

# The Frayer Model as Analysis of Instruction and Student Knowledge in Undergraduate Astronomy

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## ABSTRACT

The American public's factual knowledge about science has remained relatively unchanged over the past two decades. Research on scientific literacy connects to science education, interactive instruction techniques, and how introductory undergraduate science courses are many students' last formal exposure to science. This highlights a need for research on how these courses can contribute toward a scientifically-literate citizenry. This study qualitatively analyzes how instruction in an introductory undergraduate astronomy course informs students on an astronomy concept, specifically blackbody radiation. A case study method of thematic analysis was employed by administering a pre- and post-lesson Frayer Model to students in an ASTR 1010 section and recording the professor's lecture. Thematic analysis was conducted on all Frayer Models and the lecture transcript. Three key themes (refined understanding, blackbody spectrum, and ideal physical body) emerged, summarizing how students' knowledge changed following instruction. The results section contextualizes these themes within how the concepts were taught. Blackbody radiation was entirely foreign to most students. Students utilized a few keywords, such as "perfect absorber," to describe blackbodies. Their visual comprehension improved, for they accurately drew and labeled blackbody spectra. This study is novel in using the Frayer Model as an assessment tool in astronomy education research. The findings contextualize scientific literacy and nuance our understanding of how students conceptualize lecture-based instruction. Educators can interpret the results when considering how to teach blackbody radiation. Implications are made to a growing body of knowledge on language in astronomy education.

## Introduction

Recent data from the National Science Board's *Science and Engineering Indicators Report* show that the American public's level of factual knowledge about science has remained relatively unchanged over the past two decades (2018). When asked for a subjective report of how much they know about science, the majority of Americans respond with "Some" or "Not much" (Gallup, 2021, p. 28). These data are concerning now more than ever—our society increasingly relies on science and technology to combat issues such as the coronavirus pandemic and to support federal initiatives such as the James Webb Space Telescope.

An individual's knowledge of science comes from understanding the language of science and being scientifically literate (Wellington & Osborne, 2001). The *National Science Education Standards* define scientific literacy as "the knowledge and understanding of scientific concepts and processes required for personal decision-making, participation in civic and cultural affairs, and economic productivity" (NRC, 1996, p. 22). The public capacity to make decisions using these skills is vital for our country's future. It affects the state of democracy: voters must make informed decisions on which candidates to support, which requires them to be educated on scientific issues such as climate change (National Science Board, 2018). In light of the coronavirus pandemic, citizens benefit from baseline science knowledge when deciding whether to take vaccinations, for example, or when understanding the virus itself.

Factual knowledge of science is derived from formal schooling experience, particularly experience with science and mathematics courses (National Science Board, 2018). From primary to secondary school and beyond, students are exposed to instructional language which uncovers misconceptions, explains terminology, and dissects concepts. Therefore, instruction is a liaison between subject matter and learning (Kikas, 1998; Studhalter et al., 2021; Eun, 2010; Deslauriers et al., 2011). This is in conjunction with what students learn outside the classroom and in their personal lives. As these students become adults and take active roles as citizens, workers, and consumers, they must meet our science-dependent culture by applying their educational background. Thereafter, they can understand “how scientific knowledge is gained” and “how to distinguish scientific facts from other kinds of information” (Impey, 2013, p. 2).

The issue of scientific literacy, and its connection to formal schooling experience, prompt investigation within the education research field. Introductory undergraduate astronomy courses designed for non-science majors offer an opportunity for this analysis and the improvement of scientific literacy among students and the public. Chris Impey, a Distinguished Professor in the Department of Astronomy at the University of Arizona, explains that these classes “often represent a student’s last formal exposure to science,” meaning that what students learn may shape their “understanding of the natural world” and be carried into the public sector of scientific literacy (Impey, 2013, p. 4). What students remember may not be facts and terminology. However, it could be the rational thinking and analytical skills necessary for increasing the public capacity to make informed decisions about science and technology (National Science Board, 2018). As these courses are students’ last formal exposure to science, the teaching strategies used for their learning could carry over with the *next* generation of instructors: about 40% of students who take introductory science courses intend to become licensed teachers (Prather et al., 2013; Lawrenz et al., 2005). Teachers tend to teach how they were taught (Thomas & Pederson, 2003). Therefore, studying introductory astronomy courses can reveal the pedagogy resonating with current students that may reappear in the future.

