Understanding and affecting science teacher candidates' scientific reasoning in introductory astrophysics

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This study reports on a content course for science immersion teacher candidates that emphasized authentic practice of science and thinking scientifically in the context of introductory astrophysics. We explore how 122 science teacher candidates spanning three cohorts did and did not reason scientifically and how this evolved in our program. Our primary method of exploring teacher candidate reasoning is through analysis of responses to an apparently simple multiple-choice question. The question asks for the relative motion between the Sun and Earth and then for a scientific argument supporting the response. To explore these participants' reasoning and its potential impact on classroom practice, we also describe qualitative observations of how the teacher candidates were reasoning while participating in a science course, participant evaluations, and long-term follow-up with select program graduates after they had taught science in middle or high school. Our results suggest that participant ability to reason scientifically improved significantly and that this can impact classroom practice in a positive way.

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I. INTRODUCTION

Reports and studies on science education [1–3] teacher preparation [4,5] and standards [6–8] consistently point to the failings of science education and to guidelines of what should be done. In response to poor outcomes, there is an emphasis on how students need to ''actively develop their understanding of science by combining scientific knowledge with reasoning and thinking skills'' [7]. ''The learning experiences provided for students should engage them with fundamental questions about the world and with how scientists have investigated and found answers to those questions. Throughout grades K-12, students should have the opportunity to carry out scientific investigations'' [8].

Two important factors in a student's education are (i) the teacher and (ii) providing students with authentic opportunities in the practice of science and scientific reasoning. It has often been argued that teachers teach the way that they were taught and that it is therefore a priority that future teachers learn science in a way that reflects exemplary teaching practices [9–13]. However, most science teachers first learned science in the very educational systems that are being called into question, and then in colleges which typically model lecture-based, passive learning environments with no emphasis on practicing authentic scientific reasoning [14]. They never learned science where focus was given to ''how do we know?'' or ''what is the explanation for?'' or ''does that make sense?'' Therefore, many experienced classroom science with a perspective of the nature of science and learning that is very different from what most teachers and experts want [15–20].

In an earlier paper we described how we were able to explore, understand, quantify, and improve student reasoning in the context of introductory astrophysics [21]. We described an inquiry-oriented summer program where high-school students practiced doing science and thinking like a scientist [22]. We reported that the program produced improvement in the students' ability to engage in scientific reasoning and that the students' newly developed reasoning skills could extend beyond the subject matter of the course.

In this paper, we extend this study by investigating preservice science teacher reasoning in an alternative certification program. We study the effectiveness and impact of similar astrophysics curricula that we used with the high-school students. Our research questions are as follows: How do teacher candidates in an immersion program reason scientifically as interpreted through a specific classroom context of introductory astrophysics? To what extent can the curricula we use improve this reasoning ability? We also begin to explore the question as to whether it is possible that learning science content by inquiry can affect these teacher candidates' perspectives on teaching science.

Below we begin with a description of the preservice teachers program. We then describe our research methods

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and results, which details the reasoning we are exploring. We finish with a perspective on the implications of this study.

II. RESEARCH CONTEXT

A. Preservice teacher immersion program

This research study took place in a science teacher immersion program at City College of New York. All participants came to this program with a bachelor's degree and the intention of beginning a career as a public school science teacher in New York City. Subject matter backgrounds of the participants varied. None of the participants had formal training in education and few had degrees in astronomy or physics. Participants with a strong background in biology, chemistry, Earth science, or physics were certified in high school in their respective fields. Those with other backgrounds or with less science background were certified to teach middle-school science, which in New York City is an interdisciplinary curriculum including astronomy and physics. The program was competitive, so most of the participants had strong academic credentials. Many were from elite colleges and had advanced degrees. For the most part, they were enthusiastic about the opportunity to teach science to children. Many were nervous about preparing in a short time to do a challenging job well in a challenging environment.

Participants began their program with an intensive summer experience including education courses, field experiences, job placement support, workshops from experienced teachers, and a single science course. As is often the case in alternative certification programs, after the summer, participants were full time science teachers while they continued to receive support and take courses towards completion of their certification and master's degree. All of these activities are intended to prepare them to be successful science teachers. However, the single summer science course in introductory astrophysics is the focus of this paper.

