# An Evidence-Based Approach Towards Teaching Astronomy Labs

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December 18, 2019

# 1 Introduction

The structure of the undergraduate astronomy labs at the University of Iowa have undergone significant changes since 2011, both from an organizational standpoint and in the format of the lab activities. The shift has been driven much in part based on research indicating the advantages of an "active learning" environment (e.g. Weimer, 2002; Gregory, 2013). Completing lab worksheets were changed from an individual to a group activity, hoping to increase collaborative discussion among students. The lab activities were also restructured to emphasize less of a "cookbook" mentality, and instead foster the idea of teaching the basic principles necessary to solve the problem and leaving students to apply these principles. The room format itself was rearranged to be a more open environment, with curved tables replacing the more cubical nature of the prior arrangement (Ludovici, 2017).

The results of these changes have been mixed, however. While the team-based approach has been an enduring feature, most of the redesigned labs have been discarded over the years, often based on negative feedback instructors received from students and graduate teaching assistants (TAs). Part of the problem with these labs was the heavy emphasis on mathematical problems, a field that many undergraduates feel uncomfortable with. Specific class discussion and collaboration problems were also explicitly lacking from most labs, more frequently (but still only occasionally) being a suggested activity for the TA to implement and without much instruction or training on doing so. The newer labs, however, have tended to shy away from exploring topics in-depth and instead have focused on answering more shallow short answer questions.

In this paper I'll seek to review the current understanding of pedagogical knowledge and how it can be used to improve the educational value of the astronomy labs here at the University of Iowa and beyond. To do so, we'll need to situate ourselves in the context of an undergraduate student, considering their present thinking strategies and the best ways for helping them think more deeply and critically about scientific material. With these in mind, we can bring current best-practices into the lab in a way that will aid in student learning outcomes.

Much of our educational goals are subjective by nature, and as an experienced graduate student who has taught the laboratory portion of *Stars, Galaxies, and Universe* (ASTR:1070) and *Exploration of the Solar System* (ASTR:1080) many times, I will lean heavily on my own personal experiences throughout this discussion. My hope is that this discussion will provide a solid foundation for those looking to expand beyond my presentation.

# 2 What Students Expect

For better or worse, the introductory astronomy courses have developed a reputation for being an easy way to meet the General Education (GE) requirements in the Natural Sciences, with students often being told by their advisors that they won't need to do math. As such, students are often resistant to doing lab assignments that require the use of mathematics to solve problems, and will often leave the most mathematically skilled student in the group to work out the problem, circumventing the point of the activity and reducing classroom participation.

The most appealing aspects of taking astronomy labs have generally been the expectation of learning to identify stars and constellations in the night sky as well as learning to use a telescope. While this is generally impossible to accommodate during the day labs, the potential exists for having observing sessions at night either on the roof of Van Allen (during so called "Clear Skies" hours) or class field trips to the Eastern Iowa Observatory. It is generally the case, however, that such opportunities are not incorporated into the lab curriculum. Even for the night labs, there is often very little use of night sky observing as the activities are only contained in a few labs that are generally taught at the beginning of the semester, and the observing content tends to occupy only a small portion of those labs. Thus a major motivating factor for student engagement is largely left unutilized at the University of Iowa.

## 3 Learning Objectives

For education to be rewarding, a teacher needs to strike a delicate balance between challenging students while not unduly burdening them with anxiety, anger, or a fear of failure. If the material is too difficult, it largely demoralizes students and facilitates a helpless attitude, which results in them spending less time engaged with the material, if not dropping out all together (Clifton et al., 2015).

One way to gauge the appropriate difficulty of a course is to situate the activities in the context of Bloom's taxonomy (Bloom et al., 1956), which was revised by Anderson and Krathwohl (2001). In their revision (Figure 1), learning objectives are broken into both a knowledge and a cognitive process dimension. Along the cognitive process dimension, the lowest learning outcome is *remembering*, followed by *understanding* and *applying*. These are followed by the higher level outcomes of *analyzing*, *evaluating*, and *creating*. The knowledge dimension moves from having *factual* knowledge, to having a better *conceptual* understanding of their interrelationships, to *procedural* which involves applying methods to perform some activity, and *metacognition* as the highest level.

Education can be viewed as a journey that moves from utilizing the lowered level cognitive and knowledge tiers towards employing the higher ordered ones. If the jump between a student's current cognitive processes and the desired outcome is too large, then students will suffer from anxiety and struggle. In the lecture portion of the course, students are tested on their factual and conceptual knowledge of the material while utilize their remembering and understanding cognitive processes. This is fairly typical for the cognitive processes of first year undergraduate students, who tend to view learning as a collection of facts and knowledge as being fixed and absolute (Forsyth and McMillan, 2006). This makes the lab portion an excellent opportunity to focus on higher level processes such as application and analysis, and pointing out the inherent uncertainty involved with astronomical measurements and knowledge.