In this study, I analyze the relationship between instruction in an introductory undergraduate astronomy course and student conceptualization of material. The Frayer Model, a type of graphic organizer, is employed as the assessment tool; in comparison to previous research, this strategy is a unique approach to studying connections between instruction and student learning. Understanding students’ approaches to conceptualizing a dense subject such as astronomy could help educators maximize instruction for student understanding. It will provide context for forming scientific literacy skills, so strategies may be created to proactively transfer these skills into the public sector.

## Literature Review

Scientific language exists in every science classroom and is exercised through instructors’ and students’ verbal and written interactions with course material. As Jerry Wellington and Jonathan Osborne show, scientific literacy is not the mere memorization of terms; it is students’ ability to apply the skills they learn by approaching modern scientific research with a critical, informed eye (Wellington & Osborne, 2001). McPhearson et al. (2008) expand the context of the research above by highlighting the value of scientific literacy from the repercussions of its absence: “[i]nsufficient scientific literacy makes students susceptible to deception and misunderstandings when presented with scientific findings or pseudoscientific data and creates a population unable to make critical decisions related to science and technology” (p. 147). Instructors’ intentional use of language in instructional discourse is a vital step toward student conceptual understanding, as it can foster scientific literacy and because a lack thereof can promote student misconceptions. Scholars in the science education field have been researching this notion since the late twentieth century.

In reviewing existing research, reference studies have been conducted that explore the various functions of scientific literacy in classroom environments; these pertain to scientific disciplines such as physiology (Michael et al., 1999), physics (Gönen, 2008), biology (Yip, 1998), and chemistry (Moje, 1995). For example, Michael et al. (1999) administered a survey to probe respiratory physiology misconceptions among 700 undergraduates studying physiology at community colleges in the United States. The researchers suggest possible sources of student misconceptions they uncovered: teachers’ and students’ imprecise language use and the everyday language that appears in lectures but

that has a “special definition within the discipline” (p. S133). The latter troubles many students, as they believe they comprehend a word but must alter their approach when they learn it has an alternative scientific meaning. Research by Elizabeth Moje from the University of Utah elaborates upon these issues. Moje’s ethnographic study in a high school chemistry classroom shows that students who memorized subject-specific vocabulary could incorporate terminology more accurately into their discussions, but their understanding of the scientific themes beneath these terms was questionable (1995). The instructional approach Moje uncovered could perhaps mitigate the sources of misconceptions identified by Michael et al. but would only fulfill a portion of what, as Wellington and Osborne suggest, composes scientific literacy. Student misconception, though, is not the focus of this study; it is a frequent avenue for research because it is a clear illustration of why educators should not discount scientific literacy. As research in additional scientific disciplines shows, interactive forms of instruction can also relay the value of scientific literacy.

