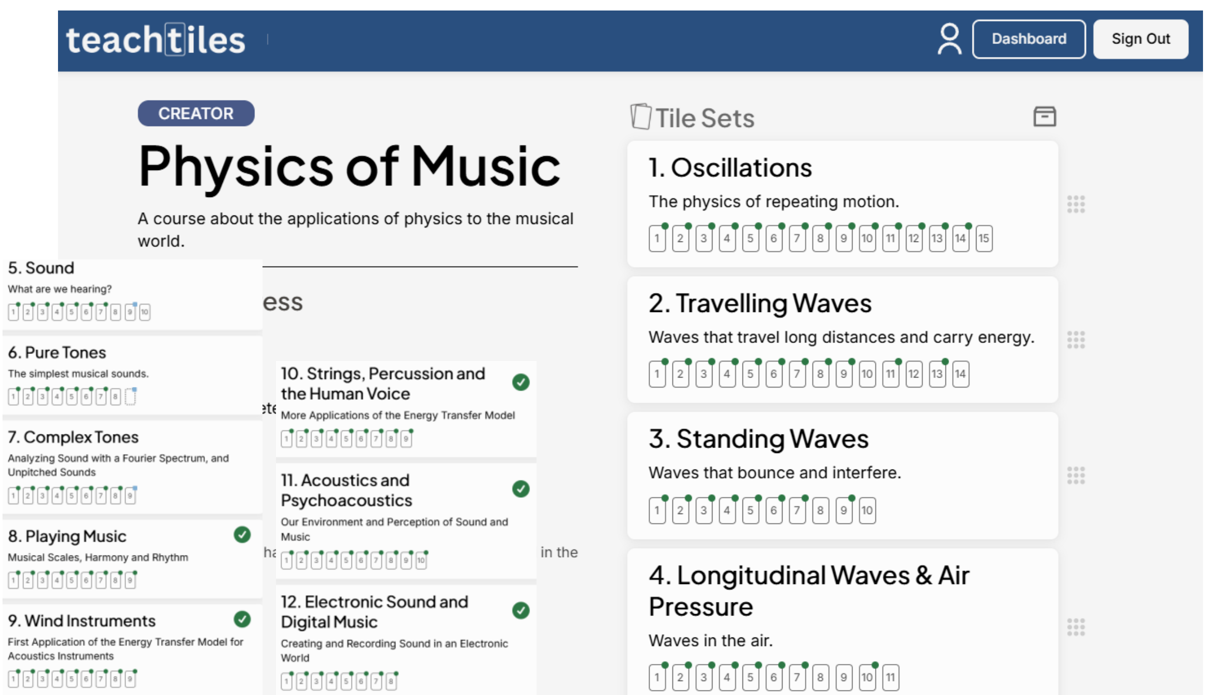


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# Thank you!

Jason Harlow

UNIVERSITY OF TORONTO
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Let’s talk more!
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