One question often raised when deciding on the lab content is whether the labs should closely align with the lecture portion of the course or follow their own tune. In the former case, the labs are largely seen as a way to explore the lecture material in a more in-depth manner, while the latter option allows labs to independently explore content that isn't covered as much in lecture and may be of more interest to the students. These differing approaches stem from differing perspectives on what the role of a teacher should be.

Pratt (2002) identifies 5 different perspectives that shape the way we teach: transmission, development, apprenticeship, nurturing, and social reform. Transmission is the most common method in secondary and higher education and lies at the heart of the idea that labs should closely follow the lecture, as it mostly views learning as the acquiring of a specific set of knowledge. It then becomes the teacher's job to effectively pass along this knowledge in a way that aids in the internalizing of the knowledge and thinking strategies associated with it. In teaching an astronomy lab, then, the goal would be to increase students' understanding of astronomy. I lean towards a *developmental* perspective, which emphasizes the development of complex ways of reasoning and problem solving. It seeks to change the way learners think rather than increase knowledge *per se*.

One major limitation towards being a general education requirement is that non-major students don't view the material as relevant for their future study. In this they are mostly right, and the lack of engagement with the material over time will cause the knowledge they learn to gradually be lost. By focusing on the *principles* of critical thinking rather than the specific content knowledge, we can help create more well-rounded individuals who feel comfortable tackling new and unfamiliar situations and problems. This will better prepare them for tackling the problems they will face in the future. Thus astronomy labs may be of better service in helping students become better *thinkers* rather than better *astronomers*.

# 4 Learning in the Lab

## 4.1 Lab Curriculum

Nearly all of the astronomy labs begin with an introductory pre-lab quiz, which generally consist of 4 multiple-choice questions and can be used by the TA to gauge the level of student understanding. In my labs, I generally give groups about 10 minutes to work together on the quiz before going over the questions as a class. I'll ask groups to volunteer to share their answers and then probe deeper if they didn't provide an explanation for their choice in order to help them expand on their conceptual understanding rather than factual knowledge. Many groups are initially hesitant to provide answers, and especially early in the semester I've made it a habit to continue in long awkward silences until one group volunteers to share their thoughts with the class in order to increase classroom participation.

One of my favorite pre-lab questions asks whether an observer in New Zealand sees an upside down moon relative to someone in Iowa City, of which nearly every group answers "False" but without the ability to justify their answer. When going over the question as a class, I'll poll the class for their responses, then announce the correct answer ("True"), and ask my students to spend a minute or so trying to come up with a diagram that illustrates the correct answer. Most groups will then figure it out, and I'll ask for a group to go over their diagram with the class on a white board (Figure 2).

Most of the current pre-lab questions, however, tend to focus on evaluating factual knowledge. As such, many questions simply come down to whether one knows the answer or not. Adding more questions like the moon example that require a more conceptual or procedural approach to answering the question might be one way to improve the effectiveness of the quiz.

When teaching night labs, I make a concerted effort to get my students up on the roof to engage in night sky observing. Not only do students enjoy the activities, but the activities help students better grasp the connection between textbook knowledge and real observations, and even leads to increased learning outcomes in topics that aren't observationally related (Jacobi et al., 2009). Towards the end of most labs, we'll head up on the roof and use star wheels (Figure 4) to identify stars and constellations. By making repeated trips over the semester, students are able to observe how the sky changes over time and expand upon their knowledge of constellations, while also becoming better at relating a 2D representation to the 3D world (which is something many students struggle with).

Besides identifying stars and constellations, we also learn to estimate angular sizes, rise and set times, and the positions of objects in both the azimuthal and (more complicated) equatorial systems using our hands as a measuring device (Figure 3). Estimating the magnitudes of stars is another night sky activity that I've had my students do, and I've found that this activity helps students recall that larger magnitudes imply fainter objects (a rather archaic and unintuitive idea that astronomers still use) as they remember doing this activity and assigning smaller numbers to brighter objects.

