The might of science is in its power to predict. Yet students rarely have the opportunity to foretell events in the natural world in their science courses. Instead, students consider problems thoughtfully fitted to the printed page, carefully crafted demonstrations, or well-honed laboratory experiments.

Using a more authentic approach, students in our celestial navigation course have been keeping observational journals, first building their own instruments and then using them to predict events in the sky. Although science has been able to model these motions of the heavenly bodies for well over two thousand years, the dance of the stars, planets, Sun, and Moon still has the capacity to capture students’ fascination and interest.

Celestial Navigation, an introductory astronomy course offered jointly in both our astronomy department and school of education, has been taught at Harvard University since 1897. Its venerable status belies its experimental nature. The course has traditionally been a laboratory for testing alternative methods for teaching science. Students have mapped local parks, piloted whale-watch trips, and serviced buoys in Boston Harbor. Using sextant (an instrument for measuring the altitude of stars ±0.2 arc-minutes) and watch (for measuring time to ±1 second), students learn to find their geographic position within a mile.

Yet, this course is different from many that teach navigation as a collection of cookbook techniques. In Astro 2, students are expected to challenge and investigate their own previously constructed understandings of astronomy. To assist students in exploring their preconceptions and constructing more powerful models of astronomical systems, the course employs laboratory activities, field trips, oral presentations, and projects, but its most powerful tool is the journal.

This paper describes the origins and details of journal use. We document the difficulties and frustrations that many students face, and how the journal can be fully integrated into science courses. We focus attention on the use of journals as a means for

**For many, journal-keeping is a creative process, an alternative to the lecture and laboratory.**

**For students who learn best by discovery, journal-keeping allows them to reveal firsthand fundamental truths about nature.**

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attaining a richer conceptual understanding of science, for identifying students’ preconceptions, and for applying the concepts learned in the classroom to the world. We trace the stage-like progression that many students follow in their growth as observers of the natural world.

PRIOR RESEARCH

Previous research assesses the value of journals and other writing assignments in the science classroom. It includes both informal observations and rigorously controlled experiments. An analysis of computer-recorded journal entries in a high-school physics class found that students primarily used their logs to tell stories, i.e., to describe events or report on observations, making few knowledge claims (Audet 1996). Teacher responses avoided didactic teaching. Instead, they were often affective in nature, attempting to motivate and support students.

Stanesco (1991) reports that learning logs help students take full advantage of field trips by providing an opportunity to develop their ideas and understanding with the teacher acting as a coach. Journals allow students to consider the events and purposes of their laboratory experiences, which grow in popularity as students begin to value their aid in understanding geological concepts (Halsor 1991). Coles reports that students come to value journal writing as a “familiar, non-technical method (expository writing) to help them learn a subject that intimidates them” (p. 189), while benefits of constant feedback accrue, especially for the new teacher. A more reflective attitude was noticed in students who were required to make connection between geology and their observations and readings (Cropp 1980).

Other informal studies of journal use in the classroom report improvement of conceptual understanding, analytical skills, and increased confidence among students who faithfully maintain a written account of their confusions and enlightenments (Ambron 1987; Ammon 1980; Duckworth 1987; Fulwiler 1982; Grumbacher 1987; Malachowski 1988; Wotring 1981). These anecdotal successes often fail to materialize in empirical studies. Tombulak and Sheldon found no difference in test grades between students who chose to complete journal assignments and those that did not in a required course taught mainly to freshman, while in a more advanced, upper-level course, they found a large and significant relationship. Others conclude that the use of writing has no significant effect on student understanding (Rumpf 1988; Jewett 1991).

One can rationalize that these researchers base their conclusions only on the results of multiple choice and short answer tests given to control and experimental groups at the beginning and end of the course. Only Steiner claims that writing “directly contributes to student understanding.” In this paper, we would like to focus attention on the use of journals as a means of creating or reaching richer conceptual understanding of science, particularly astronomy.

Journals have a long tradition in the sciences. Scientific breakthroughs are often facilitated through detailed records that reveal patterns over time.

