Computing-As-Literacy: Cross-Disciplinary Computing for All*

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Abstract

As a means of inquiry and expression, computing has become a literacy across many professional paths. This paper casts a vision for how a small, STEM-focused school supports this role of computing-as-literacy. We share several examples, both future visions and past experiences. We hope to prompt and join discussions that further the reach, use, and enjoyment of computing.

1 Computing beyond CS

More and more, computing is contributing to pursuits beyond software – in fact, beyond CS itself. Computing offers a means of inquiry toward understanding and insight. Thought experiments and live-tunable simulations, for example, offer rich environments in which to build understanding of counterintuitive phenomena (such as special relativity) or surprising interactions (e.g., climate-equilibrium simulations). Beyond inquiry, computing offers an expressive medium for experiences, perhaps tailored to an individual style or a group's priorities. Our shared-media era leaves no doubt: Computing expands humans' aesthetic range. Our goal is that this be accessible to everyone.

2 Computing As Literacy

Computing's ability to advance inquiry and expand expression surpasses older roles as a valuable-specialty and liberal-art: Computing is emerging as a professional literacy. In fact, as a personal literacy, computing is well-established – at times, perhaps, too-well-established!

We posit that computing's role as a professional literacy will deepen in years ahead. This work shares two curriculum-development paths by which our small, STEM-focused program embraces this trend:

- discipline-specific bridges using computing to scaffold student interactions and promote insight in physics, climate science, and mathematics.
- we also share tools for building computing context and community, designed to support an undergraduate-universal computing curriculum.

Both efforts are in process. They reflect our community's support for Computing-As-Literacy among all students and all fields of study, building on deep, cross-disciplinary foundations, e.g., in biology[6] and engineering[4]. The possibilities, it seems, grow faster than we can instantiate them. We look forward to teaming with other institutions on this path!

3 Disciplinary Bridge: Paradoxical Physics

Although physics is an inescapable part of the human experience, it is not intuitive as an intellectual endeavor. First-term students at our institution are "thrown into the deep end" with a half-semester special relativity class. Students solve problems and untangle paradoxes. In one classic problem a spaceship is traveling from the sun to another star[3]. But along the trip, our Sun explodes!

This scenario raises a large family of questions about the *r*elative times at which events take place. When is the explosion perceived? When is the second star reached? Formulas yield "answers," but formulas contribute less to conceptual understanding – understanding our physicists want to nurture – of concepts like time dilation or length contraction[3]. Computing provides a path for students to build those sophisticated, interwoven intuitions.

Those intuitions are visual, dynamic, and geometric. Whether imagining force vectors or watching momentum-conserving collisions, physics education benefits from more than the calculations computing offers. To illustrate this, we have built a simulation of the sun-exploding family of special relativity problems. (This and all of this paper's interactions are available at `myappkanalu.firebaseapp.com`).

When run, the student notices that moving clocks run slower than stationary ones (an example of time dilation) and that the distance between moving

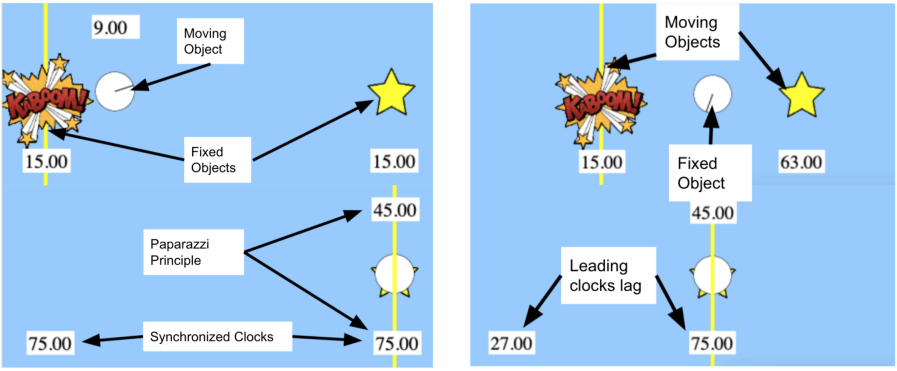


Figure 1: A demonstration of relativity. The left image depicts a simulation in the Sun-and-star's rest frame; both are at rest, and the clock simply travels from the Sun to the star. The right image depicts the same scenario, but in the clock's rest frame; from its point of view, the Sun and star are both moving to the left!