When working with telescopes, our labs have tended to make their use only a minor part of the lab, where the TA would set them up, align them, and have students just look through the eyepiece. I thought this was kind of pointless, and instead wrote a lab that has students spend nearly the entire 2 hour period up on the roof learning to use telescopes. I'll go through how to use a telescope down in the room and then again on the roof to better help them better recall the important parts and avoid some of the issues that may cause troubles (such as breaking the telescope). I have my students start with the easiest object to observe and then move towards progressively harder ones. They'll begin by observing the moon, then move towards the bright planets, and conclude with the fainter double star Albireo (Figure 5).

When in the lab itself, I like to assign questions that are more conceptual in nature and involve groups coming together to work on a white board. While I've been known to be a TA who demands a lot from my students, bringing groups together helps them tackle more difficult problems that they would struggle with individually (Clifton et al., 2015), while gradually building up from the simple to complex also helps students tackle more difficult problems. When teaching about equatorial coordinates, most labs generally just have students look up the coordinates of objects on a star chart. Instead, I gradually build up the questions to get to the point where students are given the right ascension of the Crab Nebula and need to determine during which parts of the year it will be visible at midnight while drawing several diagrams illustrating their explanation (Figure 6). This question ties together many of the things they learned in the lab and helps them think deeper about the material.

Mathematical problems are another set of problems that I have students work out together on the white board. They'll generally do some sort of analysis or procedure first, such as animating several images of an asteroid and finding the angular distance it moved. Then they'll partner up with another group to calculate some quantity, like how fast the asteroid is traveling. When they come together, the values they found will often be slightly different from one another, which initially causes some concern amongst them as to what is the true answer. Over time, however, students will come to the *metacognition* stage and realize that there is always some inherent uncertainty in our measurements and results.

Besides learning to think critically, Clifton et al. (2015) identifies learning to speak well as one of the desired educational outcomes. Public speaking is one aspect that I wish the astronomy labs placed more of an emphasis on, which is something our graduate courses have shifted towards. One place where I bring this into the classroom is in our *Active Learning* lab, where students are asked to pick a free response question and answer it. Rather than have students simply write down what they learned on the worksheet, I have my students come up to the front of the class, introduce themselves, and tell the class what they learned about their question (each group is assigned a different one). One other area that allows for students to practice their presentation skills is usually during our last lab, which is often a group presentation about either their research project results or a presentation about a spacecraft. Generally, I find the latter to have greater educational value as students speak longer and seem to be more interested in the material. Having an additional presentation around mid-semester about something space related might be one avenue to explore.

A recent change to the curriculum was the introduction of a research project, where a group works together to create a simple data product (e.g. photometric light curve, tri-color image) and perform some calculation based on it. Students would then need to write a paper that introduces their object of study, outlines the procedure they used to generate their data product, and explains how they went about doing their calculation. This semester, I took a different route than in past semesters. I had students write their papers as a group rather than individually, submit a draft version, then randomly assigned each student to *evaluate* another group's paper. I went through the basics of peer review with my students, encouraging them to identify the parts they found most effective and least effective in each section and explain why they thought this. While this activity involved both team-based work and active learning through the peer review process, it didn't have the success that I hoped it would. Most groups, despite having good feedback, didn't bother to address the comments (those that did, however, got close to 100%). Making it a group activity also seemed to just cause students to put less effort into the assignment. Thus simply implementing "best practices" doesn't always immediately lead to improved performance.

## 4.2 Social Aspects

Besides the course content, there are several social and motivational aspects that play an important role in fostering learning. Students are more motivated to learn when they feel welcomed, treated as individuals, able to fully participate, and are treated fairly (Chism, 2002), while "breaking the ice" early helps to foster greater communication and participation levels (Billson and Tiberius, 1991). In my labs, I make it a habit to learn the names of all my students, going around each week and asking for names as I take attendance. As I become more familiar with them, I'll start addressing them by name as I stop by and return the worksheet they handed in the prior week. Two additional areas that help teachers connect with students are engaging in small talk and opening up about oneself. As an introvert, these are two areas that I struggle with, but could be a way towards establishing a stronger connection with my students and making them feel more welcomed and myself more approachable.

Besides learning the names of my students, it helps students to become more familiar with one another. One common piece of advice that I received was to begin the first lab by going around the room and having the students introduce themselves, such as stating their name, major, and why they are taking this course or to state something they find interesting about astronomy. I found this advice to be rather useless in practice, however. I didn't retain the information, it took a while to get through everyone, and most students simply stated they signed up for the lab to fulfill their general education requirement. To counteract this, I changed the process from being a class discussion to a group-based one, where I give students a minute or two to introduce themselves to their group members. The result has been that students are more engaged with small-talk during the discussion time and become more familiar with one another. This strategy favors the one outlined by Billson and Tiberius (1991), who argue that students participate more readily in subgroups than with the whole class. About a third of the way through the semester I'll switch up the groups, trying to make sure everyone has new partners. In classes where I haven't shuffled the groups, students largely only come to know those in their group. When switching up the groups a couple times throughout the semester, and having groups work together at times, nearly everyone knows everyone else by the end, and groups reaching out to other groups for help or to work together becomes a lot more common.

