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Using Visual Assessments and Tutorials to Teach Solar System Concepts in Introductory Astronomy

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Abstract

Visual assessments and tutorials are instruments that rely on student construction and/or examination of pictures and/or diagrams rather than multiple choice and/or short answer questions. Being a very visual subject, astronomy lends itself to assessments and tutorials of this type. What follows is a report on the results of the use of visual assessments and tutorials for instruction on two specific solar system topics in introductory astronomy: the orbits of comets and extrasolar planets.

1. INTRODUCTION

Assessments (Brissenden *et al.* 2001) and tutorials (Prather *et al.* 2004; Prather and Brissenden 2009) are both important components of learner-centered instruction of astronomy. The assessments can be administered in several forms: pretests before instruction on a topic to identify preconceptions, then after instruction, often during the next class meeting, for student review and feedback for the instructor on what still needs to be learned, then finally post testing to determine what ultimately has been learned (Donovan and Bransford 2005). Tutorials are activities designed to keep students engaged by working with concepts in an active and collaborative manner while also attempting to dispel misconceptions (Prather *et al.* 2004; Prather and Brissenden 2009).

Recommended methods for the use of tutorials (Prather *et al.* 2004; Prather and Brissenden 2009), and learner-centered teaching in general (Bransford *et al.* 2000; Weimer 2002), rely heavily on assessment. What follows is a description of a study on the use of visual assessments to compare the effectiveness of tutorials that are also visual in nature with traditional lectures. In the tutorials, students are asked to construct and/or examine pictures and/or diagrams related to the topics being studied, while during lectures they are simply shown the pictures and diagrams. The specific subject studied are two solar system topics often covered in introductory astronomy that are very visual in nature and therefore lend themselves to visual tutorials and assessment: comet orbits and extrasolar planets.

2. PART 1: COMETS

2.1. Procedure

N=93 students in four sections of introductory astronomy taught by two instructors during the Winter 2009 semester were given a diagnostic assessment that consisted of a diagram of the portion of a comet's eccentric orbit near the Sun (see Figure 1 below) and were instructed to draw the comet at five different positions showing differences in the relative size of the coma and the tail and differences in the direction of the tail. The students were asked to do this at the beginning of the class period in which comets were to be covered. This was prior to any instruction with the only previous exposure to the material being from assigned reading for that class period of a chapter in their textbook on asteroids, comets, and dwarf planets (Bennett *et al.* 2009), where

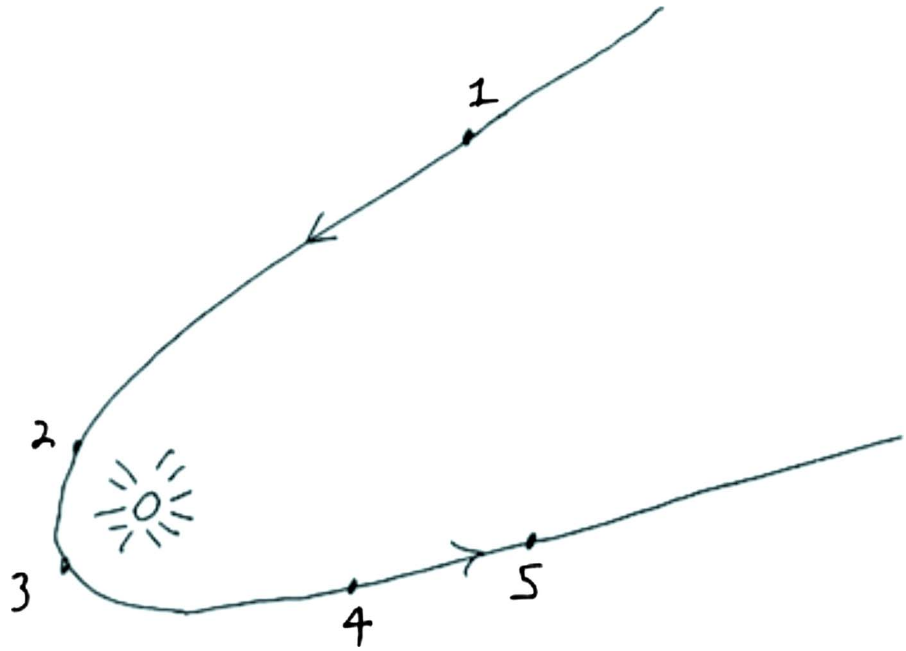

Figure 1. The diagram of a comet's orbit that was given to students at the beginning of the class period in which comets were to be covered and at the beginning of the next class period after instruction. The following instructions were included; Figure 1 shows the portion of a comet's highly eccentric orbit that is close to the Sun. At each numbered position of the comet's *nucleus* draw the comet's *coma* (head) and tail. Make sure that your drawing clearly shows any differences between the size of the coma and length of the tail and the direction the tail is pointing

they encountered a diagram showing the correct proportions and directions. Most students completed and turned in assigned written review questions from the end of the text chapter, suggesting that most did in fact do the reading.