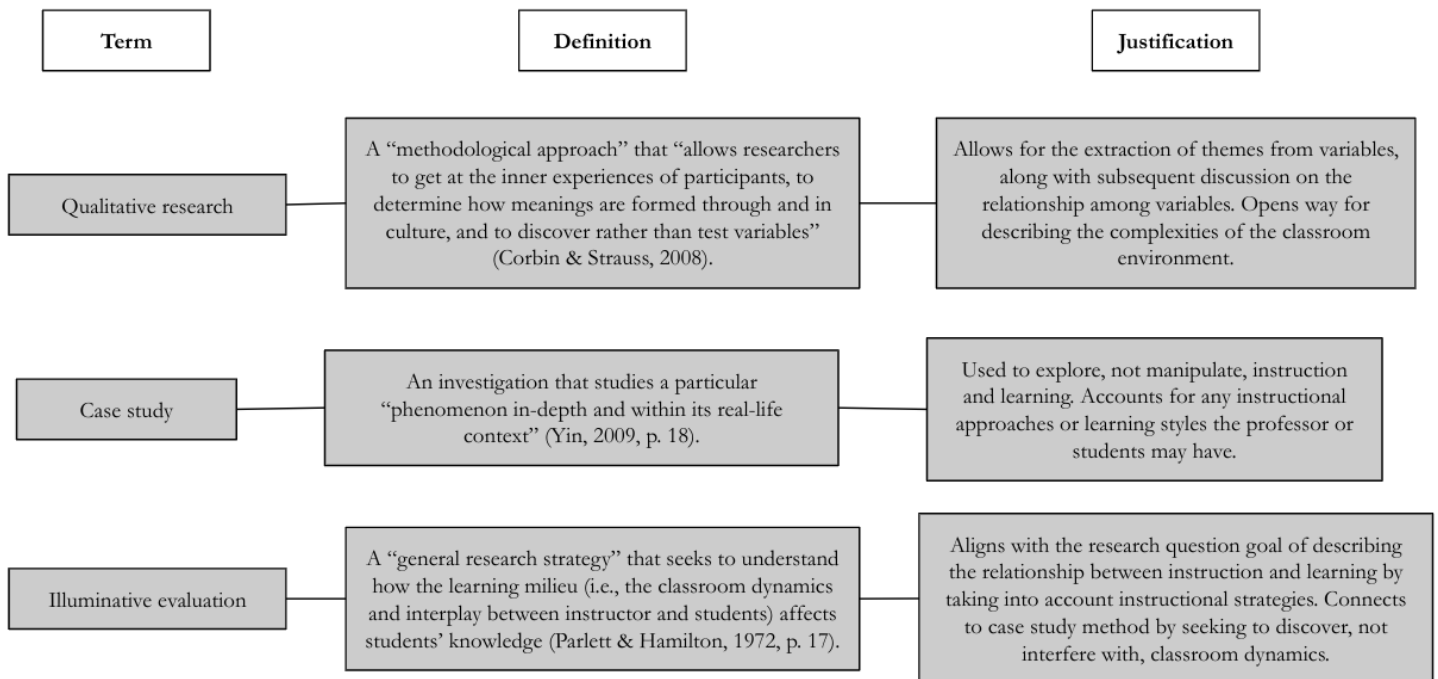
The astronomy education research (AER) field emerged in conjunction with the previously mentioned disciplines yet revealed the value of scientific literacy through studies on interactive instruction. The relevance of astronomy education also prompted investigation into the field: studying astronomy challenges students to observe and question the “natural phenomena” with which humanity has coexisted for millions of years (Bryce & Blown, 2012, p. 3). As Percy (1998) states, “[astronomy] advances physics and other sciences,” “substitutes the observational mode [in classrooms] for the experimental,” and “increases public awareness and interest in science and technology” (p. 347). Thus, interest in AER has continually expanded since the late 1990s. However, a significant academic paper in the field by Lelliott and Rollnick (2010) reveals, based on a review of one hundred and three peer-reviewed AER journal articles, that research on the *language* of astronomy is scarce. It would therefore contribute to the body of knowledge, and several studies on language have already been conducted in fields such as physiology and chemistry. Researchers have shifted their attention toward this gap in AER. In their peer-reviewed study, LoPresto and Murrell (2011) suggest instructors take time to address their students’ misconceptions *before* covering course material. Colin Wallace in the Department of Physics and Astronomy at the University of North Carolina at Chapel Hill offers instructors “Peer Instruction” questions if they seek to interactively challenge their students’ astronomical problem-solving skills (2020). Creighton and Mello sought to improve undergraduate science majors’ scientific literacy and expand student breadth of knowledge by having them explain astronomical concepts in a storytelling class (2021). These studies reveal that research in undergraduate astronomy has been done, but a large portion of it explores the dynamics of interactive instruction. Undergraduate AER has yet to synthesize the relationship between non-modified instruction, professors’ instructional language, and how students respond when asked to visually display their understanding. This gap prompts the question: How does non-modified instruction inform student conceptualization of subject matter in an introductory undergraduate astronomy course? Scientific literacy calls for one to not only understand related terminology but also to *illustrate* an understanding of a concept and apply it to modern innovation. Thus, an additional gap in AER exists: researchers in the field (including those already discussed) often collect data using multiple-choice questionnaires, surveys, one-on-one interviews, or discourse analyses. The Frayer Model (FM) is an insightful yet under-researched approach to understanding the patterns between instruction and student knowledge.

In her joint publication with the National Science Teachers Association, Page Keeley, an internationally esteemed leader in science education, describes the FM as a graphic organizer that “provides students with the opportunity to...communicate their understanding by providing an operational definition, describe characteristics, and list examples and nonexamples...” (2008, p. 99). Contrary to popular belief, the purpose of the FM is not to memorize a term. It *can* introduce unfamiliar vocabulary, but using the FM primarily helps students dissect terms and relate them to overarching concepts (Thomas, 2016).

## Methods

The current study explores the patterns between instruction and student knowledge in an introductory undergraduate astronomy course, building from previous research on the connection of instruction to scientific literacy and AER

which analyzes the effects of interactive pedagogy. To this purpose, a qualitative case study method of thematic analysis was employed, following a general strategy of illuminative evaluation (Figure 1).



