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Effectiveness of Collaborative Ranking Tasks on Student Understanding of Key Astronomy Concepts

by **David W. Hudgins**
University of South Africa and Rockhurst University
Edward E. Prather
University of Arizona
Diane J. Grayson
University of Pretoria
Derck P. Smits
University of South Africa
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Abstract

This research concerns the development and assessment of a program of introductory astronomy conceptual exercises called ranking tasks. These exercises were designed based on results from science education research, learning theory, and classroom pilot studies. The investigation involved a single-group repeated measures experiment across eight key introductory astronomy topics with 253 students at the University of Arizona. Student understanding of these astronomy topics was assessed before and after traditional instruction in an introductory astronomy course. Collaborative ranking tasks were introduced after traditional instruction on each topic, and student understanding was evaluated again. Results showed that average scores on multiple-choice tests across the eight astronomy topics increased from 32% before instruction, to 61% after traditional instruction, to 77% after the ranking- task exercises. A Likert scale attitude survey found that 83% of the students participating in the 16-week study thought that the ranking-task exercises helped their understanding of core astronomy concepts. Based on these results, we assert that supplementing traditional lecture- based instruction with collaborative ranking-task exercises can significantly improve student understanding of core astronomy topics.

1. INTRODUCTION: THE NEED FOR RESEARCH-BASED AND CLASSROOM-TESTED ASTRO 101 CURRICULUM MATERIALS

Astronomy is arguably the most popular of the physical sciences among the general public. Each year, approximately 250,000 university students enroll in introductory astronomy courses in the United States (Fraknoi 2001), and at some point in their college career, almost 10% of all U.S. college students take a survey astronomy course (Partridge & Greenstein 2003). Statistics compiled by the American Institute of Physics reveal that introductory courses in astronomy are consistently the most popular science elective among non–science majors (Mulvey & Nicholson 2001). For most students, however, this is not just an introductory science course; it is the only science course of their university experience (Partridge & Greenstein). These facts lead to a heavy burden of responsibility for introductory astronomy instructors. This is probably the university's single opportunity to empower their nonscience graduates with the practical tool of scientific inquiry and to inspire them with a sense of wonder about the physical world.

Education research suggests that most students enter the science classroom on their first day with a real curiosity about the course topic (Redish, Saul, & Steinberg 1998). Despite this curiosity, most students complete their science class with lower levels of understanding of core topics than we teachers would hope for after our best efforts at lecture-based traditional instruction (Deming 2002; Prather et al. 2004; Hudgins 2005). Most painfully, our own research on teaching introductory astronomy shows that many students finish the course with an aversion to a science (as also found by Redish et al. 1998) that initially inspired their curiosity and wonder.

Surveys have shown (Fraknoi 2001; Walczyk & Ramsey 2003; Zeilik 2002) that introductory astronomy is still overwhelmingly taught using the traditional lecture format (didactic lecture and demonstration), although this is now often supplemented with generous audiovisual aids and perhaps some computer-assisted instruction. Yet a large body of research has demonstrated that prolonged lecture-based instruction is largely ineffective in promoting student understanding (Prather et al. 2004; Dykstra, Boyle, & Monarch 1992; Halloun & Hestenes 1985; Hestenes, Wells, & Swackhamer 1992; McDermott 1984, 1991).

Science education research has demonstrated that student understanding is improved when instructional strategies promote active student engagement in the learning process (Bonwell & Eison 1991; Prather et al. 2004; Hake 1998). The call has therefore gone out from the astronomy education community (Straits & Wilke 2003), and the science community as a whole (Walczyk & Ramsey 2003), to encourage learner-centered instructional approaches. However, development of appropriate material and successful implementation in the astronomy classroom requires considerable time and effort. Moreover, many introductory astronomy instructors do not have the pedagogical expertise or sometimes the content knowledge to develop appropriate materials. Therefore, the two greatest needs in astronomy education today have been identified as (1) the development of research-based curriculum materials, and (2) quantitative assessment of the effectiveness of these materials and classroom teaching strategies (Brissenden, Slater, & Mathieu 2002; Prather et al. 2004).