Billson and Tiberius (1991) also stress the importance of being a good role model, including content that you find interesting, and providing prompt feedback. I try to show up 10 minutes before lab begins and to start on time. During the lab, I'll walk around to each of the groups and check their understanding and progress. While I make it a habit to return the prior week's worksheet at the start of lab, I've found this to sometimes have too late of an impact. Sometimes groups would fail to correctly answer some of the problems (often the math-based ones) and never seek out help. Reflecting on this, I decided to require that many of the problems that students struggle with be done on a white board, often working with another group to solve the problem. Once complete, they would need to go over their work with me and I would give them a stamp of completion in their worksheet. Having students work on the white boards also seemed to help with participation levels, as everyone could see the work and it wasn't just the scribe writing down all the steps while their partners sit idly by, while also increasing cooperation among groups. One potential drawback to this method is that groups often wouldn't write down their work in their packet afterwards, and thus if they needed the information in the future it wouldn't be readily available.

When writing my versions of the lab, I try to include content that I find interesting and either revise the way difficult problems are done or replace them all together. When we are first learning how to use a star wheel and identify constellations, I include aspects of mythology in the worksheets, talking about things such as the Pleiades and the *Epic of Gilgamesh* (which likely drew much of its inspiration from the constellations Orion and Taurus). I have also made it a task to expose my students to starlore from other cultures, such as *Biboonkeonini* (The Wintermaker) from the Ojibwe and *Maui's Hook* from Polynesian starlore (famous from the movie, *Moana*). One possibility that I could explore would be to build in some assessments to gauge what topics interests students.

Besides covering interesting topics, Forsyth and McMillan (2006) recommend introducing the material in an interesting, informative, and challenging way. When it comes to pre-lab quizzes, I'll often include graphics and point out some interesting facts related to the questions. Overall, however, providing some engaging hook to draw the students into the material is not something that I consistently practice. The most relevant case deals with our *Image Analysis 1* lab, which focuses on creating tri-color images and calculating the sizes of various objects. To introduce the material, I provide a general background of how our eyes work and how our mind processes the information to create color images (or fails to in the case of colorblindness), and then tie this into how astronomers recreate color images using filters. Putting a greater emphasis on introducing the material at the start of lab may help students become more engaged with the lab material, and less inclined towards just trying to rush through the content to finish the lab.

# 5 Conclusion

When it comes to teaching and learning, students should find the material important, challenging, and be able to perform competently. As non-major undergraduates, the specific topics taught in the labs are unlikely to cover material that will be relevant towards their long term goals, but by focusing on higher ordered thinking processes in an engaging manner we can expand their critical thinking skills and increase their interest and enthusiasm in the class. Classes can be made more challenging in a constructive manner by progressing from simple to complex problems, while having students work together to answer problems on white boards allows for immediate feedback from a TA. Besides content, there are many social and motivational aspects that can help students succeed. Establishing a welcoming climate helps students feel like they belong, and goes a long way towards allowing them to have a successful and engaging time in the class.

