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Developing Inquiry-Based Homework Assignments with Astrobites

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Abstract

The majority of physics and astronomy undergraduate major classes are structured around problem sets, an approach that does not typically make it possible for students to learn in an inquiry-based manner analogous to how scientists conduct research. One of the reasons professors often do not attempt an inquiry approach is the lack of educational tools needed to facilitate this method of learning. In this work, I describe how Astrobites — a website run by astronomy graduate students with the goal of making the latest research more accessible to undergraduates — is ideally suited to serve as an educational tool that can make problem sets more inquiry-based. I discuss how I designed inquiry-based problem sets that make use of Astrobites for several different astronomy classes that target physics and astronomy majors. I also present strategies for implementing such assignments based on assessment from the students, and provide example problem sets that received good student feedback. These assignments are intended to complement traditional problem sets, thereby inclusively providing an alternate way for students to take interest and engage in their homework for the class.

Keywords: assessment, astrobites, homework, inquiry, physics, astronomy

1. Introduction

It is common for courses in undergraduate physics and astronomy major programs in the United States to have students take a series of core courses that usually follow a similar format. In such courses, professors task students to complete weekly problem sets and take one or more exams. Both the problem sets and exams tend to focus on applying mathematical-based techniques towards solving simple problems related to the foundations of physics and astronomy. With this lack of variety, the skills students learn are limited. While solving the types of mathematically-oriented problems that are featured in typical problem sets is one skill often needed to conduct research, it is far from the only one.

In addition to mathematical work, research in physics and astronomy also "frequently involves hands-on laboratory work, measurements, programming, data analysis, and using specialized software" (Leak et al., 2017). Besides the problem solving skill of designing mathematical models that is typical in undergraduate problem sets, other problem solving skills that routinely arise in research are "troubleshooting, interpreting findings, assessing quality, or weighing multiple options" (Leak et al., 2017). One frequent strategy associated with any of these types of skills is to read existing research papers in search of a direct answer or insight that can be helpful for solving the problem.

Despite its importance, the development of the ability to read research papers in physics and astronomy is rarely taught in undergraduate courses or even at the graduate level. Rather, students are expected to learn how to read research papers in an informal manner as they are introduced to the process of conducting research. Without formal guidance, research papers can be quite intimidating and potentially serve as a barrier to entry to those interested in pursuing an academic career.

Interested in filling this void, we sought to incorporate learning how to read research papers into undergraduate classes using Astrobites (https://astrobites.org/), a graduate student-run website dedicated to making the latest research in astronomy more accessible to undergraduates. The graduate student authors of Astrobites write daily paper summaries of recent research papers, each of which is called an "Astrobite." Beyond the website itself, a group of Astrobite authors have also set up the groundwork for Astrobites to be used in undergraduate or graduate courses through a few different methods, including having students write their own Astrobites or having them answer sets of guiding questions associated with a particular Astrobite (Sanders et al., 2012; 2017). As an extension of those various approaches, papers that have been covered on the Astrobites website are ideally suited for teaching undergraduates how to read research papers because the associated Astrobite gives them a means to help understand the paper.

In addition to using Astrobites, we also sought to incorporate principles of the inquiry model developed and taught by the Institute for Science and Engineer Educators (ISEE) through their Professional Development Program (PDP). A core idea of learning through scientific inquiry is to have students learn in the same way scientists conduct research. With this approach, students also have the opportunity to develop other non-mathematical-based problem solving skills beyond just learning how to read research papers.

In this article, we discuss how we implemented homework (HW) assignments in a few different undergraduate astronomy major courses at the University of Arizona that make use of the inquiry model and incorporate Astrobites as an educational tool to help students learn how to read research papers. In Section 2, we explain how we developed the model for our homework assignments based on the ISEE PDP inquiry model. In Section 3, we discuss example homework assignments provided in Appendix A that we perceived to be successful. In Section 4, we go over recommendations for how to implement these assignments based on what worked well for us, what did not work well, and other facets we would have liked to test out but did not have the opportunity to do so. In Section 5, we summarize the main points we would like instructors to take away from the article.