In an earlier effort to address the need for research-based astronomy teaching materials, Adams, Prather, & Slater (2002) developed curriculum material called lecture-tutorials. The effectiveness of these materials was later tested by Prather et al. (2004) when used as collaborative activities to supplement traditional instruction. Similarly, in the present study, we followed the first model by developing and testing collaborative astronomy ranking tasks for use as supplements to traditional instruction. Research shows that group activities that encourage social interaction help to promote learning (Johnson, Johnson, & Smith 1991, 1998; Johnson, Johnson, & Holubec 1994). To that end, we endeavored to create conceptual exercises that could easily be incorporated as collaborative activities in the classroom.

1.1 Research Questions

Our research questions are listed below.

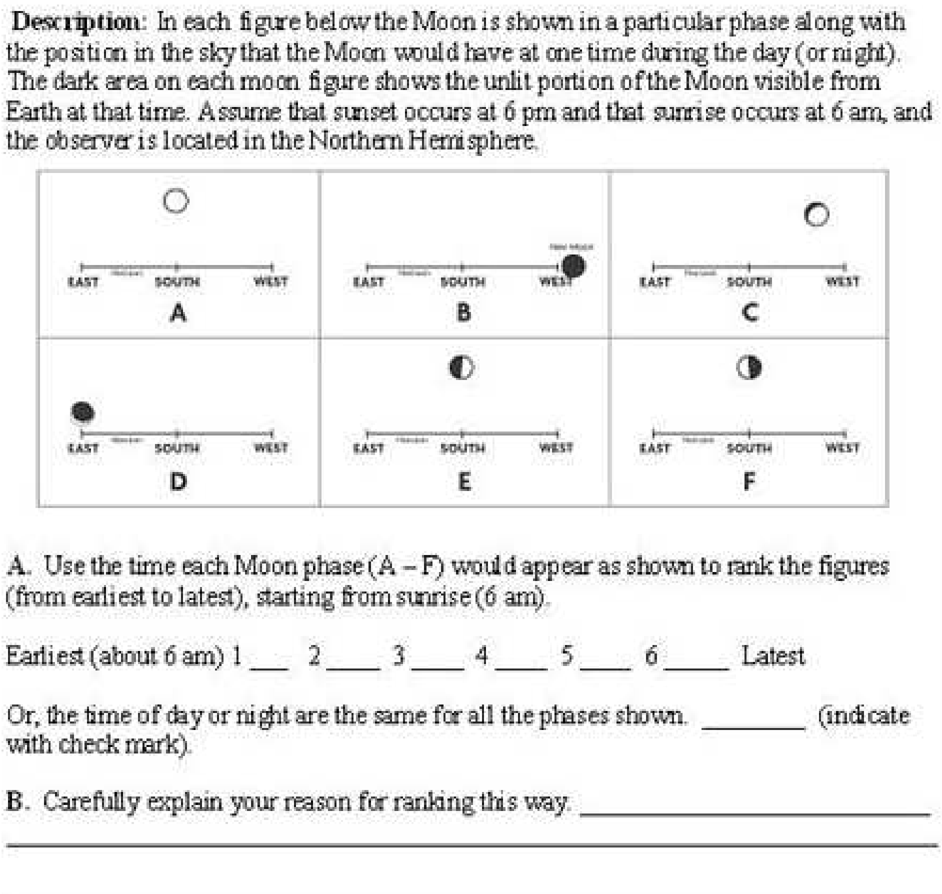
1. Does implementing a research-based program of astronomy ranking-task exercises result in student conceptual gains when used as collaborative activities in conjunction with traditional lecture-based instruction?
2. Are these gains sufficient to justify implementing them in the introductory astronomy classroom?
3. To what extent do students perceive ranking-task exercises to be valuable in the introductory astronomy classroom?

