The Spectrum Laboratory: Toward Authentic Inquiry for All:

A preliminary look at curriculum design and participant data

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Introduction

Spectroscopy is the universal analytical tool of science across disciplines, yet it is typically touched on only briefly in most students' pre-college experience, most often in a perfunctory demonstration of pattern-matching between atomic spectra. Students have few opportunities to learn the power of spectral analysis in enabling discovery, or to make connections between everyday observable phenomena and graphical representations of the color distribution of these observations.

Authentic Inquiry

Using a spectrum, one can detect an art forgery, spot ice in Saturn's rings, determine the temperature of a volcano or of outer space. Spectra are used to track the health of croplands, forests, oceans, and air quality on a planetary (and exoplanetary) scale. The **Spectrum Lab** project is testing the hypothesis that a wide variety of real-world and relevant applications of spectra can motivate both student understanding of concepts related to the interactions of light and matter, as well as support productive participation in scientific practices.

Spectrum Lab Research Questions

RQ1. In what ways does the design of the spectrum tool support students' conceptual development as they learn to interpret spectra?

- What are the different types of learning challenges and successes students experience as they make sense of graphical spectrum representations?
- How do different design supports help them develop and refine their intuitive notions of light and color phenomena to construct knowledge more in accord with scientific understanding?

RQ2. In what ways does the *Spectrum Lab* support students' productive use of science practice?

- How do students use spectra to generate and evaluate questions, predictions, and evidence and to articulate justifications for their ideas?
- Does the incorporation of real-world and professional data for authentic inquiry facilitate their evidence-based reasoning?

RQ3. What factors affect student gains in conceptual understanding of phenomena related to the electromagnetic spectrum and the interactions of light and matter?

Data Collection and COVID-19 Challenges

We anticipated gathering both qualitative and quantitative data from the following four sources, but the onset of remote teaching made the collection of in-classroom video untenable.

Research Question	Pre/ Post Assessments (Quant)	Classroom Video (Qual)	Student Projects (Qual)	Teacher Surveys (Quant)
1. How students' conceptions develop (mixed-methods)	x	x	x	
2. How students use spectra as evidence for inquiry (qualitative)		x	x	
3. Factors affecting conceptual gains (quantitative)	x			x

In addition, we planned a repeated-measures study with 5 teachers using first their "business as usual" (BAU) instruction for EM spectrum topics, followed a year later by use of the Spectrum Lab. Course reassignments and teacher transition during COVID has prevented completion of this study to date, so our BAU vs. Spectrum Lab comparison is currently with different groups of teachers and schools.

Assessment Development

Development of pre/post survey instruments: Through crowd-sourced pilot-testing and psychometric analysis of an initial set of 46 research-based assessment items, we identified a subset of 26 items that measured four Disciplinary Core Ideas related to the electromagnetic spectrum plus the practice of spectrum graph interpretation, with a good range of item difficulty and higher discrimination.[1,2,3]