Data presented here are from classes from three different summers. These are the only three classes for which matching pre and post data exist. In chronological order, class A had 40 teacher candidates, class B had 70 teacher candidates, and class C had 29 teacher candidates. Only data for those who eventually completed the summer program are included in this paper. Of the 139 total participants who started the program, we have matching pre and post data on 122. Only 2 of these 122 had degrees with a focus on physics, but others had enough background that they eventually were hired to teach physics. About half (60) of the candidates were in the middle-school science program and were to teach integrated curricula including astronomy and physics.

B. Pedagogy-content linked astrophysics course

Participant strength in the content and process of science was mixed, even among those with strong credentials. We therefore wanted to include instruction in science as part of the summer immersion program. However, program participants were preparing to teach different subject matter at different grades in very different schools. Most did not yet know the subjects they would eventually be teaching.

Since it was not possible to teach the specific content that each teacher would be teaching, we made the decision to include a science course in astrophysics. We felt that this was a strong context to exemplify instructional practices that we wanted the participants to employ in their own classrooms. They were learning content (where their own understanding was often limited) in a way that we wanted them to teach it. An inquiry approach to teaching astronomy concepts can be an effective context for preservice teachers to improve their scientific understanding of astronomy concepts [23]. With this choice of topic, essentially all participants would be learning by inquiry and would then be given the opportunity to reflect on what constitutes learning by inquiry from the perspective of a learner transitioning to teaching. If a topic were selected which some of the participants knew well and others did not know at all, such an opportunity would not be maximized.

In addition to learning the science itself, participants reflected on the process of the teaching and learning of science within the context in which they were immersed. They were also learning directly that science should be an active, purposeful process which promotes functional understanding and critical thinking. They were learning that science learners should be given the opportunity to build an understanding of benchmark principles of science based on their own observations and reasoning. The specific curriculum and instruction of the course are described in detail below.

III. RESEARCH METHODS AND RESULTS

A. Development of a scientific reasoning assessment tool: High-school enrichment program

In our previous paper, we reported on an analysis of scientific reasoning based on the scientific argument students provided when explaining the relative motion of the Sun and Earth [21]. The language and format of the question are shown in Fig. 1. Our previous paper detailed student responses and reasoning. It also detailed program instruction, development of student scientific reasoning approaches, and how students answer the same question both before and after instruction.

As a pretest, over 90% of the students selected choice B, that Earth goes around the Sun. However, almost all of them gave explanations that do not constitute good scientific reasoning. Some cited observations experts identify as irrelevant to Earth going around the Sun such as night and day. Others made vague allusions to authority or jargon, which do not constitute reasoning at all. Some used circular reasoning as proof that Earth goes around the Sun. Many cited observations that can be accounted for by either Earth going around the Sun or the Sun going around Earth, such as the seasons. After completion of the pretest, extensive conversation and follow-up in class made clear that these student answers reflected what they really thought were scientific arguments. Most struggled with even recognizing what constitutes a scientific argument.

After the pretest, the students spent much of the summer program working through inquiry-based activities in observational astronomy. Students made observations and developed multiple scientific models that can account for their observations. Students on their own reasoned that the vast majority of what is observed could be accounted for either by thinking of Earth going around the Sun or by thinking of the Sun going around Earth. The curricula and instruction were very similar to what the participants of our preservice immersion program worked through, which is described below. After going through these curricula, the students in the summer program took the same question shown in Fig. 1 as a post-test.

To quantify student reasoning, we developed the rubric summarized in Table I. Details of the development, scoring, and reliability of the rubric are given in our earlier paper, including strong correlations with instructor perspectives of student epistemologies [21]. Two reviewers scored each response. There were discrepancies in 28 of 166 items and each of these was only a single point. The average rubric score on the pretest for the four classes originally reported was 1.37 with 95% of the scores being 1 or 2 and only 2% being 4 or 5. The average post-test score was 3.90 with 11% of the scores being 1 or 2 and 69% being 4 or 5. Only matched data were included, which corresponds to 85% of students for a total N of 83. Since publishing those results from these four different summer classes of students, we have had essentially the same results from three additional summer classes totaling 56 more students and two other instructors.

B. Pretest results: Immersion program

The science course in astrophysics was the first academic experience for the preservice teacher summer immersion participants (referred to in this paper as ‘‘participants’’ in contrast to the ‘‘students’’ of the previous study). After some brief introductions, the participants completed the same pretest as the summer program students shown in Fig. 1. Responses are summarized in Table II. The answers of these college graduates on the cusp of being science teachers are nearly indistinguishable from the high-school summer program students. In each of the three classes, over 90% of the participants answered choice B, that Earth goes around the Sun. For the scientific arguments, the average rubric scores for each of the three classes on the pretest are also comparable to the summer program students with the score in class C somewhat higher. This higher score is consistent with the higher admissions requirements and fewer available spots that particular summer.