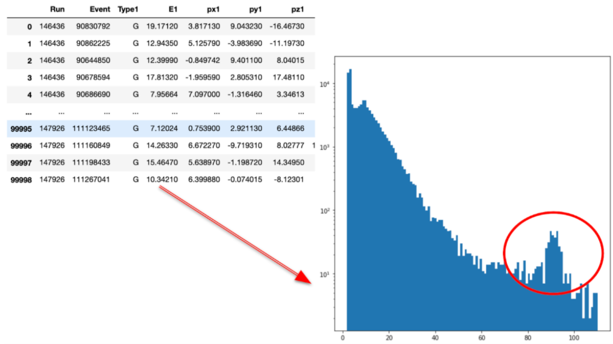
objects is smaller than their distances when not moving (an example of length contraction). Other important concepts, like "leading clocks lag" or the Paparazzi Principle, emerge from this single simulation. And, as physicists like to insist, you'll notice that nothing moves faster than light!

4 Data-Driven Physics

Physical insight and computing share more than simulations. The data-analysis branch of physics depends on computing to create insights – in fact, the computing required is accessible, and adds to student understanding of both CS and physics.

In one such example, students are provided a CERN csv file with 99,999 rows describing distinct particle-collision runs in the Large Hadron Collider[5]. This size is a sweet spot: too much data to process by hand, but a student-with-laptop will succeed! The workflow starts with experiential understanding: making sense of the features across the file's columns using concepts learned in Special Relativity. From there, the data is transformed into a list of masses; these, in turn, are graphed as a histogram. The second half of the challenge incorporates disciplinary insight: students use that histogram to determine the mass of an otherwise-unseen particle created – and destroyed – before it reaches the collision-detector.

Thus, students take data and make it meaningful to them en route to



	Run	Event	Type1	E1	px1	py1	pz1
0	146436	90830792	G	19.17120	3.817130	9.043230	-16.46730
1	146436	90862225	G	12.94350	5.125790	-3.983690	-11.19730
2	146436	90644850	G	12.39990	-0.849742	9.401100	8.04015
3	146436	90678594	G	17.81320	-1.959590	2.805310	17.48110
4	146436	90686690	G	7.95664	7.097000	-1.316460	3.34613
...	...	...	...	...	...	...	...
99995	147926	111123465	G	7.12024	0.753900	2.921130	6.44866
99996	147926	111160849	G	14.26330	6.672270	-9.719310	8.02777
99997	147926	111198433	G	15.46470	5.638970	-1.198720	14.34950
99998	147926	111267041	G	10.34210	6.399880	-0.074015	-8.12301

Figure 2: The physics assignment makes use of CERN's open source data to analyze files. Using equations from Special Relativity and the conservation of energy and momentum, students find masses for each collision in the file. Mass-histogram abnormalities indicate particles that decayed from a "rare" particle: in the assignment, students find this "mystery" particle's mass. Python's matplotlib and pandas are crucial libraries.

analysis and understanding. To cope with a task that has many steps and lots of data, students break down a problem into "helper functions," and mentally, into steps of a repeatable workflow. Such an approach supports not only physics, but real-world scientific and data-handling processes across many fields.

5 Disciplinary Bridge: Mathematics Experienced then Expressed

Like physics, mathematics is a universal requirement at HMC. Many students love math; others disagree; some are in between. Common to all groups is that humans first *do*, then *distill*. Put another way, students only meaningfully express mathematics after they have meaningfully experienced mathematics. Calculations are useful, but computationally-empowered experiences are far more useful for drawing out what mathematicians hope students will share! Here, we show two such example-experiences: the German Tank Problem and the Fenced Random Walk.