Only 23% of the drawings (18/93) correctly showed the changing directions of the tail. 13% (12/93) showed the correct changes in relative size of the tail and only just over 4% (4/93) showed correct changes in the size of the coma.

Nearly half, 46% (43/93), of the drawings betrayed a popular misconception, which was that comets always travel head first and tail last (see Figure 2 for a student example). This is understandable, based on the usual

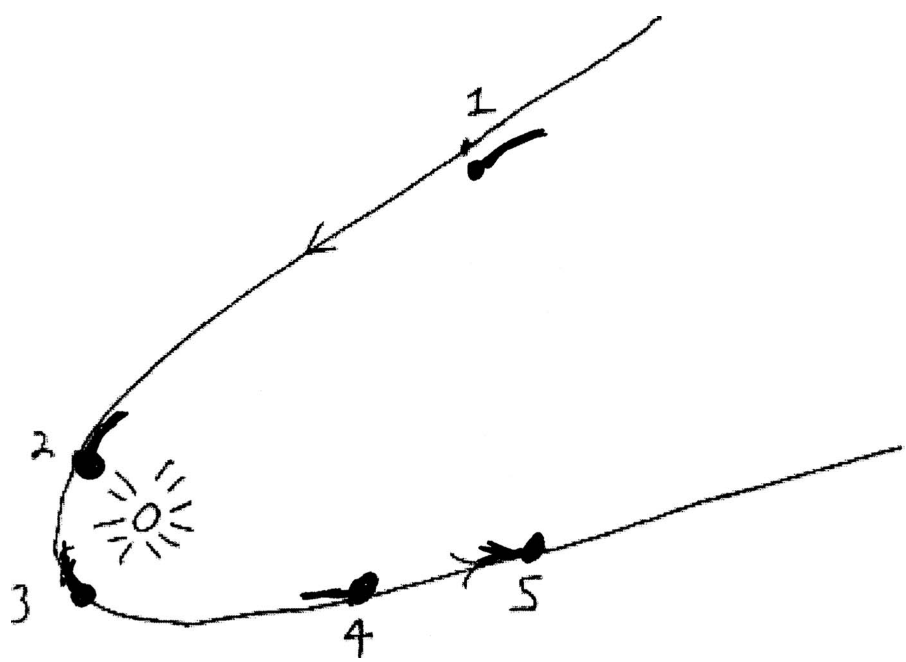

Figure 2. Student drawing showing the common misconception that a comet always travels head first and tail last

meanings of the terms “head” and “tail” and possibly due to pictures of comets, such as those found in the textbook the students were reading (Bennett *et al.* 2009), giving the impression of a still image of an object in rapid motion with the tail trailing behind the head; possibly in confusion with falling meteors.

As part of a multiple choice *Solar System Survey* on the entire solar system “unit,” that students were given prior to any instruction or assigned reading on the topics, only 14% (N = 100) responded correctly (choice c) to the question:

A comet’s tail

a. precedes its head through space.
b. follows its head through space.
c. is farther from the Sun than its head is.
d. is closer to the Sun than its head is.
e. [None of the above],

with 45% of respondents choosing “b”.

Quantitative evidence for confusion between comets and meteors is shown by the following item that is part of a separate *Misconceptions Survey* that was given to the same population at the beginning of the semester:

A “shooting star” or “falling star” is

a. a star falling to Earth.
b. a comet streaking across the sky.
c. a meteor falling through the atmosphere.
d. [either B or C above—comets and meteors are the same thing].

31% of respondents (N = 115) did correctly respond “c,” but 60% chose “b” or “d” (30% each) showing the confusion. Incidentally, only 9% responded “a” which is encouraging.

Two sections (one taught by each instructor) were given as a traditional lecture on solar system debris, including comets, that included a figure of a comet’s orbit showing the correct changes in relative coma and tail size and tail direction and emphasizing radiation from the Sun as the cause of these changes with the explanation that since the tail is material being “thrown off” the comet by heat from the Sun, it will always point away from the Sun, approximately in the direction of the Sun’s “rays.”

The other two sections (again one taught by each instructor) were given as a short tutorial (see Note 1) that included Figure 1 with explicit directions for correctly drawing the comet’s coma and tail as well as an exercise where they were asked to match each numbered position in Figure 1 with the arrows in Figure 3 that best represented the direction of the comet’s tail.