We believed that by focusing our research on answering these questions, we would help fill the need for research-based curriculum materials that are now largely absent in teaching introductory astronomy.

2. RANKING TASKS

Ranking tasks are a novel type of conceptual exercise first described in the field of physics education research by David Maloney (1987) and developed as physics classroom curriculum in the text by O'Kuma, Maloney, & Hieggelke (2000). Ranking-task exercises are based on a technique called rule assessment, originated by Robert Siegler (1976). Typically, ranking tasks present learners with a series of four to eight pictures or diagrams that describe several slightly different variations of a basic physical situation. The student is then asked to make a comparative judgment and to identify the order or ranking of the various situations based on some physical outcome or result. In this study, we developed ranking tasks in carefully structured sets focusing on each of eight specific core topics commonly taught in introductory astronomy courses. Each topical set consisted of five ranking-task exercises. The first three ranking tasks per topic were typically used as 20-minute collaborative exercises in class, and the remaining two ranking tasks were used as homework and served as problems for midterm exams.

Figure 1 presents an example ranking task developed for this investigation on the phases of the Moon. Additional astronomy ranking tasks examples are presented in the appendix.


Description: In each figure below the Moon is shown in a particular phase along with the position in the sky that the Moon would have at one time during the day (or night). The dark area on each moon figure shows the unlit portion of the Moon visible from Earth at that time. Assume that sunset occurs at 6 pm and that sunrise occurs at 6 am, and the observer is located in the Northern Hemisphere.

A. Use the time each Moon phase (A – F) would appear as shown to rank the figures (from earliest to latest), starting from sunrise (6 am).

Earliest (about 6 am) 1 ___ 2 ____ 3 ____ 4 ____ 5 ____ 6 _____ Latest

Or, the time of day or night are the same for all the phases shown. ________ (indicate with check mark).

B. Carefully explain your reason for ranking this way. ________________________
____

Figure 1. Example ranking task concerning the phases of the Moon.

The format of ranking tasks is unfamiliar to students and challenges them with an intellectual puzzle in which the path to solution is not immediately obvious. The multiple scenarios engage students' minds and force them to think more deeply about the critical features that distinguish one situation from another. A great advantage of ranking tasks is that their structure makes it difficult for students to rely strictly on memorized answers and mechanical substitution of formulae. In addition, by changing the presentation of the different scenarios (e.g., photographs, line diagrams, graphs, tables, and so on), we hypothesize that ranking tasks will require students to develop mental schema that are more flexible and robust.

3. DESIGN OF OUR ASTRONOMY RANKING TASKS

3.1 Theoretical Framework

In this study, we used a theoretical framework guided by the principles of constructivism and schema theory. The first guiding principle, constructivism, asserts that learners actively construct new knowledge by fashioning it to meet their own needs and capacities and then integrating it into their existing cognitive structure (von Glasersfeld 1981; Yeager 1991; Roth & Roychoudhury 1994). In our investigation, we designed our ranking tasks to initially elicit known student alternative conceptions (scientifically inaccurate beliefs) whenever possible. We then provided a series of conceptual exercises framed as ranking tasks, which provided a pathway to help students construct new knowledge.

Schema theory was the second principle in our theoretical framework guiding the design of astronomy ranking tasks. Schema theory views organized knowledge as an elaborate network of abstract mental structures that represent one's understanding of the world and is useful in explaining or predicting phenomena that we encounter in everyday life. This schema (sometimes called a "mental model") is generally regarded as consisting of "a framework or plan" (Stein & Trabasso 1982) of declarative knowledge, procedural knowledge, visual imagery, specialized language, categorization concepts, and rules and assumptions (Gentner & Stevens 1983; Anderson & Pearson 1984; Howard 1987; Wilson & Watola 2004). All of these are organized into a "network of connected ideas" (Slavin 1988), often called a schema.