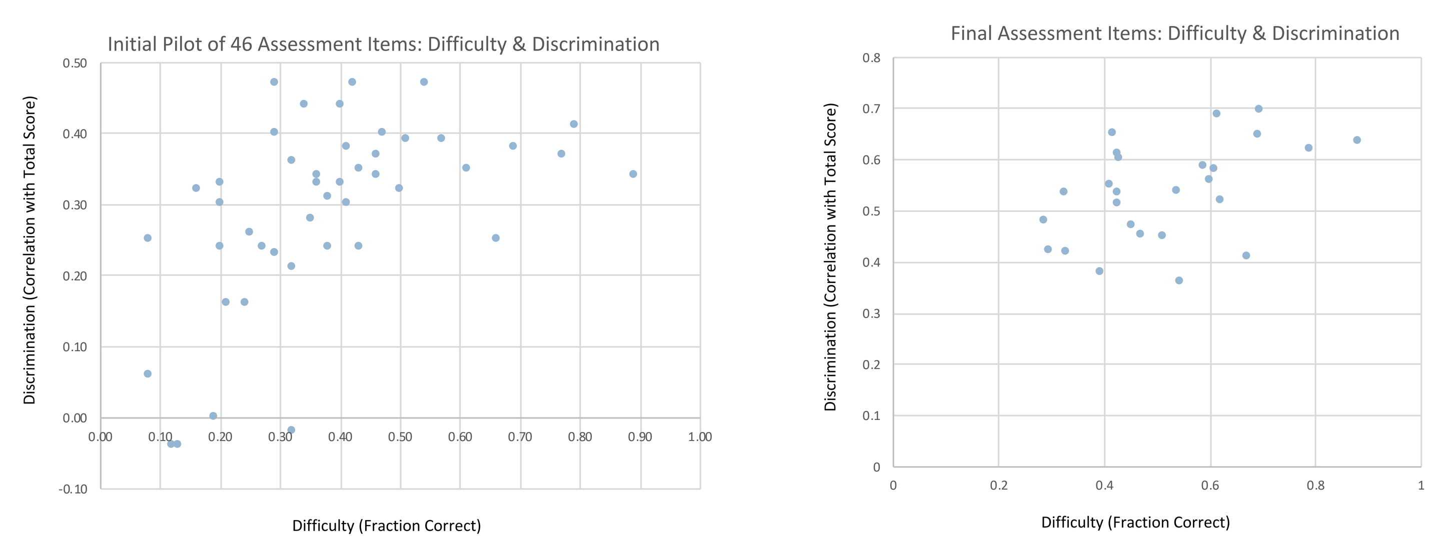


Fig 1. Difficulty and discrimination of test items, before and after piloting, rewriting/revision, and re-testing, showing improvement from the initial collection of items that included some very difficult questions that did not correlate at all with an individual's overall test performance.