6 Teutonic Tanks

The German Tank Problem is a classic statistical thought-experiment. Abstractly, it asks, "What's the maximum?" from a discrete uniform distribution,

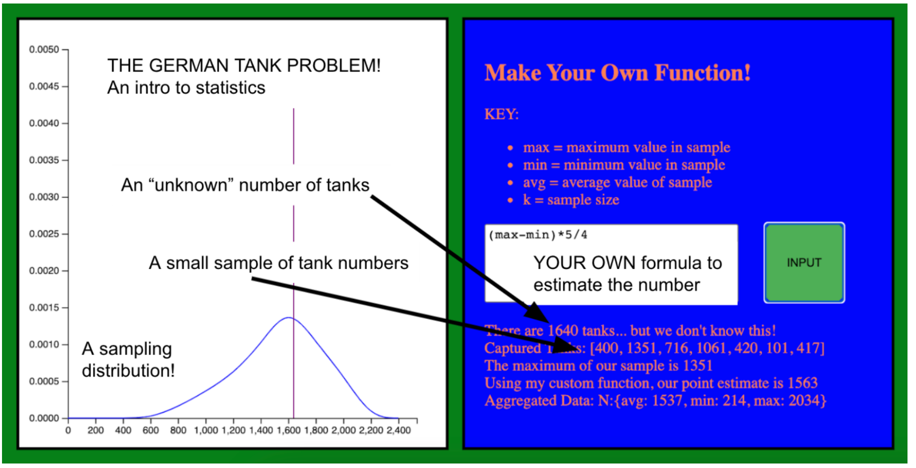


Figure 3: Students can input their own equation to estimate the max. The program will generate over 1000 random samples and calculate an estimate for each one to create a sampling distribution. The one above has decent accuracy and low precision; not so good. The challenge is to create equations that have high accuracy and high precision.

given a small subsample. Its open-endedness and authenticity are its power. During WWII Allied forces wanted to estimate the number of tanks the Axis was producing. Statisticians used the serial numbers from the small number of captured tanks to create estimates – estimates that proved to be much more accurate than traditional intelligence-gathering methods[2].

As an example, suppose seven serial numbers were known/captured: 302, 1953, 1917, 1082, 2176, 1728, and 1401. From these, we want to estimate the maximum – not of those numbers – but of the production-sequence from which they were captured. (In reality, the max was 2329.) Producing an estimate from a single sample-of-seven is not a very effective strategy. Applying another naive solution to this particular sample yields 2486, a bit too high. Using random sampling however, we can create many seven-number-samples less than 2176 (the "observed" max) and track the distribution-max from each. Taking an average of these maxima yields 2328, only one smaller than the real value!

Statistics is an incredibly valuable field, but this problem requires very little knowledge of statistics; in fact there is no "right answer." Our online interaction allows students to create their own formulas and see how well they work! Supported by a statistics curriculum, this reinforces deeper, experiential understandings of accuracy/precision tradeoffs, sampling distributions, and bias.

7 Random (Walk) Insights

Random walks offer students and instructors several points of engagement. In their computing coursework, for instance, all students create a random walker in python (initially an S) that roams back and forth until it hits a wall, returning the number of steps taken. Students build, experiment with, analyze, and extend their simulation. Through many trials, students find that a walker ventures $\sqrt{N}$ steps away from the origin after N random steps. On average, it takes $\sqrt{N}$ steps to reach the wall of the simulation.

This conclusion is powerful, because it is not intuitive: students determine this by relying on experimentation and exercising their computing skills. In CS, students create a fun and simple interface! For instructors, the simulation itself is a door to more. After all, random walks are not limited to the command-line. We have presented the web-versions to high-school and middle-school teachers, who were able to use the interface to deduce the same counterintuitive conclusions.