<table>
<thead>
<tr>
<th>Table 1. Tips for Successful Journals</th>
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<tbody>
<tr>
<td>▲ Clear guidelines and expectations. A guided observation should be made with the class as a whole at the earliest opportunity. The first few observations should be required and well-defined. Frequency and quality of observations should be discussed.</td>
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<tr>
<td>▲ Phenomena easily observed. Objects should be easily recognized and tools constructed or made available for accurate measurement of azimuth, altitude, and time.</td>
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<tr>
<td>▲ Class discussion of student observations. Students should be given an opportunity to compare and discuss their observations during class, employing the best journal-keepers to date as group leaders. The instructor should show examples of students’ first use of regular observations, predictions, data tables, and graphs as they appear. Allow students to pool their data during class to build more robust datasets.</td>
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<tr>
<td>▲ Journal summary. Build in opportunities for reflection, by requiring students to periodically summarize their entries.</td>
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<td>▲ Instructor commitment and enthusiasm. Utilize time in class for journal discussions and provide timely feedback.</td>
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<tr>
<td>▲ Interim and final journal grade. Provide an “estimated” grade for the journals, assuming continuation at the same level of effort. This will often help students who tend to procrastinate.</td>
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<tr>
<td>▲ Journal questions on exams. Include questions on all tests that can only be answered by keeping a journal.</td>
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Galileo’s (see 1989) discovery of the moons of Jupiter stands out as a prime example. When he first turned his telescope on the heavens, he saw “stars” near Jupiter and expected Jupiter to move with respect to them. Jupiter did, but seemingly in the wrong relative direction. Curiosity piqued, Galileo repeatedly observed and drew Jupiter and its entourage. He soon realized that the objects stayed with the planet and eventually concluded that they were orbiting it. The discovery that the objects were in fact moons and not stars was possible only because of well-kept records (Galileo 1989). In the laboratory, the Lavoisiers’ contributed to “a fundamental transition in chemistry, replacing the arcane tenets of alchemy with systematic scientific principles” (Alic 1986). Most of their work was recorded by Mme. Lavoisier, who used her talents as an artist as well as a scientist to advance the level of the discipline. In class, we make a concerted attempt to link the present to the past, showing examples of historically important journals and drawing parallels to students’ work.

IMPLEMENTATION OF THE JOURNAL AS A MAJOR COURSE COMPONENT

From the first class meeting, journals are emphasized as an important element of the course. Journal questions appear on tests (e.g., How does the direction to sunset change over the fall?). Journals, which are required, count as a separate grade. The journal provides a unique and private forum for students to communicate with the professor and teaching fellows about their ideas and confusions. The journal is a fertile garden from which ideas for an extensive term project often sprout. In the past, those students who invested time and energy in keeping good journals found the course (and the exams) much easier than those who did not.

▶ Guidelines. Clear guidelines and expectations (see Table 1) reduce confusion and anxiety when a journal is first introduced. Keeping a journal is a novel experience for students in science. To start, certain observations should be required. Later as students begin to find patterns and explore phenomena on their own, strict requirements are no longer needed. To this end, students make detailed observations of a new object for each of the first three weeks:
- four sunrises (or sunsets),
- four consecutive daily observations of the moon, and
- four observations of a planet against the background stars.

These guidelines provide a foundation for what otherwise might be a seemingly unfocused endeavor. The introduction of the journal always raises questions about grading. The journal grade, by itself, is worth 10 percent of the total course grade, but journal questions on exams raise its importance to 20 percent overall (with problems sets, labs, projects, and tests splitting the remaining 80 percent almost equally). We require students to complete eight weeks of observations for minimum credit. Students that do not meet this requirement know that they must make up delinquent entries to do well on the exams.

▶ Modeling the Journal. The first clear night finds the class outside peering up at the sky (Photo 1). Students break into groups and decide how to fully describe the moon or a planet. From their deliberations, we construct a list of variables that could be worth recording. In the case of the
moon, these usually include color, fullness, angle with the sun, altitude (angular height), and azimuth (angle clockwise along the horizon from north). Returning to the classroom, we build simple quadrants from protractors and string (a cost of under 75 cents each) and learn how to use an inexpensive magnetic compass to measure azimuth (Photo 2). These tools become an integral part of journal observations. In addition to these experiences on the first night, we spend time each evening session discussing the journal and student observations. Class begins with short journal discussion when a student will raise a question or initiate the conversation.