As is recommended when using tutorials, a short “debriefing” discussion occurred after the tutorial was completed (Prather *et al.* 2004; Prather and Brissenden 2009) in which the correct coma and tail sizes and directions were discussed.

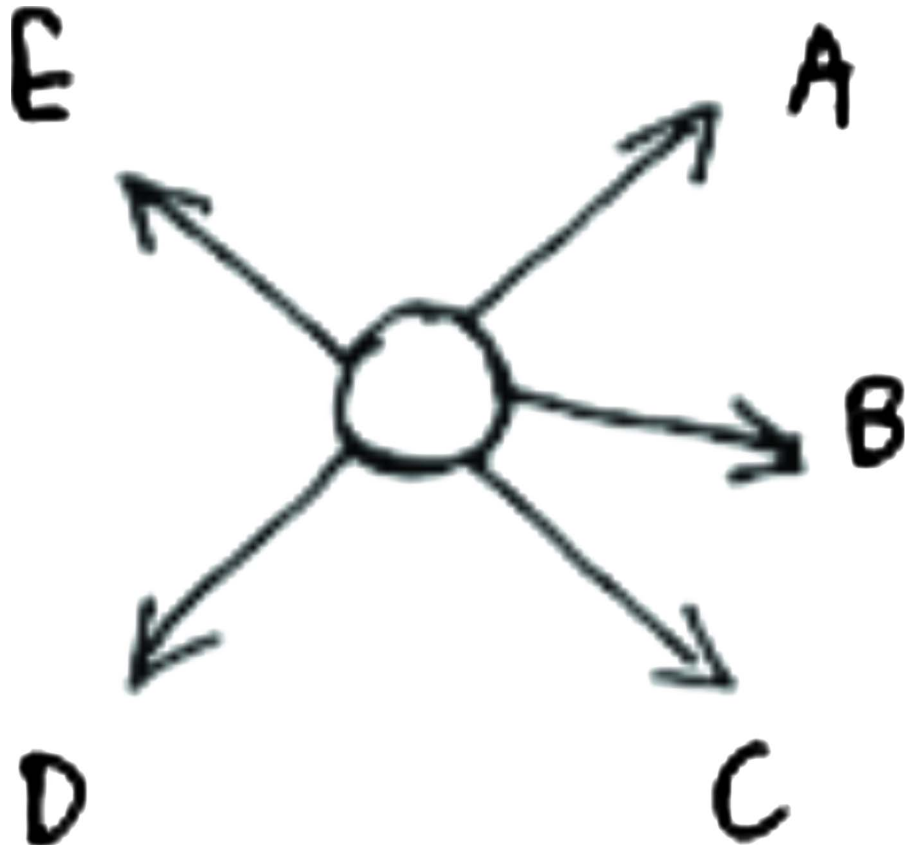

Figure 3. Figure in tutorial that students were asked to match each numbered position in Figure 1 with the arrow that best represented the direction of the comet's tail

2.2. Results

At the start of the next class session, students in all sections were again given Figure 1 as a formative assessment. Formative assessments are assessments that are given at times when they can be used to provide feedback to both the students and instructor on how well something has been learned while still allowing the addition to or the revision of student knowledge. This is different than summative assessments that are intended just to measure how much has been learned, which are often used to assign grades (Bransford *et al.* 2000; Brissenden *et al.* 2001; Donovan and Bransford 2005, Weimer 2002). Since the assessment was given at the beginning of the class period following the coverage of comets, prior to any evaluation for the purpose of determining a grade, the assessment was still part of the learning process and therefore formative.

This time (see Table 1) the sections that received the lecture on the topic, N=40, increased to 18%, a normalized gain, actual gain/possible gain (Hake 1998) g=0.15, of the drawings correctly showing the changing relative size of the coma, 33%, g=0.33 correctly showing the changing relative sizes of the tail and 65%, g =0.55 correctly showing the tail directions.

Table 1. Percentages of students drawing the coma and tail size and tail direction correctly on Figure 1 before and after instruction by lecture and tutorial

		N=93	N=40	N=47		
		Pretest	**Lec.-post**	**Tut.-post**	**g-lec.**	**g-tut.**
1	Coma size	4%	18%	46%	0.15	0.46
2	Tail size	13%	33%	70%	0.33	0.66
3	Tail direction	23%	65%	76%	0.55	0.69
4	Misconception	46%	20%	6%		