**Figure 1.** Definitions and Justifications for Method Approach.

## Participants

Eligible participants were determined by viewing an astronomy course listing for Spring 2023 at a public four-year university in East Tennessee. I contacted multiple Astronomy 1010 (ASTR 1010) and Astronomy 1020 professors teaching these courses. These introductory courses were chosen because they best align with the project goal: understand how instruction informs students; the courses allow students to “learn about [a] new form of science, and instructors get to influence and change students’ minds” (Dobaria, 2018, p. 5). The ASTR 1010 professor who consented (for anonymity, Professor Plum) agreed to have me sit in on a lecture and administer FMs to his students. His consent was obtained before agreeing upon a lecture for me to attend. Once a date was set for early February 2023, he informed me that he would be teaching about blackbody radiation, and I modified the pre lesson-post lesson FMs accordingly. His consent form had an additional requirement: permission to be recorded.

Students in the section attend roughly three hours of lecture a week and eight mandatory labs for the semester (two hours each). There are no prerequisite enrollment requirements.

Students completed a brief demographic questionnaire and were told the information would be used as group descriptors. The demographic questionnaire can be found in Appendix A. Gender distribution was 53% male, 42% female, and 5% Non-binary. Most students (84%) selected English as their native language, and 89% identified as White, 11% as Asian or Pacific Islander. Most students (84%) had not previously taken an undergraduate astronomy course. There was an equal distribution of science and arts majors in the section (32% of each), 21% were education majors, and 15% were professional or other. Most students (79%) had taken little to no (0-1) previous physical science classes.

To maintain anonymity, names were not collected. Students were told their grades would not be affected by their decision to participate in the study. Those who chose not to participate listened to the lecture but did not complete any forms.

## Data collection

Figure 2 shows the administered pre lesson-post lesson FM. Using an identical FM as the assessment tool was a justified control because it showed how student knowledge *changed*, which was one of the study goals.

<b>Definition:</b>	<b>Sentence:</b>
<b>Characteristics:</b>	
<b>Blackbodies</b> E.g., Blackbody radiation	
<b>Synonyms:</b>	<b>Sketch:</b>
<b>Antonyms:</b>	

**Figure 2.** Modified Frayer Model Instrument (Thomas, 2016).

The original FM, developed by Dorothy Frayer, Wayne Frederick, and Herbert Klausmeier in 1969, had a central term and four sections: a definition, essential characteristics, examples, and non-examples. For this study, I chose a modified version by Thomas (2016); the added sentence and sketch sections broaden the original FM capabilities and accommodate students who prefer visual learning techniques. This aligned with the illuminative evaluation strategy of keeping the research study adaptable to the classroom environment (Parlett & Hamilton, 1972); I could also generate more diverse themes from analysis. With assorted FM sections, I could also communicate student

knowledge with greater accuracy and relate it to students' practice of scientific literacy—two components of my results which may benefit future research.

The data collection process lasted about 80 minutes. Two recording devices—Voice Memos on a mobile phone and Voice Recorder on a laptop—were placed at the front of the classroom, near Professor Plum's podium, to ensure that only *his* voice was recorded and that student voices would be either undetected or muted. I used the Voice Memos and Voice Recorder apps to record on the phone and laptop, respectively; these were started before the lecture so Professor Plum could begin speaking directly after the pre lesson assessment.

Students were each given a packet following a brief introduction to my study. The packet contained four forms: the informed student consent form, the demographic questionnaire, the pre lesson FM, and the post lesson FM. The forms were color-coded to simplify my instructions. In the first twelve minutes of class, students who wished to participate were asked to read the student consent form, complete the demographic questionnaire (six circle-your-answer questions), and complete the pre lesson FM. They were reminded that participation was voluntary; all responses were to be created to the best of their ability. Students had to acknowledge that their professor was being recorded and that all student voice data would be deleted. The pre lesson FM and post lesson FM in each packet had the same code written at the bottom, which differed from the other packets and aided in correctly connecting and comparing FMs during analysis. The students who chose not to participate were instructed not to complete the packet.

To accurately test students' prior knowledge and how only the lecture informed them, students were restricted from using textbooks, discussion with others, and other materials which could have aided their responses. In the following 60 minutes, I recorded the lecture and took field notes at the back of the class. Then, I stopped the recorders, and students had the last eight minutes of class to complete the post lesson FM, after which all packets were collected.