Which of the following do you think best approximates the relative motion of the earth and the sun?

A. The sun goes around the earth.

B. The earth goes around the sun.

C. Neither A nor B are correct.

D. I do not know.

As best as you can, provide a proper and complete scientific argument for your answer.

FIG. 1. Pretest and post-test given at the beginning and end to all students of the summer enrichment program and to all participants of the preservice immersion program.

TABLE I. Rubric used to evaluate responses to scientific argument question in Fig. 1.

Rubric score	Description
1	Student uses jargon, authority, circular reasoning, or irrelevant observations or experiments and it represents a significant part of their answer.
2	Student cites relevant observations or experiments in support of their choice, thoughts are not clearly connected, little or incorrect development of ideas or reasoning, no distinction between models is made.
3	Student refers to relevant observations or experiments but part of explanation is erroneous or problematic OR student recognizes an inability to answer the question.
4	Student cites observations or experiments distinguishing between models in a consistent way but explanation is not developed or is incomplete.
5	Student cites observations or experiments distinguishing between 2 models and supports choice with proper explanation relevant to their answer (regardless of multiple-choice response).

Of the 122 participants, 85 responses were scored by the rubric as 1, 21 as 2, nine as 3, six as 4, and one as 5. There was great variety in the substance, detail, and style in what the participants wrote. Representative responses along with rubric scores are given in Table III.

A majority of these soon-to-be teachers used the same flawed reasoning as the high-school students in the enrichment program. Ann [24] made reference to the Sun rising in the east and setting in the west. Betty made reference to what Copernicus, Galileo, and NASA did without a single relevant observation or line of reasoning. Chris's explanation is summed up with the nonreasoning ‘‘the Earth goes around the Sun because it is mobile and the Sun is stationary.’’ Don used jargon as a form of circular reasoning.

TABLE II. Pretest data for percentage of preservice immersion participants' answers for each possible response to question in Fig. 1 and rubric scores for class. (MC refers to multiple choice.)

	MC response A	MC response B	MC response C	MC response D	Average rubric response	Percent scored 1 or 2	Percent scored 4 or 5
Class A ($N = 36$)	0	94%	6%	0	1.19	94%	0%
Class B ($N = 60$)	7%	90%	3%	0	1.47	85%	5%
Class C ($N = 26$)	0	100%	0	0	2.00	81%	15%

Thirty-nine participants made explicit reference to the seasons even though the seasons can be accounted for simply in either the geocentric or heliocentric model. Fifty-six made some kind of reference to gravity, but the nature of these answers varied enormously. Those citing gravity with a lower rubric score such as Eve were very incomplete or integrated nonscientific or erroneous reasoning. Those with higher rubric scores such as Lance provided stronger explanations of Newton's laws accounting for the smaller object moving more than the larger object when there is a force between the two objects. As indicated by the distribution of rubric scores and as

TABLE III. Sample full verbatim pretest responses to "proper and complete scientific argument" question in Fig. 1. A, B, C, and D refer to multiple-choice response given.