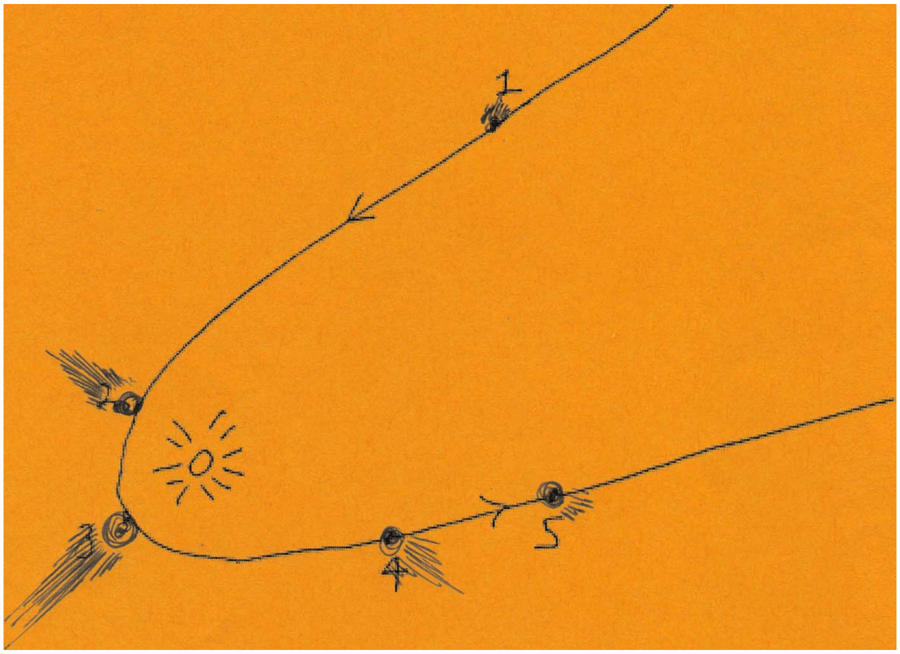

Figure 4. Student drawing showing correct variations in size of the coma and tail as well as correct orientations of the tail. Note that all students were taught in lectures that there are two tails on a comet but this was not considered part of this exercise (some students however did include two tails in their drawings)

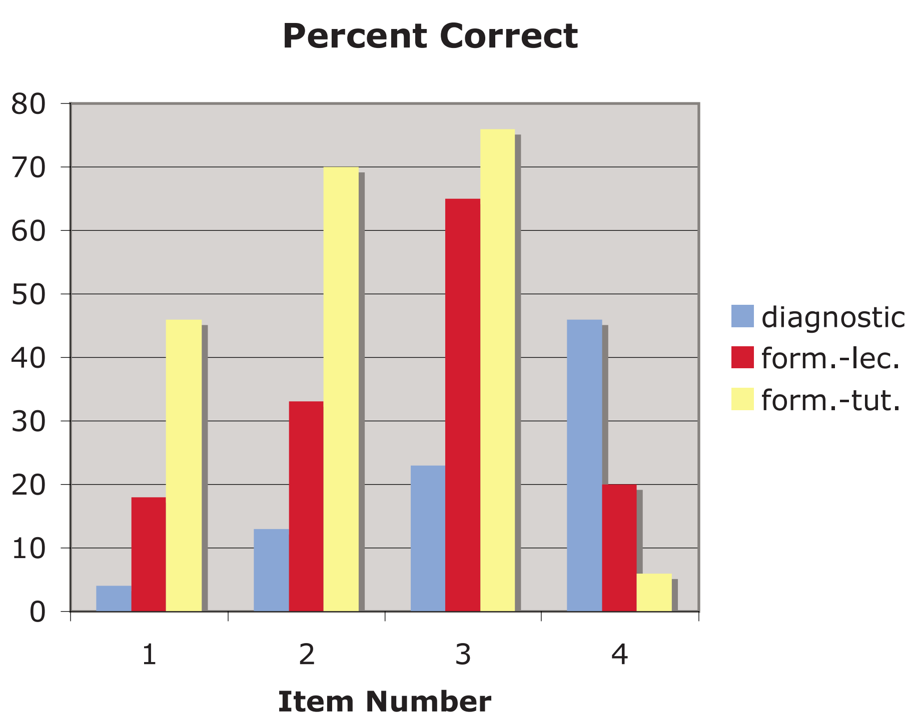

Figure 5. Percentage of correct drawings for each "item" the diagnostic assessment (blue) and formative assessment in lecture sections (red) and in tutorials sections (yellow). "Item" 1 is the relative sizes of the coma, 2 the relative sizes of the tail and 3 is the directions of the tail. Item 4 is the percentage in each group that made a drawing like Figure 2, head first, tail last

The sections that did the tutorial, N=47, did even better, 46% of drawings had the coma's relative size correct, 70%, g=0.66 the tail's relative size and 76%, g=0.69 correctly showed the changes in tail direction. Figure 4 is an example of what was considered a drawing correctly showing the changes in coma and tail size and tail direction.