Our astronomy ranking tasks were informed by schema theory primarily in the design of the sequence of related exercises covering each of eight core astronomy topics. Each series of exercises was designed to add robustness to student understanding by repeatedly framing the topic in a variety of different representations with increasing complexity of visual imagery, procedural knowledge, rules, and language.

3.2 Development of Astronomy Ranking Tasks

The astronomy ranking tasks developed in this investigation incorporated specific design features based on the results of science education research and were informed by pedagogical content knowledge (Shulman 1986; Grayson 2004)—that is, knowledge of specific difficulties and alternative conceptions that students are likely to have with particular topics, and teaching strategies to deal with those difficulties. To this end, our astronomy ranking-task sets confronted common alternative concepts and employed powerful analogies and comparisons with everyday experience (Bransford, Brown, & Cocking 2000).

We initially developed and pilot tested ranking tasks as structured sets of conceptual exercises for each of 12 introductory astronomy topics. These topics were drawn from surveys of commonly taught introductory astronomy topics complied by Brissenden et al. (1999) and Slater et al. (2001). Pilot testing with small groups of introductory astronomy students and astronomy graduate students helped us to identify a number of difficulties with the draft ranking tasks prior to the actual study.

After pilot testing of the original 12 draft sets of astronomy ranking tasks, we selected and finalized eight topical sets for use in classroom tests. These eight topical sets were (1) Motion of the Night Sky; (2) Seasons; (3) Phases of the Moon; (4) Kepler's Laws of Orbital Motion; (5) Gravity; (6) Luminosity of Stars; (7) Doppler Effect; and (8) Star Magnitude and Distance.

As mentioned earlier, we developed topical sets of five individual ranking tasks for each of these eight astronomy topics. In the end, we used these 40 ranking tasks for this research.

Based on the theoretical framework described earlier and the results from our pilot studies, each set of astronomy ranking tasks incorporated design features listed below.

1. *Scaffolding.* An essential feature of each topical set of ranking tasks was to begin by tying a major element of the astronomy topic to an idea within the everyday experience of the student. In an effort to engage students' prior knowledge, each ranking-task topical set starts with a familiar concept and then builds up to more complex, astronomy-specific applications. Results from our pilot study

suggested that it was useful to remind students of what they already know and focus their attention about the phenomenon before introducing more complex ideas that are unique to the field of astronomy. The strategy of *scaffolding* (a term coined by Wood, Bruner, & Ross 1976) guides student thinking through a series of increasingly complex ranking tasks. This enables students to reorganize existing knowledge, incorporate new language, and link new concepts as they build a more complete cognitive model of the astronomy topic.

2. *Conceptual to mathematical progression* Each set of ranking-task exercises provides repeated exposure to the concept at increasingly complex levels. In particular, the ranking tasks first focus on qualitative (nonmathematical) situations in order to promote conceptual analysis and deeper thinking by the student rather than relying on memorization or mimicking formula-based solutions. As appropriate to a topic involving specific formulae (e.g., Kepler's third law, Newton's law of gravity, Stefan-Boltzmann law), later exercises in the topical set were created that required quantitative thinking. These ranking tasks involved mathematical calculation or proportional reasoning in which students used numerical values obtained from diagrams, graphs, or tables of data.
3. *Multiple formats of presentation.* We designed the five astronomy ranking tasks within each topical set to progress through multiple forms of representation. Most often we presented the different physical situations using pictures, diagrams, graphs, and tables of data. The motivation for changing formats is to force the students to view the concept from a variety of perspectives, facilitating development of a more cohesive, robust, and versatile way of understanding.
4. *Elicit common alternative conceptions.* When we suspected or knew (Slater & Adams, 2003) of alternative conceptions or reasoning difficulties that students might harbor for a particular topic, we purposefully designed ranking tasks with physical situations that would elicit such scientific misconceptions. Physics education research has shown that traditional instruction produces little change in students' alternative conceptions (Hestenes et al. 1992). So we designed physical situations in the ranking tasks that provide the intellectual confrontation described by Posner et al. (1982) and Hewson (1981, 1982) as a requirement for conceptual change.
5. *Limit the number of physical situations in one ranking task.* Our experience in the pilot studies revealed that presenting more than six variations of a physical situation in a ranking task can result in student frustration and reduced participation due to what they viewed as excessive bookkeeping and repetition.
6. *Incorporate distracters.* In moderation, we found it useful to incorporate distracters, or attractive but unneeded information, in the ranking tasks. Providing this unneeded information can elevate students' critical thinking skills by challenging them to discriminate between relevant and nonrelevant information.
7. *Require student narrative explanations.* Finally, as suggested by Maloney (1987), each ranking task asked students to explain the reasoning underlying their ranking order. This required students to consider and identify the concepts or factors critical to the phenomena and to integrate those ideas into a cohesive argument that explicitly demonstrates that they understand how the appropriate physical laws could be used to predict or describe the outcome.