2. Homework assignment design

2.1 ISEE PDP inquiry model

2.1.1 Inquiry activity components

The ISEE PDP inquiry model features five components:

1. Introduction,
2. Raising Questions,
3. Investigation,
4. Culminating Assessment Task, and
5. Synthesis.

In the Introduction segment, the facilitators present the topic and learning goals, broadly how the activity is structured, and how learners can expect to participate and learn.

In the Raising Questions segment, the facilitators provide a means for motivating learners to ask questions to determine what they do not know and what they want to learn.

In the Investigation segment, the facilitators provide a means for the learners to investigate and answer the questions they want to explore.

In the Culminating Assessment Task (CAT) segment, learners have the opportunity to explain what they learned, ideally to the facilitators and their peers, such as through the form of a presentation.

In the Synthesis segment, facilitators wrap up the activity by summarizing the key points of what learners were expected to learn, highlighting misconceptions that may have arisen during the CAT or any part of the activity, and discussing the successes and difficulties of conducting the investigation.

2.1.2 Inquiry design elements

Besides the five components in the previous section, the ISEE PDP model also includes several elements that should be directly integrated into the design process and should not be described vaguely or treated as an afterthought. These elements include

1. Content learning outcome,
2. Practice learning outcome,
3. Equity & inclusion approach, and
4. Assessment

The content learning outcome refers to the scientific knowledge the activity is intended to teach to participating learners. This outcome should be rephrased as a content prompt, which facilitators convey to the learners as the primary broad task for them to complete during the activity. The broad outcome should also be subdivided into more specific dimensions of content that facilitators can use as indicators for determining whether the learners understand the content learning outcome by the end of the activity.

The practice learning outcome refers to the core scientific research practice(s) the activity is intended to teach to participating learners. Like the content learning outcome, it should be subdivided into more specific dimensions that facilitators can use to monitor whether learners have developed these skills. When incorporating this element into the design process, facilitators should also consider the difficulties learners may have at developing these skills during the activity.

The equity & inclusion approach refers to how specific equity and inclusion focus areas are incorporated into the design and facilitation of the activity to allow all learners the opportunity to participate, in particular those from marginalized or minoritized groups.

Assessment refers to how the activity provides a means for facilitators to determine whether learners understand the content learning outcome and the practice learning outcome. As part of the assessment, learners may produce an artifact to turn in to the facilitators, who can then assess the artifact through a rubric based on the dimensions of content related to the content prompt.

2.2 Astrobite inquiry HW model

2.2.1 Astrobite HW components

With the inquiry model components and design elements in mind, we designed the homework assignments to have four main sections:

1. Raising Questions,
2. Investigation,
3. Wrap-up, and
4. Feedback.

In the Raising Questions section, facilitators — the professor(s) or instructor(s) of the course — design the assignment to prompt learners — the students in the course — to read a portion of a research paper that motivates them to ask questions about the topic and the paper itself. They then write down the terms they do not understand, as well as a few questions

Part I: Read the abstract of this paper: https://arxiv.org/pdf/1707.00715.pdf
As you are reading, think about questions you have.

Afterwards, on the page to turn in…

(A) Write down any terms you didn't understand or follow.
(B) List two or three questions you had about the abstract. They could be on (a) something you want to know that wasn't mentioned, (b) what the authors are measuring, (c) how the authors are making measurements, (d) the results, (e) how this study connects to past work, or (f) what type of research will be done in the future?

Figure 1: Example Raising Question section.

they have about the abstract. Figure 1 illustrates a standard format for this section.

In the Investigation section, the assignment prompts learners to read the associated Astrobite that summarizes the research paper, which they can use to help understand the terms and questions they came up with in the Raising Questions section. The assignment also includes several guiding questions related to the Astrobite and the paper. These questions are intended to resemble more traditional homework questions and may cover (i) the background for the topic or the paper itself, (ii) a mathematical question related to the topic or, if possible, the point of the paper, or (iii) the conclusions of the paper. If chosen well, these questions should overlap with or be related to the types of questions learners came up with in the Raising Questions section, and provide perspective that may help them answer their own questions. Figure 2 illustrates an example set of such questions from the Hubble Tension assignment discussed in Section 3.1.