20% of the students that received only the lecture still submitted drawings similar to Figure 2, showing the head first, tail last misconception while only 6% of those taught with the tutorial did so. Figure 5 is a histogram showing the percentages of correct responses on the assessment before and after instruction by lecture and tutorial. Figure 6 shows normalized gains, g.

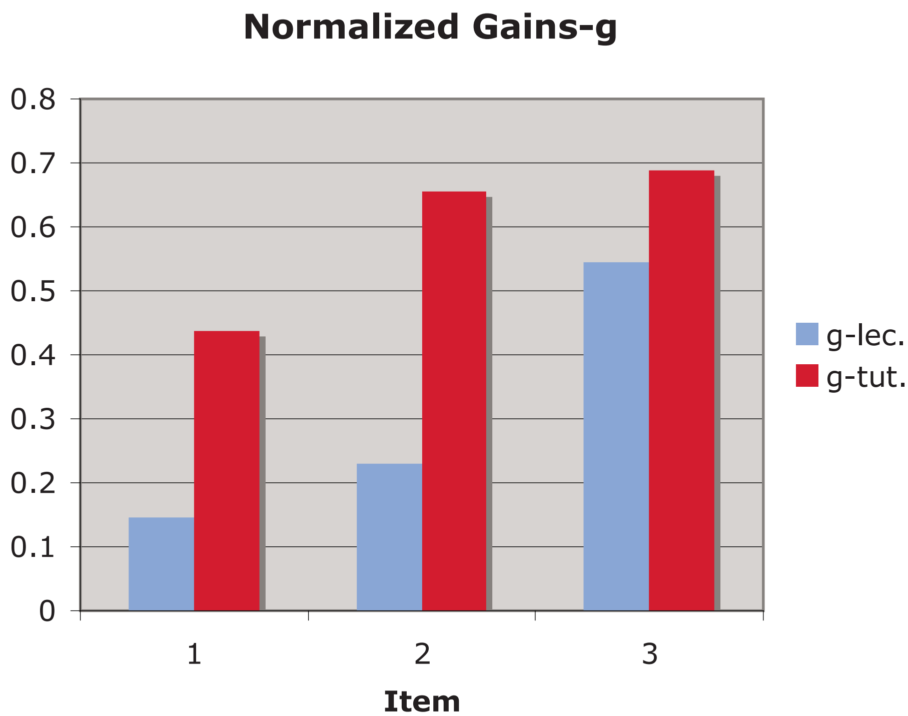

Figure 6. Normalized gains, g, on items from the diagnostic to the formative assessment in the lecture sections (blue), and in tutorial sections (red)

When the *Solar System Survey* was used as a post test a week after the exam on solar system topics, correct responses to the above shown multiple-choice question on the direction of a comet's tail paralleled results of the visual assessments (see Table 2), with 48%, g=0.4 correct responses in the lecture sections and to 55%, g =0.48 in the tutorial sections. The percentage still choosing "b" was 26% in the lecture sections and 18% in the tutorial sections.

Table 2. Percentages of students correctly answering multiple choice items from the *Solar System Survey* on comet tail direction and on what part of the comet does not change in size before and after instruction by lecture and tutorial

		N=100	N=46	N=38		
		Pretest	**Lec.-post**	**Tut.-post**	**g-lec.**	**g-tut.**
1	Tail direction	14%	48%	55%	0.4	0.48
2	Change in size	35%	46%	63%	0.17	0.43

Table 3. Comparison of percentages of students drawing the coma and tail size and tail direction correctly on Figure 1 in a formative assessment the next class period after instruction to summative assessments in sections taught by lecture and tutorial showing greater retention in the sections taught by tutorial

		N=40	N=46	N=47	N=38
		Lec.-form.	**Lec.-sum.**	**Tut.-form.**	**Tut-sum.**
1	Coma size	18%	9%	46%	61%
2	Tail size	33%	30%	70%	84%
3	Tail direction	65%	59%	76%	89%
4	Misconception	20%	15%	6%	3%

In another item from the *Solar System Survey*:

Which part of a comet DOES NOT appreciably change in size as the comet approaches or recedes from the Sun?

a. nucleus
b. coma (head)
c. tail
d. [neither b nor c change, only a does]
e. [no part of a comet changes with proximity of the Sun].

Percentages of correct responses, "a," in the lecture group went from 35% on the pretest to 46%, g=0.17 on the post test and to 63%, g=0.43 in the tutorial group.