8 Disciplinary Bridge: Visualizing Interdependencies in Climate Science

"Daisy World" is a climate-science simulation demonstrating how living things affect climate in a hypothetical planet inhabited only by black daisies and white daisies[7]. White daisies reflect a lot of sunlight; black daisies absorb a lot of sunlight (they have different albedos). The Sun grows hotter and hotter over time, but the simulation shows that under certain conditions, the temperature of the planet remains relatively constant for a long period of time.

How is this possible? The presence of daisies has a dramatic impact on the temperature of the planet. Black daisies that absorb heat bloom when the temperature is low, and white daisies that reflect heat replace them as the Sun grows hotter.

Daisy World is a great way to illustrate many fundamental climate concepts such as albedo, feedback systems, and radiative equilibrium. Despite being a relatively simple simulation, there are many functions and calculations needed. The site encapsulates these calculations to emphasize student exploration and understanding of the interdependencies present. Sliders allow students to test how different parameters affect daisy growth and temperature. A map also shows where daisies bloom and provides a different visualization of how species' populations vary over time.

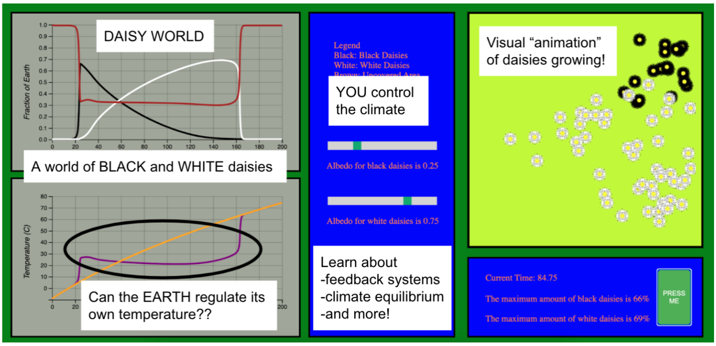


Figure 4: Students have control over simulation parameters and can generate dynamic graphs of daisies vs. time and temperature vs. time. One of the goals of this activity is to explore how to create a temperature equilibrium like the one depicted above.

9 Vision vs. Verdict

We believe these new resources can stand alone as accessible, compelling examples of computational support for science, statistics, and mathematics. As such, they have value as demonstrations, as launchpads to additional analysis, and for building intuition in CS and the bridged field.

Valuable as we hope these examples are, we hope such resources become a larger and larger part of the undergraduate computing experience. As of 2021, building such sites requires more scaffolding than could comfortably fit into a single course. This is also true of the powerful, popular PhET simulations that inspire us[1]. Every year, however, technology and sophistication chip away at these constraints!

In fact, all of these examples here been developed by students – including the coauthors – who researched the available technologies and developed the mindsets needed to leverage them. As computing tools become more accessible and powerful, we promote both the authoring of such simulations and their use as explorations – and insight-generators – in parallel. Authorship and ownership: these are our community's most important scientific resources. As these example resources suggest, computational approaches offer a natural onramp to both.

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References

[1] PhET interactive simulations. `https://phet.colorado.edu/`.

[2] George Clark, Alex Gonye, and Steven J Miller. Lessons from the german tank problem. 2021.

[3] T.M. Helliwell. *Special Relativity*. University Science Books, 2010.

[4] C. F. Van Loan and K. Y. D. Fan. Insight through computing: a matlab introduction to computational science and engineering. 2010.

[5] Thomas McCauley. Dimuon event information derived from the run2010b public mu dataset, 2014.

[6] Parrish Waters and Jennifer A Polack. Interdisciplinary research experience in computer science and biological sciences. *CCSC Eastern*, 36(3):63–69, 2020.

[7] Andrew J. Watson and James E. Lovelock. Biological homeostasis of the global environment: the parable of daisyworld. *Tellus B: Chemical and Physical Meteorology*, 35(4):284–289, 1983.