A journal “read-around” (Malachowski 1988) takes place in the evening during the third week of the course and again in the sixth week (Photo 3). Exemplary journal keepers are selected to lead group discussions with up to six of their classmates. (It is important to invite these students to lead; most will hesitate to volunteer.) Each student leader is instructed to page through his or her own journal showing observations and diagrams. A bag of cookies is provided to each leader and used as a tasty incentive for other students to begin sharing from their journals. Each group speaks with each expert for 10 minutes and then visits two other groups. We limit this session to 45 minutes, with a 10- or 15-minute all-class review before proceeding to the evening laboratory activity. The quality of field notebooks markedly improves in the weeks following this activity.

Singling out exceptional journal keepers is a useful strategy. Once students see how their classmates devise various methods to collect and organize data, many quickly follow suit, discovering patterns in their own data. The entries after the sharing session abound with graphs, charts, and tables of all types. Moreover, most students begin to make deeper, more thoughtful, interpretations of their observations that we attribute, in part, to learning from their peers. Often their classmates, who have just discovered their own misconceptions, are far better at explaining patterns and their predictive models than their more knowledgeable teachers (Photo 4). Those who still lag behind in this second leg of the journals (and whose misconceptions persist) receive more directive comments and follow-up conversations from the instructors.

To bring closure to the journal component of the course we require that each student summarize his or her eight weeks of entries. This review forces students to return to the beginning of the course. Reflection on their entries helps them to recognize the progress that they have made in the last two months. Students often remark on the number and types of misconceptions they clarified while using the journal. In addition, it provides them with a one- or two-page summary that will be helpful to them during the final exam.

▲ Instructor Commitment to the Journal. Teachers take time to read and comment on student work. Students write only on right-hand pages, leaving the left for teacher comments and questions. We comment weekly between our noon class and evening lab (our class size varies between 25 and 35), but one could read journals and put them in a drop-box for timely pick-up by students following class. Quick turnaround allows students to read and use teacher comments in the
The next series of observations. In addition, it sends a signal that we, as instructors, value the journal as a serious endeavor.

Comments to students both guide and support their work. Instructors lead with a supportive comment, finding something good in each week’s work and continue with a follow-up question that asks the student to think more deeply about their data. For example, if a student notes that the moon rose at sunset, but neglects to note the phase of the moon, we ask, “Do you think there is any connection between the phase of the moon and its rise time?” Further into the course, we urge students to make predictions based on the data they have gathered, e.g., a student that records several days of sunrise data is asked to predict the time and position of sunrise for the coming month.

In addition to making written comments in each journal, common problems or insights are mentioned during the discussion session that begins each class, with the instructor often reading from a student’s journals. Even the most reticent speakers can have their ideas shared in this manner. Students who might not fully comprehend the instructor’s comments have a chance to hear them again and listen to others’ responses. In addition, it lets many students see that others are struggling with the same issues of measurement and pattern finding.

Assessment. Grading journals appears to be a common practice, with it contributing 20 percent to 25 percent of the final grade for a course (Coles 1991; Cropp 1980; Malachowski 1988). Instructors use a variety of criteria to assign grades, but the most popular appears to be quantitative: both frequency and length of student entries (Coles 1991; Cropp 1980; Halsor 1991; Malachowski 1988). All report assigning some value to the quality of entries for their degree of insight, clarity, and use of diagrams.

Our journals are graded cumulatively once at four weeks and again at eight weeks, not on a weekly basis. We pay careful attention to the number of accurate observations (sloppy data is not credited) recorded each week and the number of objects observed (Photo 5). Commentary without substantive data is discouraged. By the end of the eight weeks, strong students should have recorded at least 25 observations in a systematic fashion for two different celestial objects. All told, it must appear that students are spending an hour measuring the sky directly each week and another hour analyzing or writing in their journals.

Students must collect enough data to clearly see trends when graphed, at least six datapoints (and often a dozen) per curve with no large gaps. Trends and patterns must be tested through forecasting the outcome of future observations. The reason for looking back is to predict the future. Students must explicitly comment on how well their patterns hold, and revise them if required. A final summary of the journal, looking back from its start, must recognize earlier misconceptions and how they changed. This reflection must account for limitations of the accuracy of instruments and their resulting errors.

On our midterm exam, students have use of their journals to answer one of several questions about the movement of planets, stars, the sun or the moon. The questions are changed each semester drawing on the common foci of each new group of students. Instructor comments direct students to be sure to observe specific phenomena that are planned for the midterm test. The set of questions includes something to challenge every student.