In the Wrap-up section, the assignment prompts learners to define at least one term and answer at least one question they had in the Raising Questions section. This section ensures that learners will have the opportunity to address what they wanted to learn in case the Investigation section did not. Moreover, learners were encouraged to consider using the rest of the paper or the internet in general to help answer their questions in the event that the Astrobite or the assigned portion of the paper did not adequately address what they wanted to know.

In the Feedback section, the assignment asks learners to give feedback so the facilitators can know if the assignment went well and how they can improve it in the future.

2.2.2 Astrobite HW design elements

We chose the content learning outcome for each homework assignment based on the material being taught in that portion of the course. We used this approach because we intended to try to fit these assignments into the existing course structure as seamlessly as possible.

The practice learning outcome for all homework assignments was to make use of resources to solve problems. Research papers are not necessarily tailored to what you want to learn, even more so for undergraduates with little to no research experience. Reading and understanding them often requires making use of other available resources. With Astrobites as an available resource, we are providing a means for learners to develop this skill needed to read research papers. This practice learning outcome also applies to other types of problem solving in research besides just reading research papers.

The equity & inclusion focus of these homework assignments is to provide multiple ways for students to productively participate. From the ISEE PDP program, "Learning environments that provide multiple ways to learn, communicate, and succeed are more likely to engage a broader range of

Part II: Read the accompanying Astrobite:
https://astrobites.org/2017/11/02/measuring-h0-with-sn-as-near-infrared-standard-candles
As you are reading, keep those questions in mind.

Afterwards, using the bite, answer the following:

(1) How are Type Ia supernovae helpful for determining the Hubble constant?
(Tips: Keep in mind Hubble's Law and the Doppler effect from the previous homework. Also, you can assume the redshifts of each supernova have already been measured.)

(2) What advantages does the J band have over the B band for determining the Hubble constant using the supernova absolute magnitudes?

(3) The distance from the Milky Way to Andromeda (M31) is 778 kpc.
(a) What is the distance (in Mpc) to the closest supernova the authors use in their sample? Compare your answer to the distance to Andromeda.
(b) What is the distance (in Mpc) to the farthest supernova the authors use in their sample? Compare your answer to the distance to Andromeda.

(4) *Extra credit*. Related to the previous question:
Why can't the authors use supernovae that are much closer to us?

(5) Do the authors of the paper think Type Ia supernovae being "bad standard candles" in the B band could be responsible for the Hubble tension? What about dust extinction?

Figure 2: Example Investigation section.

learners" (National Research Council 2000; National Research Council 2005). These assignments apply that concept by giving learners the opportunity to complete an inquiry-based assignment, which complements their usual problem sets. In Section 4.2 of this article ("Future developments"), we also discuss the possibility of adding in-class discussion groups as an extra component to these assignments to provide another way for learners to participate by letting them ask questions to and answer questions from their peers.

Another equity & inclusion focus area that the HW assignments touch upon is to address beliefs and biases about learning. From the ISEE PDP program, "One way to [project high expectations along with support for all learners' success] is to approach intelligence as a changeable, rather than fixed, trait, expressing all learners' ability to improve and build on their understandings" (Aronson et al., 2002; Dweck 2006). Having learners list the concepts from the research papers that they do not know normalizes that it is okay for any student to not know everything. It encourages them to embrace acknowledging what they do not know because they will need those gaps in knowledge to complete the assignment. This type of design greatly differs from typical problem sets that focus on having learners answer assigned problems instead of building around what they do not know or what they want to learn.

Several different sections of the assignment provide a means for facilitators to carry out assessment of the learners. The responses to the Investigation questions assess learners' general understanding of the main learning outcomes in a similar manner to a traditional homework assignment. The responses to the Wrap-up questions partially assess learners' understanding of their own learning outcomes. And ideally, the responses to the Feedback questions provide a means to assess whether learners improved on skills related to the practice learning outcome. The artifact was the turned-in assignment itself.