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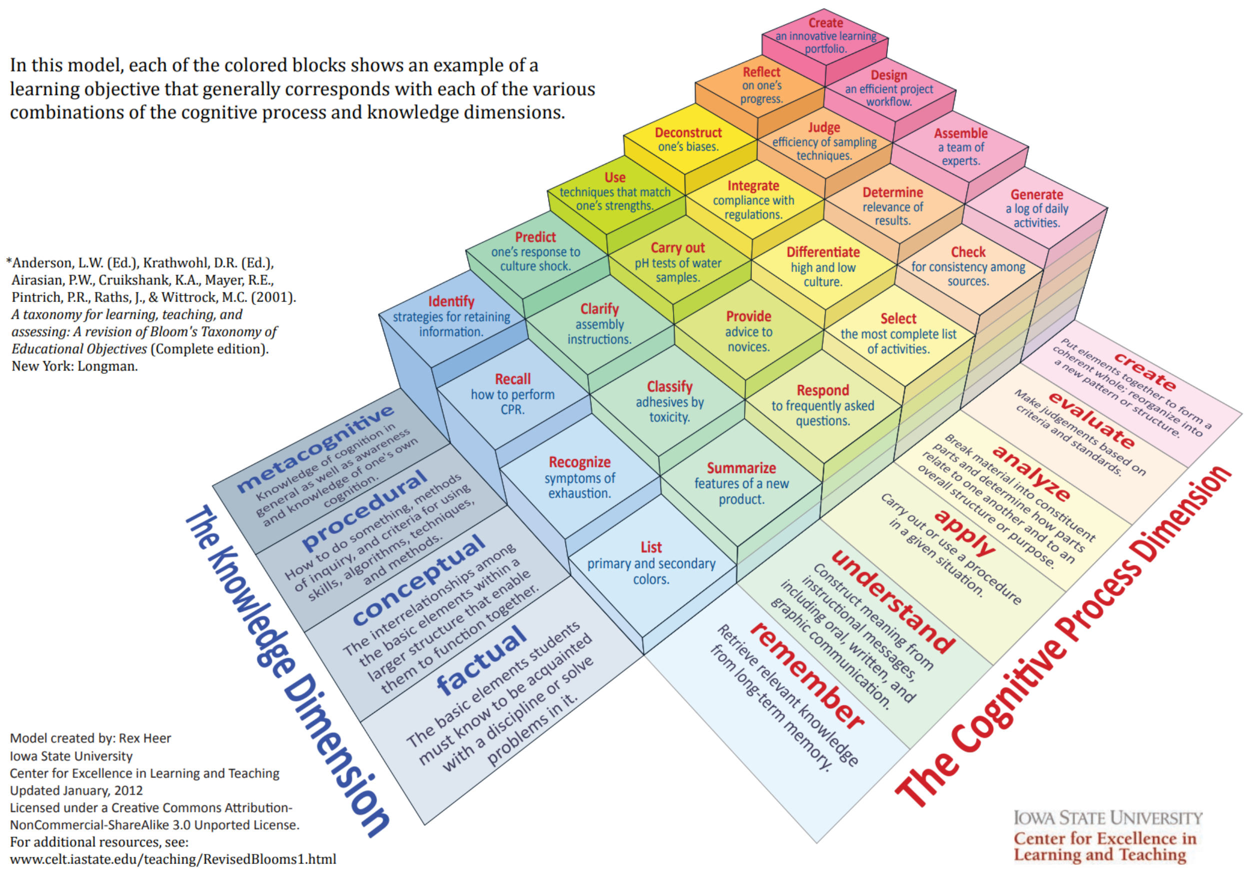



Figure 1: The revised Bloom's model, where learning objectives are broken down into cognitive process and knowledge dimensions.