The final pre-post survey currently being used in field testing is constructed from 18 of these items, plus demographics. The post-test instrument also includes a set of questions that asks about the kinds of instruction and learning activities that students experience as part of the Spectrum Lab unit.

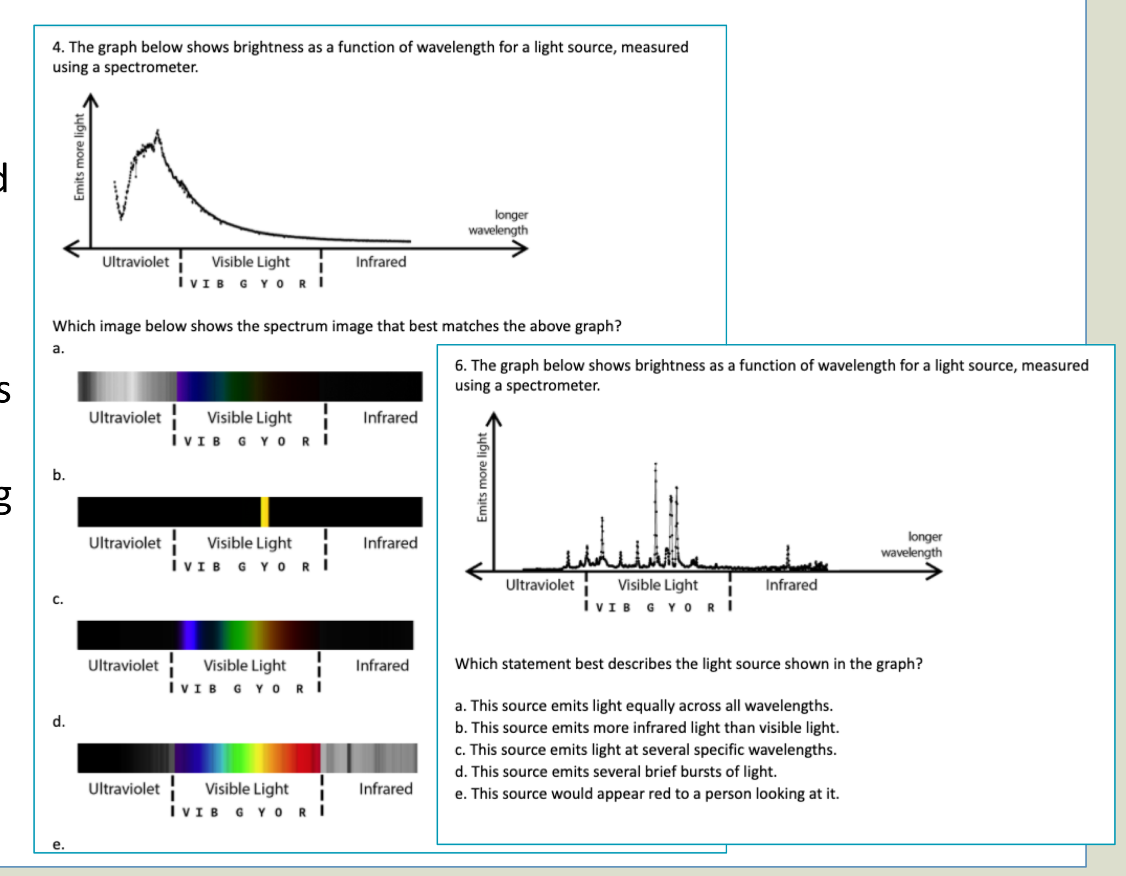
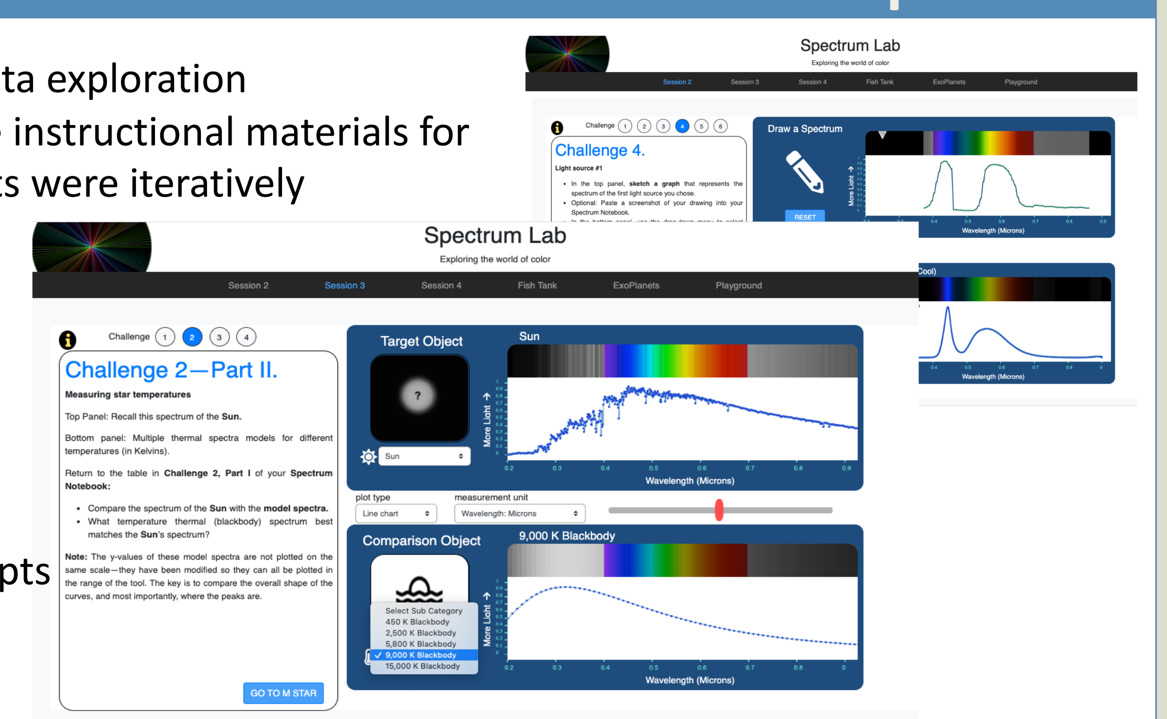