As part of the assessment, we informed learners about how much each section of the assignment was worth in advance. To promote the importance of the Raising Questions section and the idea of having learners embrace what they did not know, we gave this section a sizable weight even though all learners were awarded full credit simply if they completed this section. We also gave the Wrap-up section the same weight as the Raising Questions section and similarly awarded full or near-full credit in order to try not to discourage learners from attempting to answer their own more difficult questions. Similarly, we assigned the same weight to the Feedback section to encourage learners to complete that section and help with our assessment. Overall, the Investigation section — the most objective part of the assignment to grade — was only worth about half of the overall grade for the assignment.

3. Example HWs & feedback

Overall, we implemented six different homework assignments in three different astronomy major courses. The numbers of assignments given each semester are listed below:

1. ASTR 196: Astronomical Problem Solving
   (2 in Fall 2020; 1 in Fall 2021)
2. ASTR 250: Fundamentals of Astronomy
   (1 in Spring 2020; 1 in Spring 2021)
3. ASTR 300A: Dynamics in Astrophysics
   (2 in Fall 2020; 1 in Spring 2021)

We believe the three example assignments discussed in this section were the most successful. One facet we felt worked for each of these examples was how well the guiding questions in the Investigation section connected to both the research paper and the course material while still remaining solvable in relatively few steps. Full up-to-date versions of these example homeworks are provided in Appendix A.

3.1 Hubble tension

The first homework assignment we developed was for ASTR 250: Fundamentals of Astronomy, the first astronomy major course at the University of Arizona, which is mostly for second-semester freshmen and covers a wide range of topics. The topic of this assignment was the Hubble tension, the discrepancy between the values of the Hubble constant (the expansion rate of the universe) that result from two main different methods of measurement. The classes leading up to the assignment covered the distance modulus, the redshift-distance relation, and the general idea of the Hubble tension, but not the specifics behind the competing methods for measuring the Hubble constant. The content learning outcome was to better understand the supernovae method for measuring the Hubble constant.

Learners were only asked to read the abstract of the research paper. The majority of the class was already familiar with most of the jargon in the abstract, resulting in a relatively small range of terms and questions in the Raising Questions component. The lone mathematical question in the Investigation section made use of one of the figures in the Astrobite.

This assignment was the shortest duration one we developed as learners only had two days to complete the assignment. Overall, learners spent about 1.5 to 2 hours on the assignment, not much longer than the little over an hour they spent on their usual assignments. The assignment received the best feedback compared to any of the other Astrobite assignments with 26 out of 27 learners stating they would like another one of this type of assignment. Some of the positive feedback included one learner who stated that the assignment sparked their interest in reading a few more Astrobites largely separate from the assignment. The one learner who did not want another one of these assignments still acknowledged that it was helpful for improving their weaknesses.

We viewed this assignment as the most successful and the best model for future assignments in terms of the positive feedback, the performance of the learners, the simplicity of the paper choice for the learners, and the ease of creating suitable investigation questions. As we discuss in Section 4.1 ("Tips & pitfalls") though, there were various reasons why it was not straightforward to replicate this level of success in the other assignments thereafter.

3.2 Planet Nine

The first homework assignment we were able to test out twice was for ASTR 300A: Dynamics in Astrophysics, the second astronomy major course at the University of Arizona, which is mostly for first-semester juniors and focuses on dynamics in astrophysics associated with planets and galaxies, and provides an introduction to hydrodynamics. The topic of this assignment was Planet Nine, a theorized but yet-to-be-discovered ninth planet in our solar system. The classes leading up to the assignment covered basic orbital dynamics and the three basic orbital elements of semimajor axis, eccentricity, and inclination. The content learning outcomes were to apply their knowledge of those basic quantities towards mathematically-oriented problems and to introduce the argument of pericenter, one of the other three more complex orbital elements.

We administered this assignment in two different iterations of the course, the first of which was in a manner similar to regular take-home homeworks and the second of which was as an in-class homework, both of which followed the homework format in use that semester. Learners liked the assignment in both instances.