Name	Participant response	Rubric score
Ann	B. While it was first proposed that we lived in a geocentric universe (earth centered) it was later discovered that it is sun centered, heliocentric. We know that the Earth revolves around the sun using day length and seasons as evidence. We can use the sun's position as evidence—the sun rises in the east & sets in the west (northern hemisphere) indicating that it is in fact, heliocentric.	1
Betty	B. A long time ago, it was assumed that the earth was the center of the galaxy. However, scientists like Copernicus and Galileo observed the movement of the sun via telescope. Through many documented facts, diagrams, and analysis, they discovered that the earth revolved around the sun, discounting the universally accepted hypothesis. Their conclusions have been supported by scientists throughout the ages (in addition to NASA & other space programs) leading this to be accepted fact.	1
Chris	B. The sun is a large star that is the center of our solar system. The earth and other planets rotate around the sun on pathways called orbits. Thus the earth goes around the sun because it is mobile and the sun is stationary.	1
Don	B. The solar system is a heliocentric model, meaning the sun is at the center and planets orbit around the sun.	1
Eve	B. The gravitational force of the sun keeps the earth in orbit around the sun. It takes the earth 365 days to orbit around the sun once (one complete rotation).	1
Felipe	B. The sun is the central dwarf star of the universe and the planets revolve in orbit around the sun. Copernicus and Galileo all proved theories describing and challenging the theory of the earth being the central foci of the universe. This can be seen also in the change of seasons. As the earth continues to rotate around the sun and changes its proximity to the sun. It causes differing temperatures.	1
Gail	C. You are measuring both the relative motion of the earth and sun, the speed of our sun is measured by the sun's relationship to other stars. The relative motion of the earth can be determined by how long it takes the earth to rotate around the sun.	1
Hal	B. Hypothesis: the earth orbits around the stationary sun in an elliptical fashion. The planetary system consists of the sun and of planets which orbit it. Evidence of earth's orbitation around the sun include: photographical video images—the change of seasons/the calendar year—the cycle of daytime and nighttime.	1
Irwin	B. The earth is orbiting the sun because of the gravitational force that the sun exerts on the earth. The sun is a much larger body, therefore it exerts a larger gravitational force on the earth, a smaller body.	2
Jill	B. The sun is exponentially larger than the earth—gravity would be our first clue that earth orbits the sun. The earth is drawn to the sun, and the large mass. Also, seasonal patterns make the most sense (are best explained) and can further prove this by the tilting & rotation of the earth around the sun.	2
Ken	B. I suppose there are a couple of scientific arguments, though I don't really know what would be considered "proper."	3
Lance	B. Due to the relative masses and distance between the Sun and the Earth, the Earth orbits the Sun. This is the result of the sun's gravitational pull on the Earth. The sun has a much greater mass than the earth and this is what causes the earth to orbit the sun rather than the sun orbit the earth.	4

exemplified in Table III, poor reasoning is common among the preservice teacher participants.

After the participants completed and submitted the written pretests, the class as a whole was given the opportunity to discuss their multiple-choice responses and scientific arguments. This discussion reflected the same answers provided on the written pretest, even as the conversation unfolded. Eventually, participants recognized that answers based on jargon, authority, day or night, etc. did not constitute a sound scientific argument. They then came to understand that observations such as the seasons which can easily be accounted for in either model were not a good foundation for an answer. Even for those who attempted to incorporate gravity in their argument, there was clarity that basing a full scientific argument on it was nontrivial. For example, many based their answer entirely on the Sun exerting a larger force on Earth than Earth exerts on the Sun, in violation of Newton's third law. Regardless, there were no participants who were able to give any evidence that the Sun was large compared to Earth.

C. Instruction: Immersion program

Difficulties understanding topics in basic astronomy are well documented [25–28]. However, previous research has focused on conceptual ideas, such as causes for the seasons, the phases of the moon, and night and day. These studies looked at the extent to which students identify the scientifically accepted community consensus reasons for these phenomena. However, little has been studied as to the extent to which students can execute the *reasoning* involved in how what is known can be justified, which is the focus of our research. Regardless, understanding the conceptual difficulties has led to the development of curriculum that helps students understand these astronomical ideas [29,30], which we have used. As described below, these curricula support students practicing the requisite scientific reasoning.

Also well documented are student conceptual difficulties with force and motion [31,32], including thinking motion implies force [33] and that forces of two interacting bodies are not equal [34]. We have also employed instructional strategies based on this research [20,35].

The astrophysics course for the immersion program met for two weeks in June, 4.5 days each week for approximately 6 hours per day. During this time, the nature of science was practiced in context and discussed explicitly. With some curricula and methods also covered, the time spent on the astrophysics activities was considerably less than what was spent during the summer enrichment program described above.

As with the summer enrichment program, both the instructional philosophy [36] and curriculum employed in the observational astronomy part of the course was largely from the Astronomy by Sight module of *Physics by Inquiry* [30]. Subject matter included daily motion of the Sun, size and shape of Earth, phases of the moon, daily and annual motion of the stars, and motion of the planets. Other implementations with similar curricula or approaches (including our summer enrichment program) have resulted in improved dispositions and attitudes about the nature of science [37–39].

Throughout, the emphasis was on the process of science rather than the presentation of facts. Participants actively made observations and used these observations to construct and develop multiple scientific models of the Universe. After making shadow plots of the Sun, participants experimented with a flashlight and nail and reasoned how they can account for the daily relative motion of the Sun. After making and sharing observations of the Moon, participants observed the appearance of a ball near an illuminated bulb in an otherwise dark room. Motion of the stars and planets was explored in a similar spirit. Throughout, participants were not given answers. Instead, they were guided to develop ways in which they could account for their observations and were constantly asked to justify, explain, reason, and interpret.