The final exam includes one jour-
nal-related question, usually students must describe some prior conception that changed as a result of careful observation and analysis of the heavens. This question allows students to gather and organize the many thoughts and ideas about astronomy they developed during the semester. Student responses are often introspective, with many freely admitting confusion and curiosity even as the course comes to a close. For example, one student sums up his experience observing the path of the sun on his exam:

Before this course I thought the Sun always rose in the east and set in the west. It never occurred to me that the height of the Sun actually changed over a year. . . . I saw the average max. height of the Sun decline as we moved toward the winter solstice . . . I noticed that the Sun didn’t seem to be as close to setting in the west as it should have been. B.E.

We grade final exam answers such as these based on the student’s use of journal observations. The above selection demonstrates these students’ efforts to come to grips with questions through observation.

**STAGES OF STUDENT PROGRESS IN JOURNAL KEEPING**

Students engage in a number of different strategies as they measure and try to make sense of the movements of celestial objects. Most students pass through several stages, developing an increasing sophistication over the semester that fits well with the “exploration—conceptual invention—concept expansion” learning cycles of Abraham and Renner. Most begin by exploring connections with their lives or with past learning, then move to find support for their beliefs. Only after they discover that their ideas are erroneous or too simplistic from sporadic data collection, is there an incentive to invest in a more regular and purposeful regimen of observation. From these rich sets of data, students ultimately find patterns from which they invent predictive and powerful models that explain more than their old ideas (Duckworth 1987; Posner 1982; Roth 1985).

The learning cycle in science, first posulated by Karplus, has also been formalized in other domains by McCarthy (1980) as the 4MAT System. In 4MAT, students must first seek personal connection with a phenomena, often finding fault with their comprehension. Next they develop or are exposed to a new way of looking at the problem, followed by practice in applying it. Last they may extend, generalize, or reflect on their new knowledge to further enlarge their understanding.

Some students feel a need to declare their theoretical knowledge, skipping over making observations in favor of voyages of the imagination or recapitulating theories with which they are comfortable. For example, one student chose to examine the daily path of the sun and the moon. Rather than take the time to measure positions several times each day over a week or more, he prematurely at-

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**Keeping notes and measurements allows students to test their theories and build new ones based on nature, not the teacher, as the arbiter of what works and what does not.**

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**Stage 1. Seeking Connections.** Most students begin their journals as a diary, seeking connection by recording their feelings about the sky. They often describe the beauty of a moonrise without noting more quantitative aspects such as its duration and position with respect to north.

I have begun making nightly observations of the moon. I have been a little uncertain as to just what the moon’s motion in the heavens is and so I hope to gain a more complete understanding. I was also inspired to begin making observations of the moon because of the spectacularly bright full moon, which appeared in the night sky last week. C.P. 10/28

This stage of journal writing is useful because students begin to notice qualitative features of the sky. They find that the sky is full of interesting objects, that these objects move, and that they are part of recognizable constellations. This connection to the heavens precedes any commitment to measurement since students often fear they will make gross errors and possibly expose ignorance.

While we do not dissuade students from such statements, we continually emphasize the goal of predicting celest-
tial patterns. With this in mind, we direct students to test their ideas in the real world. J.D.’s problem was that he started with a theory that celestial objects moved in a cycle and thought that a sine curve would represent these movements well. However, the sun’s motion is more complicated than a simple sine function. After reading this entry, we suggested that it would be valuable to actually graph the path of the sun through the sky on a daily and weekly basis to discover the pattern of its movement. One of our most mathematically competent students, he resisted dedicated observation despite numerous comments and consultations. More data just complicated the issue for him. He never felt comfortable collecting data without knowing the equation would fit.

Instructors should not be crestfallen if not every student dives into observation and data analysis. Fieldwork will be new and perhaps confusing to many students who have been taught that science is neat and tidy. Many students expect that all phenomena can be reduced to simple rules and formulas, that nature is as simple as the problems at the end of textbook chapters. Patience and persistence may be the best method for handling students that balk at the journal concept.