The lecture recordings were digitally transcribed using NVivo, a qualitative data analysis software, which prevented the need for transcribing by hand. I made multiple revisions to the transcript in Word, correcting for software errors, condensing it to just the 60-minute lecture, deleting student voices, and splitting it into codable sections. I conducted a member check with Professor Plum in which he had time to review the transcript and inform me of needed changes. I saved the final transcript in a private file and deleted both audio recordings.

Demographic statistics were separately calculated, and coding was conducted on copies of the FMs. Entirely blank pre-post FM *sets* were discarded, but students were told they could leave their pre lesson FM blank if they did not recognize the tested concept; thus, many sets had blank pre lesson FMs but completed post lesson FMs.

All study designs were approved by my institution's IRB to ensure the ethical standing of my procedures.

## Data analysis

I used thematic analysis to identify what information students gained from the lecture and what concepts were taught. Thematic analysis is a qualitative method for categorically describing the patterns that emerge from initial codes of data; it produces overarching themes in phrase or sentence form (Saldaña, 2021). In this study, themes were created from how categories on the pre lesson FMs differed from those on the post lesson FMs. These differences resembled what students *learned* from the lecture.

Thematic analysis was conducted in three steps for the FMs and two steps for the lecture transcript. First, I read through the FMs and transcript multiple times to familiarize myself with the data. Then, I began open coding. I coded the data as I read, which mitigated bias that could have been introduced had I preconceived possible codes from my research question; if appropriate, I used In Vivo codes (quotes of what students wrote or the professor said) to improve the credibility of the codes (Saldaña, 2021). I revised the original codes in the second coding cycle by deleting, condensing, and categorizing as necessary. This allowed me to generate the categories for pre lesson FMs, post lesson FMs, and the transcript, which are presented in Table 1. Finally, I analyzed how the FM categories changed from the pre lesson FMs to the post lesson FMs. This included how categories were altered or which new categories emerged on the post lesson FMs. These differences became the three themes I generated to answer my research ques-

tion. The transcript categories were analyzed alongside the FM themes to understand how *instruction* informed students. Doing so allowed me to place the FM themes into the context of the lecture and conclude which lessons were key for student conceptualization.

## Results

There were 19 completed FM sets total. I condensed 13 pre lesson FM codes into four main categories, 28 post lesson FM codes into four main categories, and 64 transcript codes into five main categories. Differences among six major categories from pre lesson FMs and post lesson FMs were condensed into three key themes, which reveal how students' knowledge of blackbodies changed. Table 1 presents these results and Table 2 defines the themes.

**Table 1.** Identified Themes and Categories from Frayer Models and Lecture.

	Pre lesson FMs	Post lesson FMs	Lecture
Categories	"Unknown" Absorptive properties Does or does not emit light "Unseen"	"Perfect absorber" "Emits light" Blackbody spectrum Idealization	Blackbody characterization Instructional approaches Traveling light Atmospheric influences "Manner in which they glow"
Differing/new categories	Absorptive properties Does or does not emit light	"Perfect absorber" "Emits light"  Blackbody spectrum  "Idealization"	
Themes from differing/new categories	Refined understanding  Blackbody spectrum  Ideal physical body		

Two major categories within "Manner in which they glow" were Temperature scales and Kirchhoff's Laws.

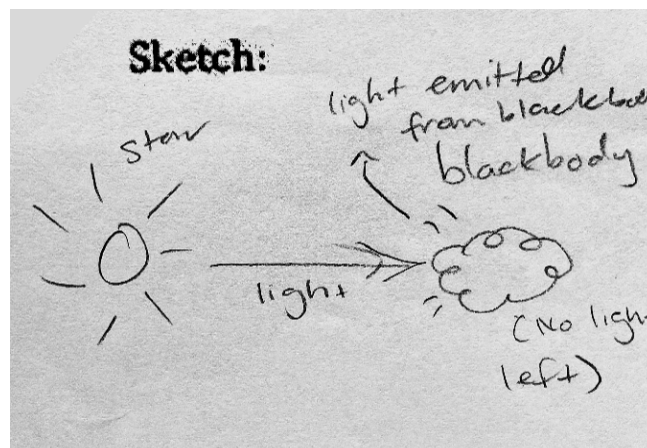
**Table 2.** Definitions of Themes.

Theme	Definition
Refined understanding	Students refined their understanding of two key components of the blackbody definition.
Blackbody spectrum	Students gained a new understanding of the spectra blackbodies emit. Examples include sketches of multiple different spectra and consideration of temperature effect.
Ideal physical body	Students incorporated that blackbodies are idealizations. This means blackbodies are discussed as hypotheticals. Many things in nature glow <i>approximately</i> , but not exactly, like a blackbody.