Participants experimented and reasoned and came to recognize that they can account for most of their observations in multiple ways. In particular, they focused on Earth spinning about an axis while revolving around the Sun and by thinking of the Sun and other celestial objects all revolving around a stationary Earth in a particular coordinated way. They were never asked the pretest question directly during class, but they were asked to account for relevant observations. They typically recognized that there was more than one way to do so, although with the Earth-centered accounting of planetary motion becoming more cumbersome.

In addition to the observational astronomy, participants explored Newton's laws of motion in a similar inquiry-based spirit. Included was a development of an understanding of gravity and the relationship between force and motion for circular motion and its relevance to what was explored in the program. Near the end of the course, but prior to the post-test, the instructor led a discussion on important relevant historical observations such as retrograde motion, phases of the planets, and the moons of Jupiter. Participants did not have the opportunity to explore these topics in the same inquiry spirit, but this conversation was rich given that there was now an appreciation of the relevant inquiry approaches. Participants were guided to making relevant connections of the relative motion of Earth and the Sun on their own. Implications were never stated outright.

D. Qualitative observations: Immersion program

Because of the nature of the course and the disposition of the instructor, the classroom atmosphere was lively and interactive. There was opportunity to get to know the students well, through both direct discussions and the

TABLE IV. Post-test data for percentage of preservice immersion participants' answers for each possible response to question in Fig. 1 and rubric scores for class.

	MC response A	MC response B	MC response C	MC response D	Average rubric response	Percent scored 1 or 2	Percent scored 4 or 5
Class A ($N = 36$)	0	56%	0%	36%	3.33	17%	58%
Class B ($N = 60$)	3%	50%	2%	42%	3.38	20%	53%
Class C ($N = 26$)	0	46%	4%	50%	4.54	0%	81%

inquiry-based classroom interactions. Participants were encouraged to question, challenge, and discuss.

Although there were no recordings of classroom discourse taken, there were several consistent patterns in all of the classes. First, participants recognized their confusion with the seemingly simple pretest question and were engaged in exploring a meaningful answer with authentic reasoning. They often stated this explicitly. With the instructor, they also unpacked the diversity of responses described above until there was recognition of which ones were vague and which ones did not explain that Earth goes around the Sun.

Early in the course, participants readily admitted to having believed that a science lesson was a body of information to be provided and written down. They recognized this as they adjusted to the instructor prodding them into figuring things out for themselves instead of just telling them answers. For example, in the first few days, there were many who explicitly asked what the answer to the pretest question was. By the end, groups had rich discussions without the instructor detailing which observations could be more easily accounted for in the two different models.

As the course progressed, most participants grew increasingly comfortable with the nature of the class. Their skills with working with each other to answer their own questions increased. After repeated practice, they learned the difference between knowing something because they had been told it to be true and knowing something because they understand (and have often executed) the steps that underlie the idea. By the end of the course such practices were much more self-directed.

E. Post-test results: Immersion program

At the end of the astrophysics course, the identical question shown in Fig. 1 was included on the final exam. Participant-written explanations were evaluated with the same rubric in Table I. Post-test results for each of the three classes are shown in Table IV, which are matched to the data presented in Table II.

Comparing Table II with Table IV, there is a significant shift in responses to the multiple-choice question between pretest and post-test. This improvement is across all three classes, despite the slightly different populations. On the pretest, 93% of the participants selected choice B, that Earth went around the Sun. On the post-test, 51% selected choice B while 42% selected choice D, "I do not know." However, as represented in Table V and described below, these "I do not know" answers are often substantiated with sound scientific arguments. Apparently having a class of teacher candidates begin a program stating that Earth goes around the Sun and leave the program stating that they do not know what goes around what has its merits. It was clear from working with these individuals that they all recognized that the scientific community consensus is that the Sun goes around Earth. Nevertheless, upon finishing the program, regardless of multiple-choice response selected, there was significantly improved scientific reasoning. The diversity of answers and explanations also suggests that participants were not coached into a specific answer via the curricula.

Of the 122 post-test rubric scores, there were four responses scored by the rubric as 1, 14 as 2, thirty as 3, 47 as 4, and 27 as 5. The rubric score average for the pretest was 1.50 with 87% of the scores being 1 or 2 and 6% of the scores being 4 or 5, and for the post-test it was 3.65 with 15% scored 1 or 2 and 61% scored 4 or 5. The overall shift in rubric scores from pretest to post-test is shown in Fig. 2.