As a take-home assignment given over one week, learners spent about 3 to 4 hours on the assignment. Overall, 23 out of 28 learners gave positive feedback. Some of the positive feedback included liking the authentic nature of the assignment, giving praise for the application focus, and stating it gave meaning to what they were learning. Others liked that the assignment was different, stating it was a good break from math or made them feel better than just doing math.

As an in-class assignment for a 75-minute class, learners were tasked with completing the Raising Questions section and reading the Astrobite beforehand, completing the investigation questions in-class in two groups of three, and then finishing the write-up after class. Even though 75 minutes proved to be a relatively short amount of time for the entire investigation section, student feedback was still mostly positive.

We liked that the Investigation questions for this assignment are centered around what is effectively one main question that makes use of a few different types of equations related to orbital dynamics. We also liked that the guided question is relatively open-ended with a variety of different solution methods, another aspect that resembles actual research. We were impressed when a few learners came up with a simpler method in their solution that we had not thought of beforehand.

3.3 51 Peg b

One of the more unique homework assignments we developed differed from the others because it tasked learners with reading an entire research paper. This assignment was developed for ASTR 250 and focused on the original discovery of 51 Peg b, generally recognized as the first confirmed exoplanet. Because the 51 Peg b discovery paper is only four pages, this topic is one of the few examples of a paper where it is reasonable to have a lower-level undergraduate class read an entire paper. The classes prior to this assignment covered the variety of modern techniques for detecting exoplanets, while an earlier part of the course covered various solar system topics including the Roche limit. The content learning outcome was for learners to better understand the radial velocity method for detecting exoplanets, the method through which 51 Peg b was discovered.

The assignment was split into two parts such that learners were tasked with completing the Raising Questions section and reading the Astrobite in the first week, and then finishing the assignment in the second week. Overall, learners spent about 3.5 to 4.5 hours on the assignment, including about 1 to 1.5 hours reading the paper. Although not as well-received as the other two previous examples, 18 out of 27 students gave positive feedback, including three students who did not finish the assignment and did not leave feedback. The negative feedback mostly related to the assignment being too long. Some of the positive feedback included that the setup helped for reading the paper more in-depth and the assignment did a good job of connecting class topics to research.

Beyond our interest in being able to give learners a full research paper to read, we liked the idea of giving the first guided question in the assignment — calculate the mass of the planet 51 Peg b. Had this assignment been replaced by a regular problem set, learners would have still had to answer the same question, but with the relevant values given to them. Instead, our assignment required learners to figure out how to read the relevant values off of a plot or from a table of values in the research paper, making use of the actual published plot of the light curve.

4. Recommendations

4.1 Tips & pitfalls

While we considered the three examples in the previous section to be successful, several other assignments we designed did not work out as well. One general challenge we faced was that not all of the assignments were straightforward to design in a reasonable amount of time. Here are some specific issues we encountered and some potential solutions:

1. *Too long to complete*: After the success of our initial, relatively short two-day assignment, we attempted to design longer assignments. The two main ways we lengthened the assignments were (i) to have students read more or longer portions of the research paper, or (ii) to have more mathematical questions or more difficult mathematical questions in the Investigation section. Although students also had more time to complete these assignments, the longer completion time resulted in more negative feedback or more students not turning in the assignment. Part of the reason for that poor reception was that the majority of the class works on the assignments relatively last-minute, typically within two days from when the assignment is due, if not less.

   One of the most straightforward solutions to this issue would be to keep the assignments short.

   Another solution that may still allow for longer assignments is to split the assignment in two. Facilitators could assign an earlier due date for reading the portions of the paper and submitting the Raising Questions section, and potentially reading the associated Astrobite. Overall, we recommend that the combined amount of time learners have to complete both parts of the assignments should be one-and-a-half or two times longer than they typically get for a usual problem set. Facilitators should also convey the longer probable completion time when assigning the homework so learners know what to expect.