In the following sections, I first present the themes by discussing how they emerged from pre lesson FMs and post lesson FMs, then discuss the lecture categories related to each theme. The *Instructional approaches* category is woven into each discussion to explain *how* instruction informed students. This adheres to the method strategy of illuminative evaluation and allows for not just a presentation of the information taught but also the instructional approaches used for conveying the information.

### Theme 1: Refined understanding

The most common theme identified across the FMs was that students refined their understanding of two major components of blackbodies' definition: their absorptive properties and quality of emitting light. On pre lesson FMs, students described blackbodies as absorbers of energy and light. Of the seven pre lesson FMs in this theme, two students used the synonym section to liken blackbodies with black holes, perhaps because black holes also absorb all light. Following instruction, eighteen students defined blackbodies as *perfect* absorbers of *all* incident light. Instead of equating blackbodies with black holes, they wrote that black holes "act like" blackbodies because they absorb surrounding light. Sketches visualizing these absorptive properties clarified that *all* light is absorbed, and some is emitted. Figure 3 provides an example.



**Figure 3.** Sample student post lesson sketch of blackbody absorptive properties.



Students' pre lesson FMs showed mostly that blackbodies "emit light" or radiate light. Three of the seven completed pre lesson FMs had sketches, one an unlabeled line curve spectrum and the two an orb radiating light. Post lesson FMs, on the other hand, included many new phrases such as "blackbody glow" and the idea that blackbodies "emit *constant* light". In general, a greater portion of post lesson FMs agreed that blackbodies "emit light". Unlike the pre lesson FMs, no post lesson FM stated that blackbodies "do not emit light".

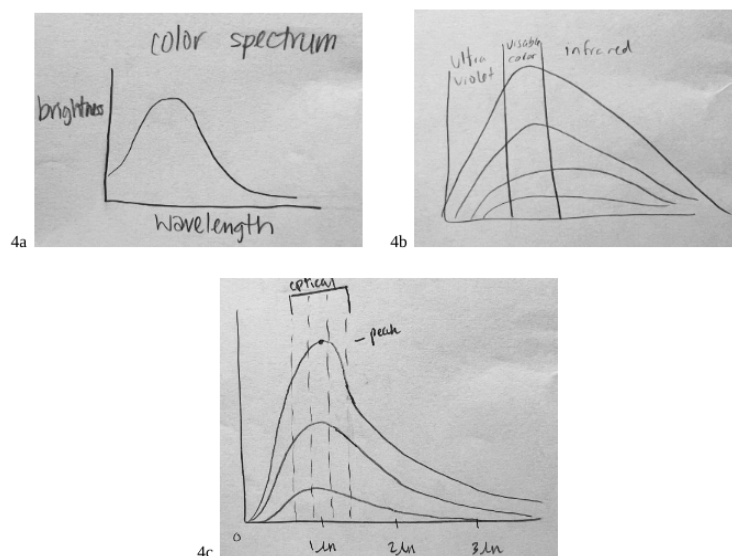
Professor Plum began his lecture with a "bridge," discussing a planet like Mars that absorbs light like a blackbody. He emphasized that both the absorptive and glowing features of Mars would be important later in the lecture. This address of an object familiar to students allowed him to later transition into the idea that blackbodies do the same but in a "perfect" way. He defined blackbodies and broke information into simpler terms:

"... technically, a blackbody is not a black hole. It's defined to be a perfect absorber of light ... all that means is that it's not reflective. If you shine something on it, it reflected not."

Almost all students recalled this definition on their post lesson FM. Professor Plum also noted that "blackbodies still glow, and it's the manner in which they glow" that is relevant for the class. Similar to how he did with Mars, he discussed blackbody glow, emphasizing the relevance of blackbodies by stating that "while almost nothing glows exactly like a blackbody, almost everything glows approximately like a blackbody ... your body, the chair, the desk, the ceiling, the building, the road outside." Many students incorporated this "approximation" into the definition, characteristics, and sentence sections of the FMs. Professor Plum related glow to flux and the strength of light depending on its distance. He called it luminosity and related it to the wattage numbers on lightbulbs (recalling familiar objects). He tied blackbody glow to the spectrum blackbodies produce (i.e., wavelength at which their emitted light exists).

