Using R to Assess Mathematical Sense-Making in Introductory Physics Courses

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We study university students' reasoning in physics and engineering courses. Our theoretical perspective builds from research on students' intuitive "epistemologies"—the ways they understand knowledge and knowing, specifically with respect to the role of mathematics in sense-making about physical phenomena [1]. Students in conventional courses are known to treat formulas as algorithms to use for finding answers, rather than as having conceptual meaning [4]. Students who frame mathematics as expressions of ideas, we expect, are better able to move between different kinds of representations (graphs, equations, their own intuition, diagrams, causal stories) as they conceptualize and reason about physical situations. We call such fluency a kind of "physical/mathematical sense-making" [3], and seek to support it in our instruction and assessment.

In this paper, we used R exclusively to clean, visualize, and analyze student assessment outcomes from three different instructional treatments of student sections in an introductory physics course.

- Instructor 1 was teaching a large section of students ($n = 142$) using a sense-making approach for the first time.
- Instructor 2 taught ($n = 146$) students, drawing from over 15 years of his experience developing sense-making pedagogy.
- Instructor 3 was a highly-rated instructor using a traditional approach with his students ($n = 138$)

Instructors 1 and 2 specifically encouraged their students to reason conceptually, and to create arguments and counterarguments for how physical situations might play out. All three sections were given identical final exams containing multiple choice and free-response items. We identified five out of the eight multiple choice items as "sense-making-oriented," and predicted *a priori* that Instructor 2's students would outperform students from the other two sections on that subset. We then conducted a one-way analysis of variance on the normalized five-item subscores of section 1 ($M = 0.679, SD = 0.252$), section 2 ($M = 0.723, SD = 0.243$), and section 3 ($M = 0.591, SD = 0.272$). The ANOVA was statistically significant, $F(1, 424) = 7.84$, with $p < 0.01$ at $\alpha = 0.05$. Post-hoc Tukey HSD tests indicate Instructor 1's students significantly outperformed Instructor 3's students ($d = 0.347$), and Instructor 2's students significantly outperformed Instructor 3's students ($d = 0.485$) at $\alpha = 0.05$. We further note those differences are not significant across the raw scores of all eight multiple choice items. In our presentation, we will also report results of continuing work of that dataset, including: (1) identifying epistemologically-oriented patterns in students' free-response data, and exploring free-response/multiple choice patterns within and across students. (2) Using students' scores on the Maryland Physics Expectations Survey to examine the validity and reliability of our analyses. [2].

References

[1] David Hammer and Andrew Elby, *Tapping epistemological resources for learning physics*, The Journal of the Learning Sciences **12** (2003), no. 1, 53–90.

[2] Edward F. Redish, Jeffrey M. Saul, and Richard N. Steinberg, *Student expectations in introductory physics*, American Journal of Physics **66** (1998), 212–224.

[3] Alan H Schoenfeld, *On mathematics as sense-making: An informal attack on the unfortunate divorce of formal and informal mathematics*, Informal reasoning and education, 1991, pp. 311–343.

[4] Bruce L. Sherin, *How students understand physics equations*, Cognition and Instruction **19** (2001), no. 4, 479–541.