Fig 3. Sample items from final assessment.

Spectral Data Viz Tool & Curriculum Development

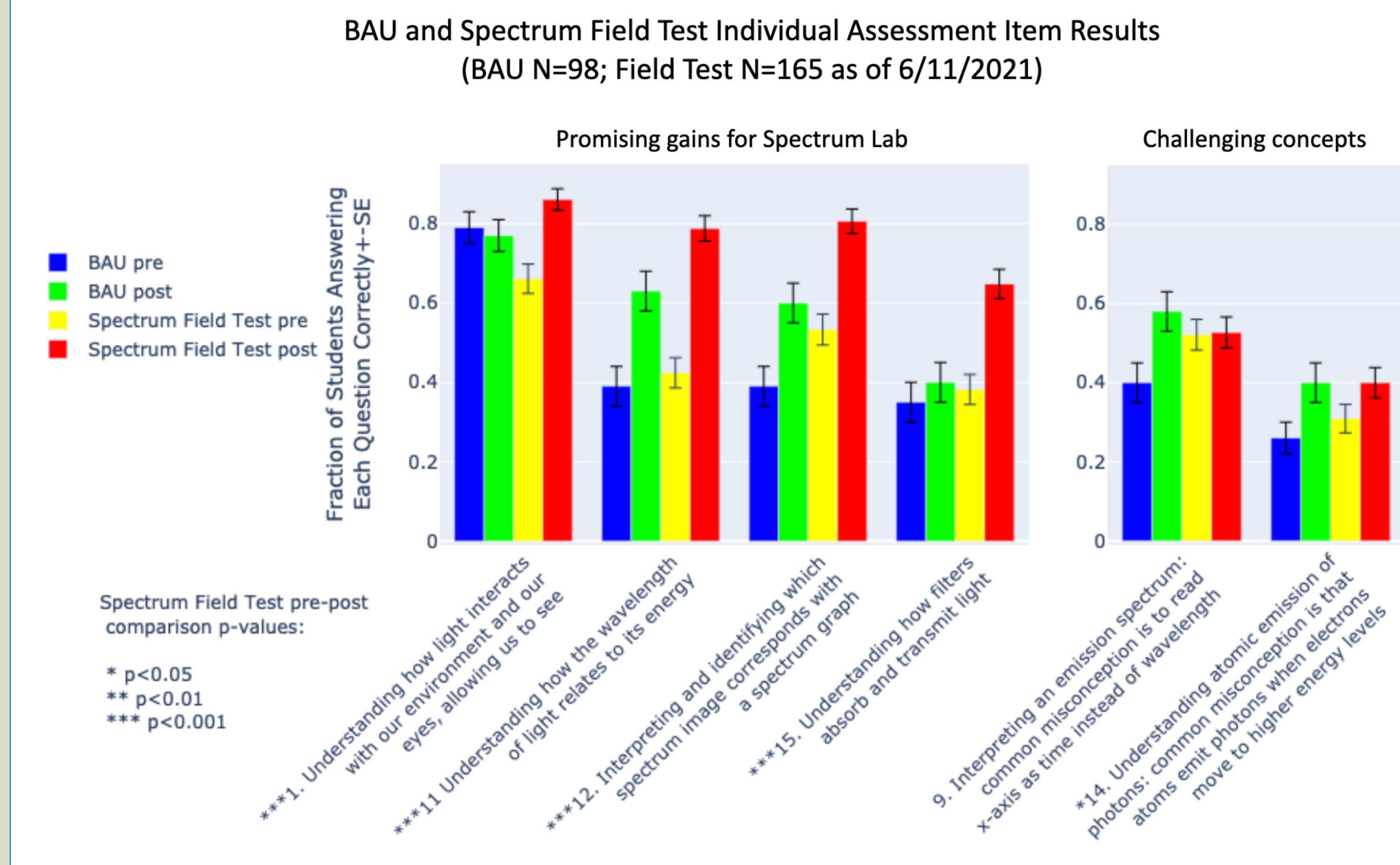
The Spectrum Lab data exploration environment and the instructional materials for teachers and students were iteratively developed through two stages of pilot-testing.

The data tool is designed to help students consolidate light and color concepts and explore how a spectrum represents real processes in nature



The tool displays target and comparison spectra as both plots and color images on a continuous scale that includes ultraviolet, visible, and infrared; the student controls the spectrum with a slider to examine different parts of it.

Preliminary Results from Ongoing Field-Test



Promising Gains.

Early pre-post data from our field-test classrooms suggests that the Spectrum Lab intervention is helping students consolidate light and color concepts over and above traditional instruction. In particular, the curriculum uses the photon model to provide multiple opportunities for students to make sense of the path light follows from an emission source; to intervening materials that may reflect, absorb, or transmit those photons; to a detector (eye/spectrometer) that senses or sorts the remaining photons by energy or wavelength (e.g., Questions # 1 and 15 above)

Challenging Concepts.

We are discovering that the curriculum seems not yet to be helping (more than traditional instruction) with a couple of concepts that are notoriously difficult for students. This is particularly true of the association of emission line spectra with the atomic structure as represented by the Bohr model and its quantized electron levels (e.g., Questions 9 and 14 above). To date, most of our field-test teachers have been physics and astronomy teachers, with most chemistry teachers scheduled to participate in Fall 2021. Might the results on these items and concepts differ with the differing content emphasis of chemistry courses?

Future Work

Data from the Spring 2021 Field Test cohort is still coming in as of this DRK-12 PI Meeting, and our field testing will continue in Fall 2021, with analysis and dissemination of results to come in the Spring of 2022. In addition to pre/post student surveys and teacher questionnaires, we are collecting and will be analyzing final Spectrum Lab projects from students that teachers classify as novice, medium, and high performers. These authentic performance assessments challenge students to use real data to synthesize and apply the concepts and skills learned during the Spectrum Lab unit—either by designing a healthy and eye-pleasing fish tank or by analyzing existing exoplanet spectra to propose a new observation by the James Webb Space Telescope.

The thing I liked the most about participating in the Spectrum Lab would be the challenges that allowed me to compare and contrast the spectrograms of different objects. – 9th gr. physics

I think all the activities were great, especially the ones where we were matching elements in planets´ atmospheres to spectrum graphs like you do in Chemistry. It was also nice being able to apply everyday life organisms and objects such as the tree and light bulbs. – 12th gr. astronomy

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