## Theme 2: Blackbody spectrum

Another common difference was that students gained an understanding of blackbody spectra. Pre lesson FMs did not mention blackbody spectra, although one student drew an unlabeled line curve spectrum. Five out of nine post lesson FMs in this category drew a blackbody spectrum. There were multiple types: four of the five drew a continuous spectrum with bell curve-shaped lines, and one drew a blackbody emitting an emission line spectrum. Students appear to have connected astronomers' use of spectral lines with visualizing blackbody glow. No post lesson FM spectrum was fully labeled, but all sketches indicated that blackbody spectra have brightness and wavelength as variables, or that spectra are divided into major bands (e.g., infrared, visible light, ultraviolet).



**Figure 4.** Sample student post lesson sketches of blackbody spectra.

For written sections, four of the nine FMs in this category defined blackbodies as an “approximation for the continuous spectrum produced by many astrophysical objects,” which related to Professor Plum’s note that “almost everything glows approximately like a blackbody”. Five post lesson FMs used the term “Planckian” as a synonym. Thus, students understood how Planck’s law defines blackbody spectra as dependent upon a blackbody’s temperature. Professor Plum did not mention “Planckian,” but described how blackbody emission, and its peak wavelength, are temperature-dependent.

Just as students predominantly used visuals to describe blackbody spectra, Professor Plum relied on visuals to *teach* blackbody spectra. He introduced the spectra by relating them to his earlier discussions of blackbody glow:

“A spectrum is how you break down a glow into the different colors.”

To introduce these concepts, Professor Plum did not “worry about precision”. Most explanations were given in layman’s terms (plain, uncomplicated English). He taught the different spectrum types (continuous, emission line, absorption line) through Kirchhoff’s three laws. In addition to layman’s terms, he emphasized seeing the laws “in action”: he used a “schematic, representative cartoon to illustrate” the three spectra. He also lit three gas tubes so students could see the three spectra through the gradings he distributed. He relied upon familiarity when describing the continuous spectrum:

“If you had Prob and Stats ... you might be familiar with the idea of a bell curve ... [the spectrum curves have] this long–what we call–tail. That’s a blackbody spectrum.”

Students drew the continuous spectrum in this manner. The following illustrates his layman's terms:

“Continuous: no gaps. Emission line: essentially all gaps with the occasional color showing up ... Absorption line: essentially all continuous”.

FMs mentioned both the Kelvin Scale and blackbody spectra, but failed to mention Wien’s Law which combines these two concepts; Wien’s Law relates the wavelength of blackbody spectra to temperature. Professor Plum, however, did mention Wien’s Law.

### Theme 3: Ideal physical body

Seven out of nineteen post lesson FMs included that blackbodies are idealizations, shown by the words “ideal” or “hypothetical” under the definition sections of the FM. A few students used these qualities to reason how a blackbody is a *perfect* absorber. Students generally understood that blackbodies are unique in this sense and that objects on Earth can only behave like blackbodies.

Professor Plum only mentioned the term “idealization” when he introduced blackbodies. As represented by the FMs, he acknowledged that the term describes a hypothetical, but many objects still glow like blackbodies.

“Funny thing, the place where it exists most exactly like the ideal ... the cosmic background radiation ... the space of the universe is pervaded with this light ... When you make a spectrum, it’s basically perfectly a blackbody ... while almost nothing glows exactly like a blackbody, almost everything glows *approximately* like a blackbody.”

The description of blackbodies as ideals justified Professor Plum’s labelling of them as perfect absorbers. Despite the minimal time spent in the sixty-minute lecture repeating the word “idealization,” a notable number of students wrote this information on their post lesson FMs. Professor Plum spent more time describing blackbody characteristics using examples, such as the lightbulb wattage example or the gas tubes example. No students mentioned these examples in the FMs; FM responses used briefer definitions, though definitions were not the focus of the lecture.

## Discussion

This study shed light on how instruction in an undergraduate astronomy course informs student conceptualization of blackbody concepts. This research is one of few to incorporate the Frayer Model into AER (Thomas, 2016) and the first to incorporate it in undergraduate AER. The analysis revealed that instruction was most students’ first exposure

to blackbody radiation in an undergraduate astronomy course. Those with some prior knowledge refined their understanding of defining characteristics, and all students improved their visualization of blackbody spectra. Finally, students relied upon keywords (“perfect absorber,” “idealization,” “emits light”) to describe blackbodies, although these words were minimally emphasized during the lecture. These were not only present in the definition section of the FM, but also the sentence section, where Professor Plum’s real-life examples could have been mentioned, but were not.