2. *Too many questions*: Similar to the completion time issue, assigning too many questions in the Investigation section can be an issue regardless of the time that students have to complete the assignment. Even with low difficulty, too many questions potentially made it more difficult for learners to focus on each individual question. Moreover, learners preferred having fewer mathematical questions so that they could focus on the conceptual parts of understanding the paper, noting that three separate such questions proved to be too much for many of them. Beyond the Investigation section, too many questions also discouraged learners from being interested in spending time answering their own questions from the Raising Questions section later on.

3. *Hard-to-find data values*: One feature we wanted the homework assignments to incorporate was the need for learners to look up data — either in the Astrobite or the paper itself — using plots or tables that were not specifically designed for being used in a homework assignment. This type of task is very different from typical homework problems that already include the given values or have them readily available for lookup in an obvious location such as a textbook. Nevertheless, having some difficulty in finding the data is a more authentic scenario that better resembles what occurs in actual research.

   Our intent did not work as well as we had hoped in part because we were extremely vague about when learners needed to look up data and had never told them about this type of task being a feature of these assignments. As such, we subsequently modified the homework to be less vague about needing to look up data. We also recommend letting learners know about this feature of the homework beforehand.

4. *Devising good mathematical questions*: For many papers, it is not straightforward to design mathematical questions suitable for an undergraduate problem set related to the key ideas of the paper. We had two potential workarounds to this issue, both of which involved starting with the questions that might be given if this was a regular homework assignment, such as one from a previous iteration of the course or problems from a textbook. One solution we tried was to take those "traditional" problems and adapt them for the specific topic of the paper (e.g. as was done in the 51 Peg b assignment). Another solution was to take one of those "traditional" problems and just leave it in the assignment as a separate additional problem even if it did not relate to the paper at all. Both of these strategies greatly reduced the time needed to design the assignment and were well-received by learners.

   An alternative solution to this challenge would be to not have any mathematical questions and just focus on the conceptual parts of the paper. As an in-between solution, learners could also be tasked with plotting data from the paper in lieu of using it for more mathematical purposes.

5. *Finding the right Astrobite*: Not every topic has a good Astrobite that would be suitable to use in these types of assignments. While we were able to quickly identify suitable bites for some of these assignments, we found it to be one of the most time-consuming tasks for others.

   The simplest solution is to use or adapt one of the bites or assignments provided in the examples from the previous section. Astrobites also provides lists of recommended bites on various topics to use in courses in general, albeit not for this purpose specifically (Sanders et al., 2017: p. 11).

   Another way to make it easier to find a suitable Astrobite would be to broaden the content learning outcome. We chose rather specific content learning outcomes to fit the assignments directly into their respective courses. Nonetheless, searching for an Astrobite on a very broad topic (e.g. the solar system) where the methods and conclusions of the associated paper likely do not connect well with the course material is much easier than finding an Astrobite on a very specific topic (e.g. the Kuiper Belt) where the methods (e.g. orbital dynamics) directly invoke material that is part of the course curriculum.

4.2 Future developments

We hope we have established the groundwork for others to use or design these types of assignments in their courses. Beyond what we have implemented so far, we also have suggestions for potential improvements. We did not get the opportunity to test out some of these ideas because courses were still online during the pandemic while we were implementing these assignments.

1. *Post-assignment discussion groups*: Because we only ask learners to answer a few of their questions in the Wrap-up section, the assignments likely leave at least a few, if not many, of their questions unanswered from the Raising Questions section. These unanswered questions may serve as a good basis for having students discuss the research paper and potentially the broader topic in class.

2. *Investigation discussion groups*: One major difference between these homework assignments and typical ISEE PDP inquiry activities is that group work is not integrated directly into the design. While learners may end up working on the homework together (as with any assignment), there is no such requirement and many learners may end up working primarily alone.