Table V highlights representative matched participant responses along with the rubric scores. Like most of the students who selected "I do not know," Min and Nora noted that all of the observations that they had made could be accounted for either way. Min made no reference to anything differentiating the quality of the two models. Nora made an allusion to the heliocentric model being "simpler," but did not find the simplicity to be compelling enough to prefer it. There were others who selected choice D, citing Newton's laws, planetary observations, and other relevant references, but also stating that these

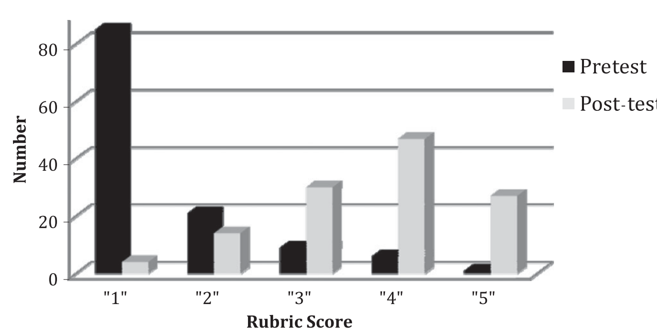

FIG. 2. Distribution of rubric scores for preservice immersion participants on the pretest and post-test ($N = 122$).

TABLE V. Sample full verbatim matched responses to "proper and complete scientific argument" question in Fig. 1. A, B, C, and D refer to multiple-choice response given.

Name	Pretest response	Rubric score	Post-test response	Rubric score
Min	B. There is an elliptical orbit of the earth around the sun. Evidence of this can be seen in changes of seasons	1	D. is my answer because the observations and inferences made in class do not support either A or B singly as the answer. All of the observations of the sun, moon, stars, Polaris and even the planets can be supported using models of the sun going around the earth or the earth going around the sun. Since both A and B can be prove via earthly observations neither best approximates the motion of the earth & sun. Nor does either least approximate the motion.	4
Nora	B. All of the planets rotate around the sun, allowing us to experience the changes associated with the seasons (i.e. daylength). One complete rotation is one year	1	D. Through the observations and models that we created as a class, we do not know which body is still and which is orbiting. Just b/c the heliocentric model is simpler to recreate it does not necessarily mean it is correct. Each observation we made of the daily motions of the celestial bodies can be accounted for by having the sun go around the earth or by having the earth go around the sun.	4
Ollie	B. The solar system, as its name illustrates, operates by planets orbiting around the sun.	1	B. The collected evidence in these two weeks suggest that either model, the earth goes around the sun or vice versa, justify our observations. That is the trajectory of the sun, east to west, the trajectory of the moon, east to west also, the latitude of the sun in respect to the earth. However, it's far more complicated to build a model in which the sun goes around the earth and perhaps the greatest reason is newton's second law which talks about the force applied to an object is directly proportional to its mass times its acceleration $F = ma$. With that being said, our observations have shown that smaller objects follow a circle path around bigger objects. We also observe newton's laws in planets and their moons. For this reason, it's plausible to think that the earth, which is much more smaller than the sun according to our observations, goes around the sun rather than the sun going around the earth. We see this pattern in the universe, smaller objects going around bigger ones	4
Paul	A. From our position here on earth the sun is rotating around us. We observe its motion starting on the horizon in the east in the morning and travelling to the western horizon in the evening. From our frame of reference with respect to the sun alone, the earth is motionless.	2	B. If we only use our observations of the sun, moon, stars and planets we can develop several models to explain the sun's motion. Two of these are the earth-centered (the earth is relatively motionless and the sun, moon, stars and planets are revolving around it) and the sun-centered (the sun is relatively motionless and the earth rotates on its axis with the moon orbiting the earth and the stars fixed a long distance away). Combining these 2 models with Newton's 4 laws dealing with forces, motion, acceleration and mass and the observation of Jupiter's small massed moons orbiting the larger massed planet we can conclude smaller masses orbit larger massed objects. Calculating the mass of the sun with respect to the mass of the earth (based on large distance to sun and still large size observed on earth), we can calculate the mass of the sun being much greater than the mass of the earth. Therefore the best model to explain this is the earth rotates around its axis (which creates the sun, moon, stars and planet motion) and revolves around the sun.	5

observations were not convincing enough to prefer one model to the other. The pretest responses of Min and Nora suggest that they have the capacity to parrot the community consensus answer to the question. Their post-test responses suggest that after the two-week course they acquired the much-needed additional perspective of what constitutes a scientific argument.