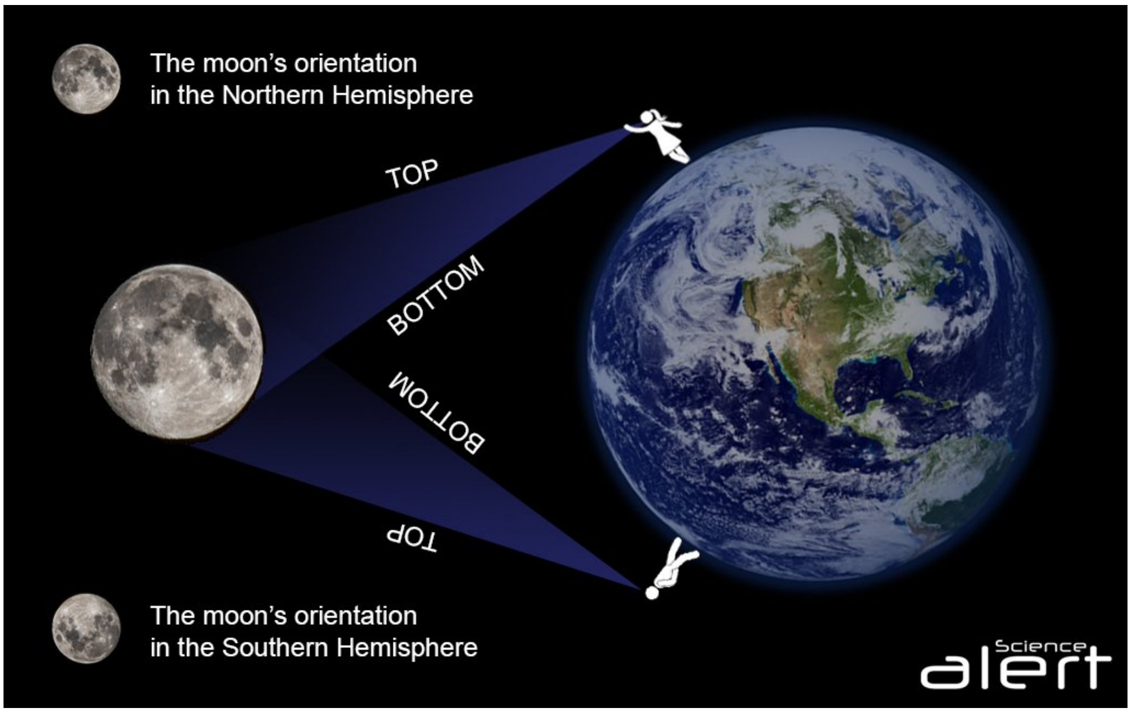



Figure 2: An observing in the Northern and Southern hemisphere see the moon upside (and flipped) relative to one another.

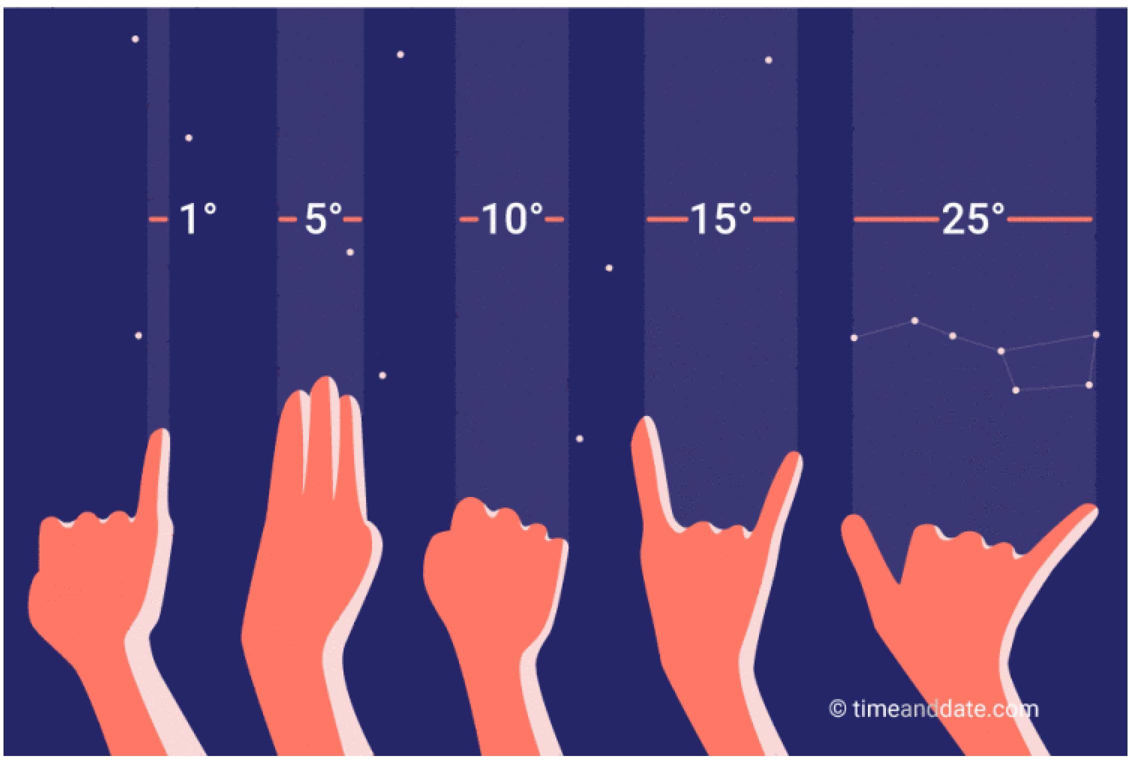



Figure 3: Estimating angles with your hands when held at arms length.