The visual assessment shown in Figure 1 was given a third time, as summative assessment at the same time as the multiple-choice *Solar System Survey* was given as a post test, a week after the exam on solar system topics, approximately 3 weeks after the coverage of comets described above. Note that these summative assessments *were not* part of the exam. As seen in Table 3, the percentage of N=46 students from the lecture sections that correctly drew the relative sizes of the coma and tail and the directions of the tails *dropped* to 9%, 30%, and 59%, respectively, but the percentage of drawings showing the head first, tail last misconception also dropped to 15%. Percentages correct for N=38 students from the tutorial sections *rose* to 61%, 84%, and 89% with misconceptions dropping to a 3%, a single student in that population. In summary, the students who did the tutorials not only *outperformed* those who were lectured to on a formative assessment, but seemed to show greater *retention* on a summative assessment as well.

3. PART 2: EXTRA SOLAR PLANETS

3.1. Procedure

Prior to any instruction on but again after assigned reading (Bennett *et al.* 2009) on extrasolar planets N=84 students from the same four sections taught by the same two instructors in the Winter 2009 semester were asked to complete the visual assessment shown in Figure 7.

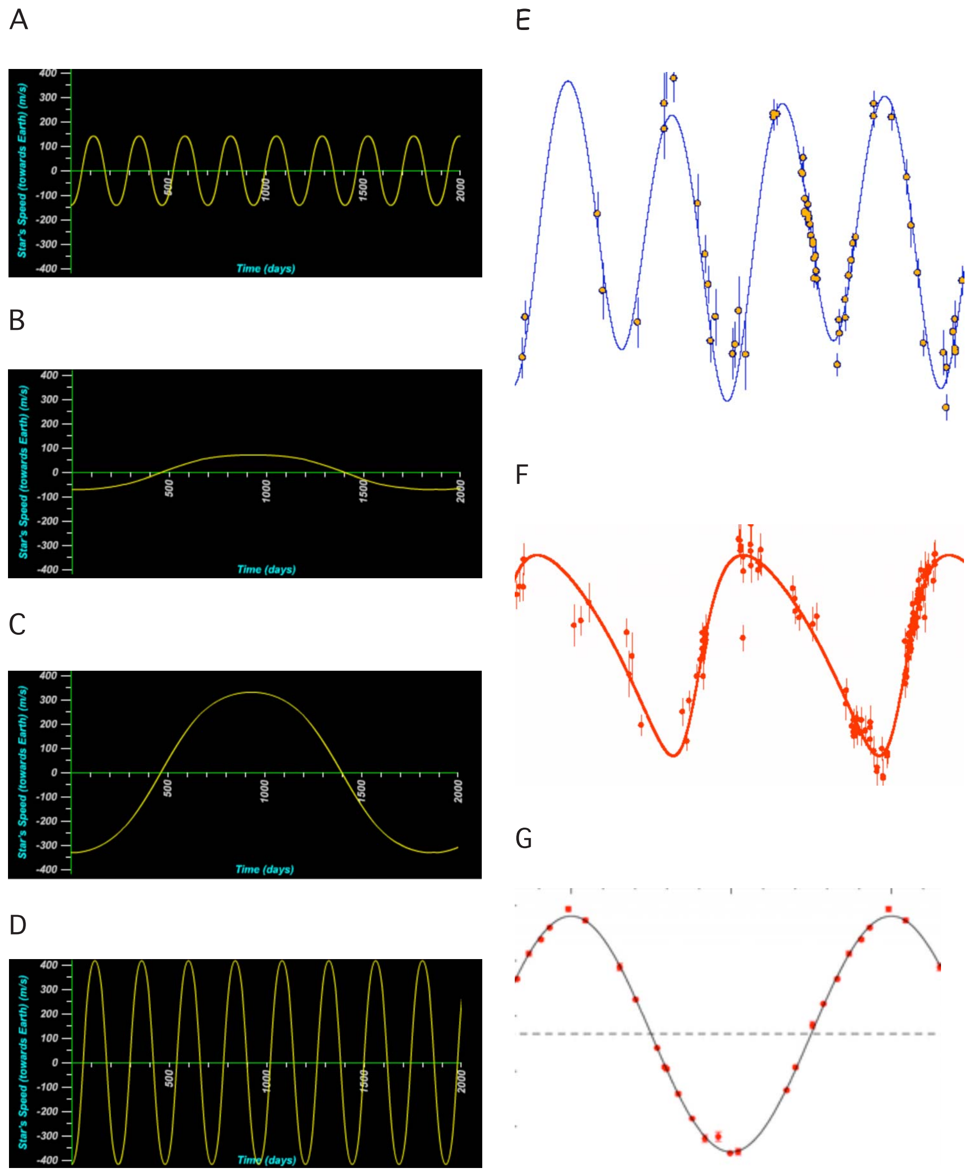

Figure 7. Visual assessment used prior to and after instruction on detection of extrasolar planets (see Note 2)