Stage 2. Disordered Data and Questions. Once connected and encouraged to explore further, students begin making measurements. The narrative portion of the journal also evolves from poetical prose to detailed descriptions of astronomical observations. Students use their quadrants and compasses, often supplemented by drawings of what they see. At first, many journal entries describe the sun or moon’s position relative to trees or buildings. Students often try to prove what they already believe, attempting to shore up often shaky understandings. For example, here a student has drawn the position of the moon among the background of bright stars:

I’m beginning to not only realize how little I know, but also how many misconceptions I have. This sounds very naive and ridiculous now, but I just assumed the stars and moon moved together—obviously didn’t think much about this one! So now that I realized how completely clueless I am, my curiosity is beginning to get the best of me.

R.S. 10/8, 11 PM

In this entry, two weeks into the course, R. reveals her confusion and expresses interest in answering the question of how the moon behaves. The moon is moving against the background of stars. Had she not recorded her observations in her field notebook, she may never have realized she had a misconception. And even if she had realized it, she may not have had the confidence to voice her confusion in front of the class. This recognition that nature is not behaving as she thought is a concrete manifestation of her preconception being challenged, a necessary precondition for conceptual change (Posner 1982). For her learning to be “meaningful,” she must begin the hard work of reconstructing her beliefs (Ausubel 1978). Journals are a place to admit and explore misunderstandings and to research and perhaps answer compelling questions.

Stage 3. Finding Patterns in Carefully Collected Data. Some students do not enjoy observing or make the effort to observe regularly. Students have other commitments and stronger interests. Therefore, they delay journal observations until the day or night before it is due. Instructor comments make it clear that lack of data is not acceptable; students must make an effort to collect data so that last minute failures do not occur. Random observations, at differing times and dates, often iden-
tify holes in student knowledge, but do little to build understanding of patterns and models. Sporadic entries should be avoided; rarely do they lead to interpretable patterns and often they increase misunderstandings. Instructor comments should lead students towards developing a plan for regular observations and thoughtful investigations.

Students must search for questions that can be answered through an organized series of observations. In the following entry, R writes more to herself than to the instructor. After her initial misconception, she made many observations of the moon, wanting to be able to discern how the moon moves through the sky. Here measured angles and times allow her to quantitatively express her new understanding:

```
What I have observed is that the moon starts out (after the new moon) rising at an azimuth of about 220° shortly after the sun sets. It remains low on the horizon and sets shortly after it rises at an azimuth of about 241°. Each evening, it appears to rise roughly 50 minutes earlier and at an azimuth 12° east of where it was the day before. R.S. 10/12/92
```

Even though R confused first sight of the moon with rising, the entry is significant because the data are verifiable and repeatable. R is asked to forecast, in a teacher comment, how the moon will behave in the future. It is not surprising that with this newfound understanding R begins to make and check predictions.

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. . . What I am predicting, is that the moon will continue this pattern until full moon when it will reach its peak altitude, will be out for the longest period of time and will be its brightest. R.S. 10/12/91
```

The journal offers a place to store all these questions, predictions, data, and answers. Both the student and the teacher can track the progress of the student through the students’ journal entries.

A look at another student’s work reveals how successive observations result in the ability to make predictions about the rising and setting time of the sun. In addition, E takes the time to make clear and detailed drawings at the time of observation, demonstrating a talent that otherwise might have remained hidden.