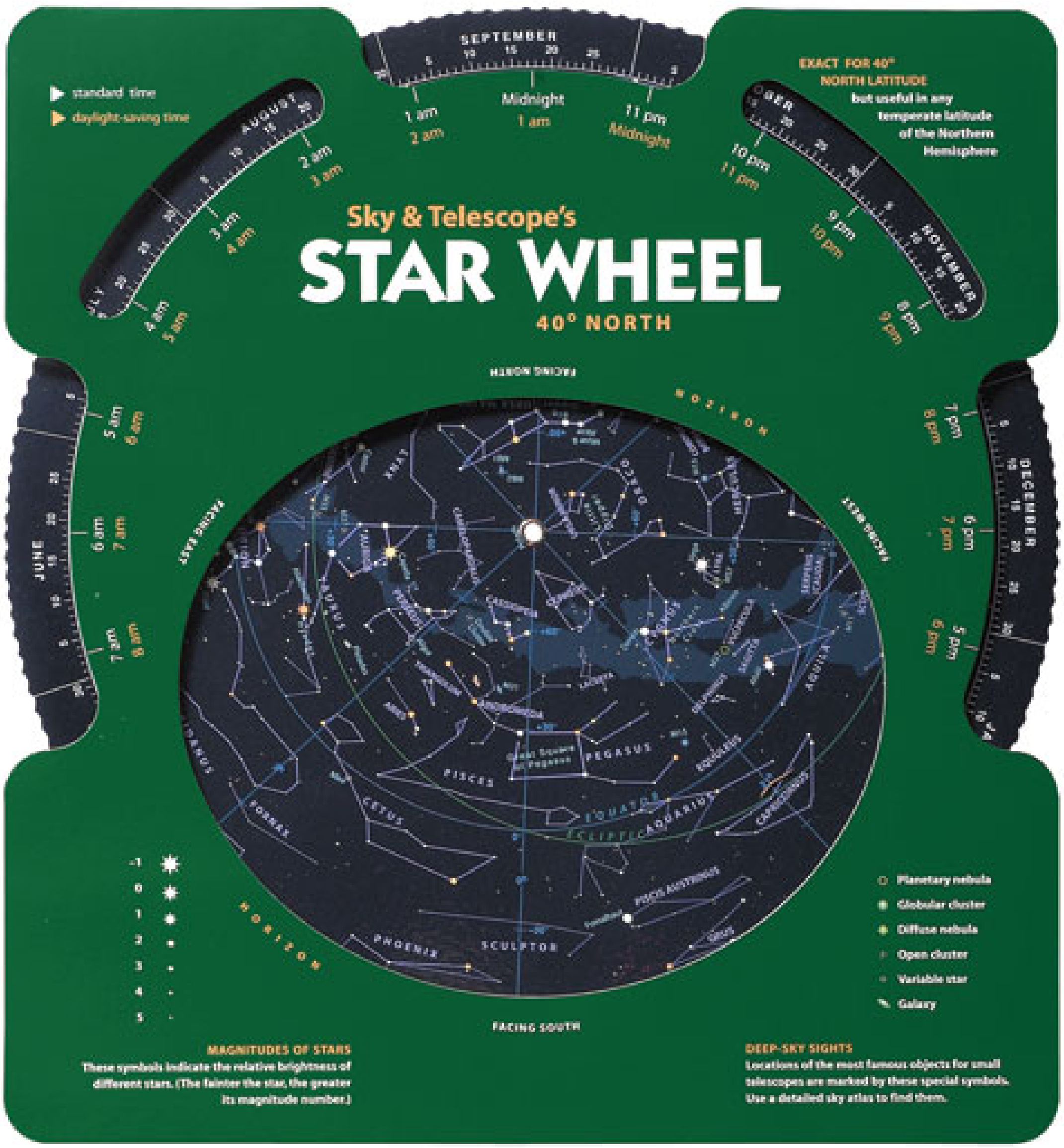
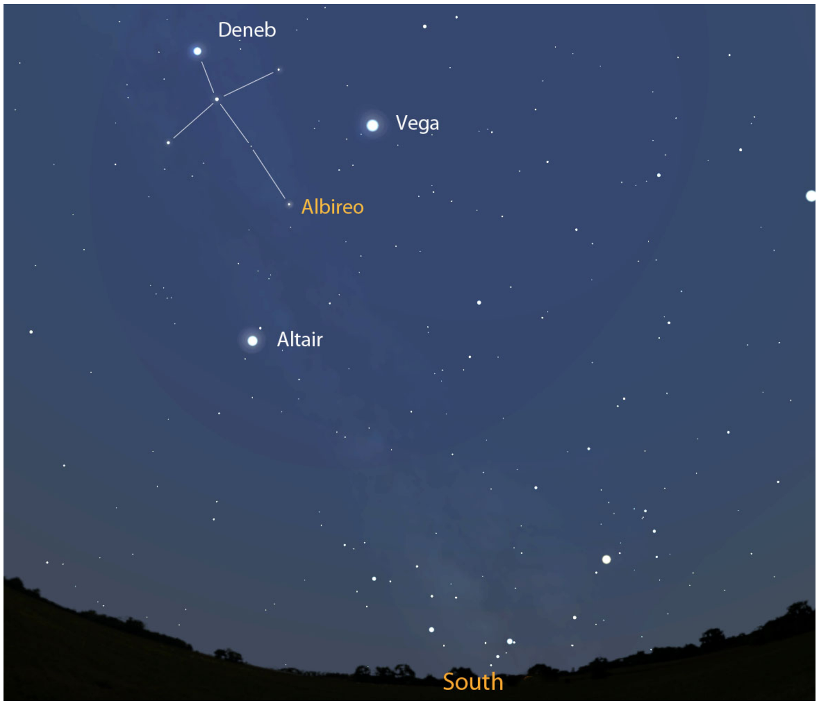