Extrasolar Planet Questions

1-Label each description with the letter that matches the plot that it most likely represents
_____A massive planet in a close orbit
_____A massive planet in a far orbit
_____A lighter planet in a close orbit
_____A lighter planet in a far orbit

D
C
A
B

2-Choose which graph below represents:
_____ A planet in an eccentric orbit
_____ A multiple planet system
_____ A planet in a circular orbit

F
E
G

With each response being scored as 1 point, students averaged 3.6/7=51% on the diagnostic assessment. 22/84=26% answered all four parts of question 1 (showing the effects the of the properties of the planet on the waveforms of the changing Doppler shifts) correctly and 45/84=53% answered all three parts of question 2 (on whether the waveform indicates a circular or eccentric orbit or the presence of multiple planets) correctly.

In the same fashion as with the instruction on comets described above, students in two sections (one taught by each instructor) received lectures featuring the website www.exoplanets.org as a visual aid and two sections were taught with the aid of a tutorial (see Note 1) that stresses student examination and construction of diagrams of how the waveforms of plots of the changing Doppler shifts are affected by planetary mass and orbital properties as well as orbital eccentricity and the presence of multiple planets.

3.2. Results

As with the assessments of instruction on comet-orbits, the sections that did the tutorial experienced greater gains on the formative assessment than the sections that received the lecture. Table 4 shows that the tutorial sections' (N=42) score on the visual assessment rose from 51% to 70%, g=0.4, while the lecture sections (N=49) rose to 60%, g=0.2. 62% of the tutorial section answered all four parts of question 1 correctly compared to 41% of the lecture group.

Table 4. Comparison of percentage scores on the extrasolar planets visual assessment shown in Figure 7 on diagnostic, formative, and summative assessments in sections taught by lecture and tutorial showing greater gains and retention in the sections taught by tutorial

	Diagnostic	Formative	Summative
Lecture	51%	60%	53%
Tutorial	51%	70%	70%

For question 2, only 50% of the tutorial sections answered all three questions correctly while 55% of the lecture group did so. Neither group showed much change from the above mentioned diagnostic assessment result of 53%. So while the tutorial shows an advantage over lecture in instruction on the effects of planetary mass and orbital distance on the waveforms (question 1), it does not seem to provide an advantage on the effects of eccentric orbits and multiple-planet systems (question 2), despite the fact that it includes sections about both. Overall, on the formative assessment 38% of the students in the tutorial sections had a perfect score on the visual assessment compared to 29% in the lecture sections.

The summative assessment was given, again, as with the comet-orbit visual assessment at the same time as administration of the multiple-choice, whole unit, *Solar System Survey*, 1 week after the exam on solar system topics. The N=38 students in the tutorial sections remained at 70%, about the level of their formative assessment, but the N=46 students in the lecture sections reverted back to near their preinstruction level of 53%. Again, as with comet-orbits, retention on the summative assessment seems to favor tutorials. Table 4 and Figure 8 show the percentages correct for each group on each assessment.