The latter result nuances previous research conducted by Eve Kikas: in her longitudinal study, Kikas found that secondary students who were required to memorize definitions of astronomical phenomena (without integration into their knowledge) were able to remember said explanations two months after studying them but had reverted to their everyday knowledge after four years (1998). Kikas concludes that teaching by stressing memorization has little long-term incorporation into students’ knowledge. My research shows that, even with teaching that emphasizes the context and relevance of concepts, students still gravitate toward definitions when asked to recall the concept. Despite this, my student participants showed the development of *visual* scientific literacy skills; these skills could be what students carry into the public sector, particularly because research like that of Kikas has dismantled their memorization of definitions as having questionable applicability. Despite students’ unexpected takeaways, prior research reassures that the context- and relevance-heavy teaching strategy found in my study is still important (Özcan, 2015; Prather et al., 2009).

For visual recollection of blackbodies, students are mostly informed by temperature scales and blackbody spectra shown during lectures. Interestingly, students mentioned the word “Planckian,” which was not stated in the lecture, but was their way of showing that they understood how blackbody radiation depends upon temperature. This finding aligns with Kardaras’s and Kallery’s belief that students should have this understanding for “in-depth stud[ies] of blackbody radiation” (2020, p. 1).

Instruction in the studied ASTR 1010 section used visuals as the cornerstone for explanations, both through presentation slides and demonstrations of flux with lightbulbs and gas tubes. These appear to be effective strategies for teaching the blackbody spectrum, particularly if visual understanding is the goal. Numerous studies support this conclusion (Ka Chun Yu & Dove, 2017; Bower & Liben, 2021; Crider, 2015). Indeed, my FM results are supportive evidence for this conclusion and further show that students develop visual scientific literacy skills when learning blackbody concepts. With my conclusions and the advice of these previous studies, educators can proactively teach blackbody radiation, and following, if desired, use the modified FM to assess student knowledge.

## Conclusion

The purpose of this study was not to test whether students were scientifically literate. Scientific literacy can not be developed following one lecture, and it is not solely derived from formal education. Literacy skills are practiced outside of the classroom as well, and students’ mental models of astronomy are equally shaped by their personal experiences and observations. The results can, however, provide context for forming scientific literacy: what students derive from astronomy instruction and how they visualize blackbody radiation.

Equally important are the implications of this study’s conclusions. When visualizing the blackbody spectrum, the priority is not understanding “technical jargon” of Kirchhoff’s Laws. Rather, focus should be placed on visualizing the differences between the continuous, emission line, and absorption line spectra and logically deducing how they appear from nature. The results of this study support these suggestions: students’ drawn spectra represented that they understood Kirchhoff’s laws without having to *recite* the laws. Such implications are valuable for astronomy educators because they broaden present research on teaching blackbody radiation. With a nuanced understanding of instruction, educators and researchers may use this knowledge to intentionally promote scientific literacy among students. Researchers may also analyze how students learned to understand what scientific literacy skills are currently being transferred from instruction, and better gauge the future of scientific literacy in America.

The FM has made its debut in AER. This study shows that the versatility of this tool reaches the astronomy classroom and proves useful in the instruction of highly-visual concepts, such as blackbody radiation.

Finally, future research could investigate how the consistent mentioning of the relevance and implications of astronomical phenomena during instruction affects student sentiment toward astronomy. Assessment could also be conducted on whether said students remember astronomy concepts for longer periods of time, or if they revert to their personal experiences. These analyses could be placed in context with whether those students follow scientific advancements in their lives following post-secondary education.

## Limitations

This study has several limitations that may hinder the effectiveness of the data and conclusions. The small sample size limits the generalizability of the findings and conclusions. Only nineteen FMs were analyzed from a population with little ethnic diversity. Therefore, my findings do not accurately represent the entire undergraduate population taking introductory astronomy courses. Due to time constraints and permission requirements, I could only attend one lecture. Having more FMs to analyze and a broader range of lectures to attend would have made the findings more robust, and the conclusions more accurate.

Typically, coding in qualitative research is done through cross-checking: each member independently codes the data, then results are discussed and edited multiple times to mitigate personal bias and ensure the data is accurately represented. I performed coding independently, which could have led to errors or biases in the categories and themes created. An effort was made, though, to adhere to the iterative nature of qualitative coding through multiple coding cycles, in vivo coding, and data triangulation.

## Acknowledgements

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