Ollie and Paul selected choice B on the post-test. Both identified that most observations can be accounted for either by thinking of Earth going around the Sun or by thinking of the Sun going around Earth. Both then used Newton's laws as an argument for why it makes more sense to think that Earth is going around the Sun since Earth is much smaller than the Sun. Paul makes explicit reference to a classroom activity as to how it was determined that the Sun is much bigger than Earth. Ollie and Paul correlated a Newton's laws explanation of small things going around big things with astronomical observations of small things going around big things (such as the moons of Jupiter). Others selecting choice B referenced the complicated nature of describing planetary motion or that planets appear closer to Earth at some times more than at other times.

Table V exemplifies how Min, Nora, Ollie, and Paul showed significantly improved reasoning after the astronomy course. Of the 122 participants who completed the pretest and post-test, 58 had a gain in their rubric score of 3 or 4, and another 29 had a gain of 2.

F. Participant evaluations

At the end of the astrophysics course, participants completed an anonymous survey specific to the astrophysics course. They were asked to rate from one to five how effective they felt the activities were in "helping you to prepare to be a science teacher," with five being "extremely helpful." Despite the fact that most participants knew that they would be teaching little if any astronomy, the average participant response was 4.77 with over 80% rating it 5.

Written comments about the class were also overwhelmingly encouraging. "I thought it was very helpful to have us engage in scientific inquiry as students to help us as a teacher." "I really liked the astronomy activities. It made me question the way I learn about things and the way that I might be able to teach effectively." "I found the basic science inquiry learning lessons very helpful because it changed my perspective on teaching." "It was a useful inquiry for both the content, but especially the methods." "The hands-on astronomy activities were of most value because they implemented the pedagogy we were learning." "Great course as a transition to becoming a teacher." "I enjoyed and appreciated that we derived every concept we learned about through experimentation. These types of activities were hardly used in my prior science education in high school or college." "The astronomy activities were most useful for me. They opened my eyes to the process of learning science, and what it means." "Science learning method absolutely focused me on teaching reasoning and scientific reasoning that can be modified to all ages."

G. Follow-up

Anecdotally, observations of participants subsequent to the immersion program are encouraging. For approximately 2–3 years after their first summer, participants continued to work with us as they gained classroom experience and obtained their degrees or certifications. As part of this process, we observed them in their classrooms, particularly in their first term. Quantitative data relevant to this paper are difficult to collect and interpret given struggles all first year teachers have teaching in New York City. Comparisons with nonimmersion program teacher candidates are also difficult given the very different demographics between immersion and nonimmersion teacher candidates. Nevertheless, those with experience observing New York City teaching candidates describe immersion program graduates as strong with respect to creating an inquiry-oriented science classroom. This is based on explicit conversations of those who have worked with scientific teacher candidates at our college from the Teaching Fellows program and not from the Teaching Fellows program.

As part of a long-term follow-up, four immersion program graduates agreed to provide feedback reflecting back on their experience with the astrophysics course described in this paper. We wanted to know more about the extent to which the course impacted their relevant perspectives as teachers. These were individuals with whom there was continued communication after graduation and were therefore not a random selection. Nevertheless, based on our communication with program graduates over the years, we believe that their answers are representative of many.

All four had successfully graduated with a master's degree and had at least two years teaching experience in the public school classroom. They were asked specifically to reflect on how the astrophysics course described in this paper affected their perspectives on scientific reasoning, their perspectives on science and inquiry, their perspectives on teaching science, and their classroom practice.

Amy was primarily an 11th and 12th grade physics teacher. She described her approach as trying to make instruction "engaging" and "relevant" using "hands on and inquiry activities." Reflecting on the astrophysics course, she stated "It was the first opportunity I had to do inquiry myself. It was a career practice-altering event." "(It) changed the way I saw physics could be taught. I did not know how to construct productive inquiry activities with my students and was unsure of their value and/or validity before that course. It really made me do a 360 from a traditional idea of physics teaching to a much more student-centered approach." "It permanently affected my practice making it more inquiry and constructivist based." "I took away a changed perspective of how knowledge could be developed and that it was a personal, more lasting method."