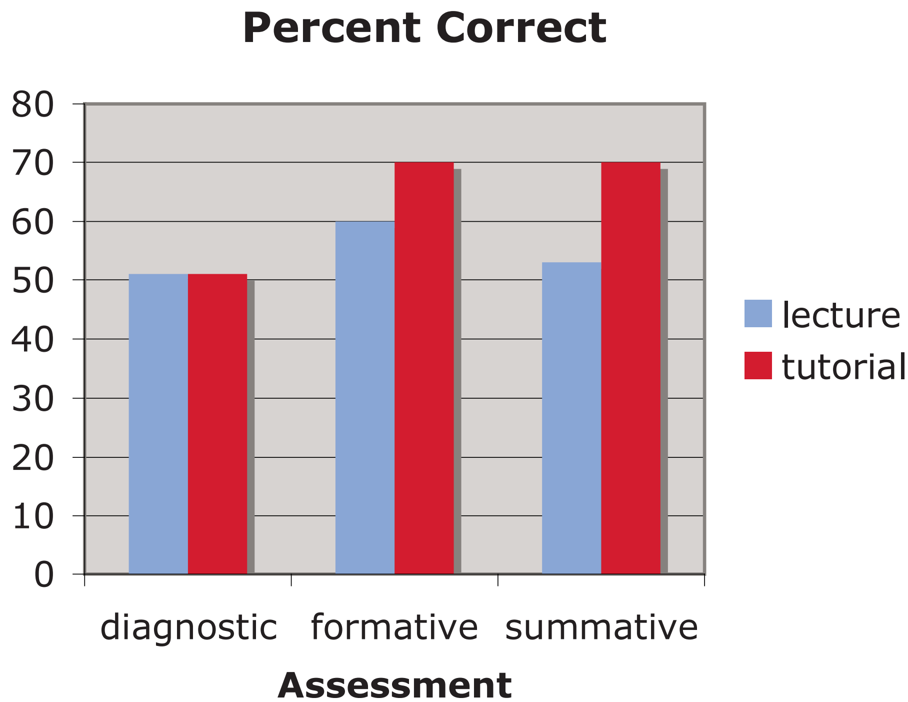

Figure 8. Percentage of correct responses on the diagnostic, formative, and summative exoplanet visual assessment for students given a lecture (blue) and doing a tutorial (red) on extrasolar planets

4. USE IN OTHER COURSES

The extrasolar planets visual assessment and tutorial were also used with some smaller groups including an introductory largely nonmathematical descriptive-physics survey course, for Allied-Health majors. In the physics course, N=36 students scored 56% on the visual assessment prior to any instruction or reading on the topic. This is similar to the introductory astronomy students who averaged 51%. After a similar lecture to what astronomy students received, again featuring www.exopplanets.org, the physics students scored 76%, g =0.45 on a formative assessment at the beginning of their next laboratory period. After doing the tutorial during laboratory period, the assessment was given a third time, as a summative assessment at the beginning of their next lecture period. They averaged 74%, nearly identical to their postlecture, pretutorial average, showing that, in this case, the tutorial did not increase what was already a large gain from lecture.

The students in the descriptive level physics class had not had any significantly different instruction on gravity and orbits than the astronomy students, but they did have much more experience with waves from previous study of sound and light. This could explain some of the difference in postinstruction averages.

Another, even smaller sample, N=17, came from an also nonmathematical descriptive *Science of Sound & Light* course for Fine-Arts students. These students averaged a surprisingly high 74% on the assessment *before* any instruction on extrasolar planets. This could be attributed to having studied sound and light waves for nearly an entire term. After a lecture that compared the effect of the mass of a planet on the changing Doppler shift's waveform to the effects of the loudness of sound or brightness of light on their waveforms and the effect of distance from the star to the pitch of a sound or wavelength of light the *Sound & Light* students averaged a 93%, g=0.71 on the visual assessment. However, as in the above-mentioned descriptive physics class, doing the tutorial afterward added virtually nothing to the already large gain.

Note that the physics students had gains from lectures alone that brought them to levels similar (76%) to that of the astronomy groups that did the tutorials (70%) and the sound and light students were at these levels (74%) prior to instruction. The reason for the fact that doing the tutorials after the lecture did not result in additional gains for either group is not clear, but any direct comparison to the results of the astronomy classes is difficult not only because the tutorials were done after the lecture rather than instead of the lecture, but also because what the students had been taught prior to coverage of extrasolar planets was much different than in the astronomy classes.

5. CLASSROOM USE

Suggested classroom use of the visual assessments and tutorials (when not using the assessment to test the effectiveness of the tutorials as in this study) is as follows. First, administer the assessments diagnostically, prior to any instruction, but possibly after assigned reading, then immediately deal with any misconceptions that are evident. This could be done active and collaboratively by students, having them exchange papers and discuss their results. Next, use the tutorials for instruction, preceded by short introductory lectures and followed by also short, wrap-ups or debriefings. At the beginning of the next class period, the assessments should be given again, this time formatively allowing the students to again compare results and discuss any problems that are still present. This will aid them in preparing for the eventual graded summative assessments on the subjects.

Using the visual assessments and tutorials in this manner includes all the steps in the recommended use of tutorials (Prather *et al.* 2004; Prather and Brissenden 2009) as well as the *National Research Council* recommendations for effective science teaching (Donovan and Bransford 2005). It also includes the *National Academies'* principles of "How People Learn" fostering a learning environment that is learner, knowledge, assessment, and community centered (Bransford *et al.* 2000).

6. CONCLUSION

The results of the study show that introductory astronomy students that did the tutorials had both greater gains and retention than those that received lectures on the same topics. This shows that, initially at least, both visual assessments and tutorials show promise as tools for learned-centered instruction in introductory astronomy. The assessments and tutorials presented here could perhaps serve as models for similar and potentially useful assessments and tutorials on other topics in introductory astronomy.

Acknowledgments

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NOTES

Note 1: Tutorials are available from the author (lopresto@hfcc.edu) on demand.

Note 2: Figures in second part of assessment used with permission from www.exoplanets.org.

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