```
▲ 9/21: sunset at 6:27 PM disk set in approx. 1 and 1/2 min. (very rough)
▲ 9/24: sunset at 6:25 PM disk set in approx. 2 min.
▲ 10/1: sunset 6:31 PM six minutes later
```

Figure 1. Student graph of the motions of the Sun. Note the large change in the altitude of the Sun above the horizon as the day progresses. This curve slowly shifts upwards as spring progresses.
then 7 days ago

\[ \text{Day 7 earlier each day...} \]

Dec. 21 sun should set around \(6:19\) \((6/7 \text{ min./day} \times 81 \text{ days})\) - 1 hr daylight savings = \(4:10\) PM [brackets added]

Here, E demonstrates that through a combination of observation, calculation, and critical thinking he can begin to explain natural phenomena that many people take for granted. The field notes act as a foundation for his discovery of the changing length of daylight. As a result of his work, E not only knows that the days change in length, he owns this knowledge. It is evident that students can derive great joy from authentic investigations such as E’s. Regardless of the level of complexity, successful investigations lead to further inquiry-based learning experiences. A student who performs a task such as this on her or his own builds self-confidence, an interest in science and the ability to interpret the surrounding physical world.

Stage 4. Graphing and Modeling.

Careful data collection concerning a certain phenomenon sets up the problem of finding patterns. Such patterns are necessary for accurate prediction. Students generally use one of two approaches. Some attempt to work strictly from the tables they produce, while others use graphs to find trends and patterns. Tabular analysis is usually unproductive, and calculating finite differences or rates from noisy data is often fruitless. Measurement errors obscure the patterns.

Few students begin graphing their data immediately. In each of the last five years, humanities majors were the first to generate graphs to find patterns in their data, while science students held back because, as one student put it “we don’t know the curve along which the data should fit.” Humanities majors are more pragmatic; here a student plots 21 data points and connects her points with curves, with her comments following (Figure 1).

It seems as we leave winter behind, the sun is getting higher in the sky and (inferred) the more sun we see—rising at a lower azimuth and setting at a higher azimuth. It looks from the graph as if the slopes of the lines might be similar, i.e. does the sun have a correspondence between azimuth and time or maybe an overall ratio of increase in altitude per azimuth increase?

S.D. 3/17

S’s plots have a profound impact on her understanding of the relationship between the quantities she has measured, altitude, and azimuth of the sun. She has found trends in rising and setting points and in the maximum altitude. Now she has a theory about the similarities of the slopes, which would be nearly impossible to connect had the data stayed in a tabular format. Even more profound is that she can add new data to her graph throughout the course. Her graph has become a visual representation that compares and makes sense of many measurements.

The pattern she found, that the path of the sun was higher each week along its entire curve, quickly swept the classroom. Soon students were plotting their data in the same fashion and comparing graphs with others. These patterns led students to theorize about the systems that create such patterns.

For navigators, the universe is geocentric, the celestial bodies revolve about the Earth. It is impossible to solve navigational problems from a heliocentric viewpoint. So students must begin to construct a view of the universe that is productive for this special purpose. Here a student builds a kinesthetic model of the Moon’s movement based on class activities, but using his own data,

Face south, in the northeast sky the Sun...
comes up at 90° or east. The phase of the Moon determines its location. If the Moon is full, the hands are at 180° angle from each other, and if the Moon is new, the hands are in the same position. S.F. 5/8

This connection of student observation, discovery of patterns in their own data, and building falsifiable predictive models fulfills the goals of utilizing journals in our science course.

CONCLUSION

Journals can be a useful and central feature as a portion of introductory astronomy courses, particularly for sky watching. Keeping written records of the heavens is a skill that aids student learning of the course content. They reinforce links to science concepts and connections to how new science is produced. Journals provide an opportunity for students who may not excel in timed exams, problem sets, or classroom questioning to succeed through this special channel of interaction with the instructor.

Journals should be well planned by the instructor, starting with weekly observational requirements and moving to student-generated projects. It is important to include journal activities in class, using discussions to aid in sharing discovered, data, and analytical techniques. Journal question on exams help students to make connections to the other course content.

Students often progress slowly through stages in their journal writing. They must first find some connection to the natural world. This often takes the form of more poetic or qualitative association. Quantitative data collection, especially in an organized and systematic fashion, takes several weeks to develop as a valuable source of information. Previous experience with graphing seems to make little difference in students’ ability to find patterns in nature’s display.

Using graphs in this way is a foreign idea for most students and their use must be encouraged. The models and theories that have been taught since childhood must be discovered anew by students in the context of natural phenomena. Often it is those students who do not perform well on exams who excel in journal keeping. Be prepared for those who do well on conventional assessments to balk at journal keeping, since role learning plays no role in learning from journals. They should be encouraged to concentrate on data collection first, without seeking any views from books or experts.

Keeping a journal marks the first time many students, including science majors, have to observe and quantify natural phenomena. Keeping notes and measurements allows them to test their theories and build new ones based on nature, not the teacher, as the arbiter of what works and what does not.

Keeping a journal over a long period aids student learning of how science is done and how dead ends and confusions are inevitable on the road to understanding. For many, journal keeping is a creative process, an alternative to the lecture and laboratory. For students who learn best by discovery, journal keeping allows them to reveal firsthand fundamental truths of nature.

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