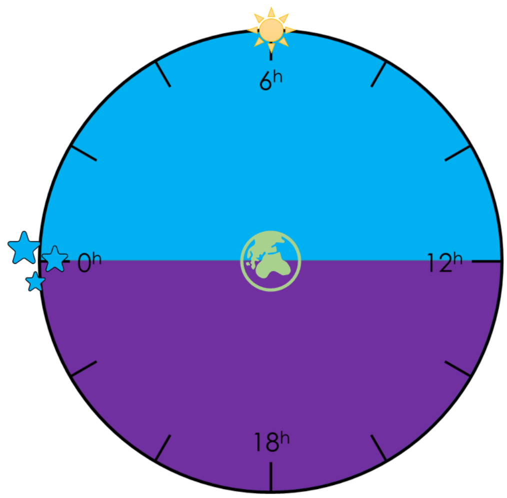

Figure 4: Picture of a star wheel. These are used to help students identify stars and constellations in the night sky.



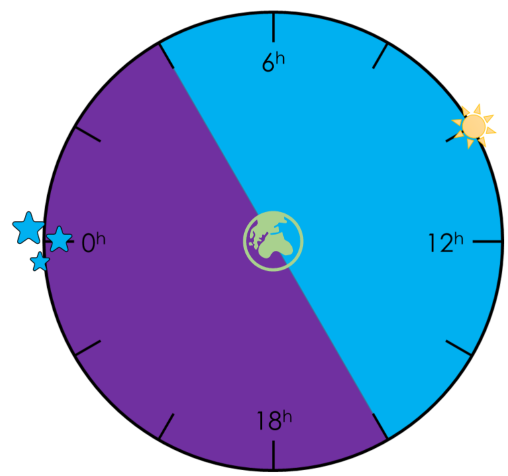
(a) Location of Albireo


(b) Albireo when seen through a telescope

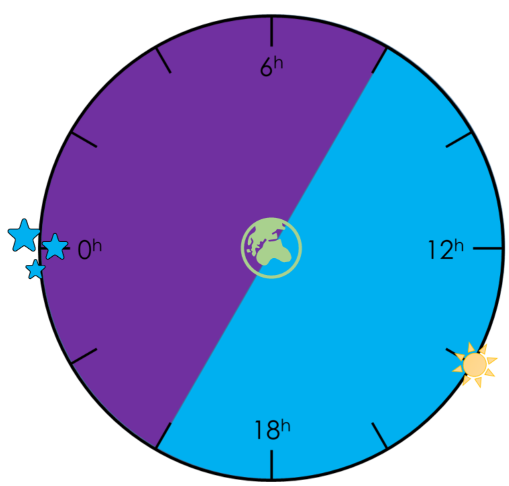
Figure 5



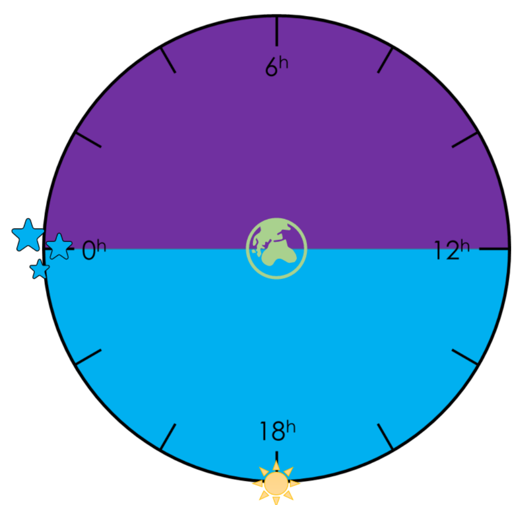

(a) On horizon @ midnight




(b) Above horizon @ midnight




(c) Above horizon @ midnight




(d) On horizon @ midnight

Figure 6: For an object with a right ascension of $0^h$, it will be on the horizon at midnight when the Sun has a right ascension of (a) $6^h$ (Summer Solstice) and (d) $18^h$ (Winter Solstice). When the Sun has a right ascension between these two values (b,c) the object will be above the horizon at midnight.