Bea was a middle-school general and Earth science teacher. She preferred "guided inquiry and project-based learning." Bea said the astrophysics course made her see science as "more challenging than simply memorizing definitions and formulas." Like Amy, she contrasted the way she learned with previous courses in science. "I realized that most of my previous education in science was inadequate because there was so little inquiry involved. I began to think of real science as doing science, as opposed to simply reading about it, or copying endless notes." However, as a teacher she described this as good and bad. "I realized I shouldn't be standing in front of a room pontificating all day. This was both a relief and a dilemma. A relief because I had had nightmares of droning on about the Krebs Cycle all day to semi-comatose twelve year olds for the rest of my life, and a dilemma because it was so ingrained in me from my own education that it was difficult to not fall back on it, especially when classroom management became an issue." She also commented on teaching the way she learned astrophysics was not always supported. "The Principal was unhappy with the amount of time spent in the lab in place of note-taking and vocabulary drills. For (him), science was only a body of facts to be memorized long enough to score well on an exam."

Carrie was an Earth science teacher in grades 10 and 11. She would try to teach where "students can figure out the science concepts through hands-on labs and inquiry-based activities." Her comments about the astrophysics course mirrored those of Amy and Bea. "It changed my perspective because for once in my life I had to solve the problem to figure out the answer, concept instead of being told the answer through lectures and readings ... I feel this was the first time where I actually learned and truly understood the content." In describing the impact of the astrophysics course on her own teaching, she described "making inquiry-based labs where the students really have to solve problems" and "creating lessons where students can ask questions and solve those questions themselves."

Drew taught primarily 10th grade biology. He described his teaching as "mostly teacher-driven, with regular opportunities for student-inquiry in a guided structure." In describing the astrophysics course, he stated that, "The stress placed on the use of directly observed evidence to predict and explain natural phenomenon as opposed to reliance on hearsay, jargon, or facts reminded me of the reason why science is such an important and powerful tool in society." He focused on inquiry and science. "This course greatly affected my belief that inquiry is important and convinced me that it is likely the most important skill that scientists use when they perform their research. After this class I was convinced that inquiry was one of the hallmark traits of science that makes it stand apart from other disciplines ... This class introduced me to a way to teach scientific inquiry in the classroom, and provided an excellent example of how to go about conducting a class through guided-inquiry. It made me much more aware of the importance of teaching the skills of scientific inquiry as opposed to simply teaching the content of science." Even as a biology teacher, Drew described the positive effect of the astrophysics course on his teaching. "I have tried to apply the lessons learned about the importance of direct observation, the use of evidence and the use of logical reasoning to explain and predict natural phenomenon in my classes. I am constantly seeking to find ways to include more inquiry in my classroom and to more fully develop the inquiry skills of my students... The fact that I believe in this approach to instruction, as opposed to a content-driven approach is a direct result of this class. Without seeing such a great example of what guided-inquiry instruction could look like, all further instruction in inquiry would likely have seemed like faddish educational jargon that was not truly applicable to a classroom."

IV. IMPLICATIONS AND CONCLUSIONS

One of the outcomes of this study is evidence that giving future teachers the opportunity to participate in learning science where scientific reasoning is emphasized in context can result in improved skills with reasoning. We found that the reasoning transcended the topic being learned and translated to the way teachers describe their classroom practice. Aspiring science teachers have mixed science background and the propensity to teach as they have been taught. Therefore, an approach such as the one taken in the science course described in this paper can be invaluable.

Ideally, future teachers would participate in exemplary learning of science at all of their educational levels, but this is not always possible. It is therefore encouraging that the program described in this study was successful even at the graduate level. At City College of New York, like at many institutions, the majority of science teachers first begin their preparation to become teachers at the graduate level having already completed most of their formal science studies. Our results suggest that learning of science content in a way that models exemplary practice can be an important part of immersion into teaching science effectively.

Our results suggest that even science teacher candidates with strong training in the subject area have modest scientific reasoning skills as interpreted in a specific context. Our results also suggest that there is opportunity to develop these skills through practice and reflection with curricula such as described in this paper. Furthermore, teachers gain perspective as to how this should impact their own teaching.

A future thread of our work will be trying to understand and improve the connection between what is presented in this paper and in-service teacher classroom practice. How do teachers translate the reasoning skills that they have developed in this astrophysics course to the way they teach their students in their subject areas? How can they navigate challenges such as standardized testing, curriculum mandates, teacher evaluations, and their own students' epistemologies? One of our goals is to have teachers successfully implement the scientific reasoning skills they have developed with the students that they teach in their science classes.

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