   As such, it may be beneficial for facilitators to organize in-class discussion groups. These groups could serve a variety of purposes such as (i) to work on the Investigation questions, (ii) to answer their questions from the Raising Questions section, like the idea for the post-assignment discussion groups, or (iii) to discuss the broader topic. These discussion groups would inherently work well with the recommendation to split the assignment in two, and would be an alternative to the post-assignment discussion groups. A standard way to organize these discussions as a component of an inquiry-based activity would be to have learners ask and answer each other's questions, with facilitators present to guide these discussions at times.

3. *Teach in tandem how to read research papers*: While there are certainly benefits to introducing learners to reading research papers in this inquiry manner, one potential disadvantage is that learners are not being taught directly how to read papers. One solution that makes use of the PDP inquiry model would be to teach how to read papers during the Synthesis component of the assignment. As the Wrap-up section of the assignment differs from having the facilitators lead the Synthesis component, facilitators could add a true Synthesis component by having a post-assignment discussion in-class in which they would provide advice for reading papers. This "practice learning outcome"-focused discussion group could be done in tandem with or in lieu of the other "content learning outcome"-focused suggested discussion groups.

4. *Gradually read more of each paper*: If a course includes more than one of these assignments, facilitators could have learners read more sections of each research paper in a logical manner. For instance, learners could progress by reading just the abstract of a paper on the first assignment, followed by reading the abstract and introduction on the second assignment, and then the abstract, introduction, and conclusion if there is a third assignment. Preparing a series of assignments in this manner would likely work better if done together with the previous idea on this list of also explaining how to read research papers.

4.3 Differences from PDP model

While the Astrobite inquiry HW model highlights some of the strengths of how we invoked the PDP model, there were other aspects of the model we left out that could potentially improve our homework model if they were included.

While we usually had a learning outcome, we did not develop a separate content prompt or specific dimensions of content as part of our design. Rather, we just conveyed to learners the general learning outcome.

Without those specific components, we did not develop any rubric beyond assigning weights to each section, and in particular did not create a rubric focused on the main dimensions of content we wanted learners to learn.

Another potential weakness was that the artifact was centered around the assigned questions. Even though we attempted to balance out the assignments by giving substantial weights to the sections outside of the Investigation, in practice, learners probably spent much more of their time working on the assigned questions than their own questions.

Lastly, while we attempted to assess the practice learning outcome through the Feedback section, we did not explicitly tailor the questions to that aspect of the assignment.

We encourage others interested in using or developing these types of assignments to consider these design aspects if they have ideas or are interested in improving these assignments.

5. Summary

We developed a new style of homework assignments centered around Astrobites and the inquiry model from the ISEE PDP with the broader goals of introducing undergraduates to research papers as part of their coursework and to add more variety to their homework assignments in general. With these goals, we hope students can go beyond using mathematical models and tools to solve problems — frequently the only research skill taught by typical homework assignments in physics and astronomy courses — and develop a broader set of skills that they can apply to conducting research.

We have already implemented these types of homework assignments in astronomy major courses at the University of Arizona with students ranging predominantly from freshmen to sophomores. We regard the better assignments provided in Appendix A as successful, while the other half of them needed improvement.

Some strategies we learned for developing better assignments were to split them into two parts and to limit the amount and length of the mathematical questions. One strategy we used to make it easier to develop mathematical questions for these assignments was to adapt them from a corresponding traditional assignment related to the topic.

We recommend trying to add discussion groups or some other type of group work to these assignments, an aspect we did not have much opportunity to test out thus far. We thought that working in teams was a major strength of the PDP inquiry model that we did not fully incorporate into the design of these assignments.

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Appendix A

Examples of homework assignments presented in the article are available as supplementary documents. The latest versions of these examples of homework assignments are also available online in a Google Doc format as follows:

A. Hubble tension
https://docs.google.com/document/d/1K78oG0ujub3jsRcefUYaTTpCdiNWpgl7sa8_BLalbxE/edit

B. Planet Nine
https://docs.google.com/document/d/1b5ge6jjRAiWF7ZAcuzpOWGsit0PQiYVvJpFqBPqFa2Y/edit

C. 51 Peg b
https://docs.google.com/document/d/1ba9JAxHmp_rX2MJe4AFqM34enQsbbnH5wxTakXh86i8/edit