4. RESEARCH METHOD

4.1 Overview

This study used a one-group repeated-measures design. This design maximized the sample size and enabled more powerful statistical analysis by using matched-pair data from individual students across the three treatments: Preinstruction, Post–Traditional Instruction, and Post–Ranking Task. The primary data source was 253 students enrolled in an introductory astronomy course for non–science majors at the University of Arizona, a large Research Level-1 doctoral-granting institution.

4.2 Quantitative Testing

A bank of 28 multiple-choice questions was created that consisted of three or four questions for each of the eight key astronomy concepts covered in this study. These 28 questions were developed to address the most commonly taught aspects of the eight astronomy concepts covered in this study. Many questions were based on previously published evaluation instruments, including those from from Prather et al. (2004) and Seeds (2004), and the Astronomy Diagnostic Test (Hufnagel 2002). These questions were used in the Preinstruction and Post–Traditional Instruction assessments. For the Post–Ranking Task assessment, a second bank of 28 multiple-choice questions was developed. The questions were carefully designed to be conceptually similar, yet incorporated small changes in context that ensured students would be forced to reanalyze and provide unique answers to these questions.

On the first day of class prior to any instruction, student initial understanding was assessed using the 28-item multiple-choice Preinstruction test described above. The results from this Preinstruction test formed a baseline from which to measure subsequent changes in student understanding.

In later course meetings throughout the semester, as each of the eight selected astronomy topics was presented, students were provided with what can fairly be described as high-quality traditional instruction by an experienced and highly qualified astronomy instructor. Traditional instruction is defined as consisting of assigned preclass individual reading, and didactic lecture using carefully prepared PowerPoint visual aids, illustrations, and summary slides. It also included in-class computer-based demonstrations and animations, plus limited Socratic questioning of students. Typically, this traditional in-class instruction required about 30 minutes of a 75-minute class. After instruction, students took a three-or-four-item multiple choice Post–Traditional Instruction test covering only that day’s specific astronomy topic.

After the Post–Traditional Instruction tests, students worked in small self-formed collaborative groups to complete a set of three or four ranking-task exercises developed for that day’s astronomy topic. This required about 20 minutes of a 75-minute class. Completion of the ranking-task exercises was followed immediately by administration of a multiple-choice Post–Ranking Task assessment test consisting of three or four questions.

4.3 Qualitative Questionnaire

As a cross-check of the multiple-choice assessment tests, student understanding across a sample of three of the astronomy topics (phases of the Moon, luminosity of stars, and gravity) was also measured using qualitative questionnaires. These questionnaires posed a conceptual exercise that required both a word-based answer, including a narrative explanation describing how the student reasoned about the conceptual exercise. The questionnaires were completed by half of the students, who were randomly selected from the students in attendance, both Post–Traditional Instruction and Post–Ranking Task. A sample of the qualitative questionnaire concerning gravity is presented in Figure 2.

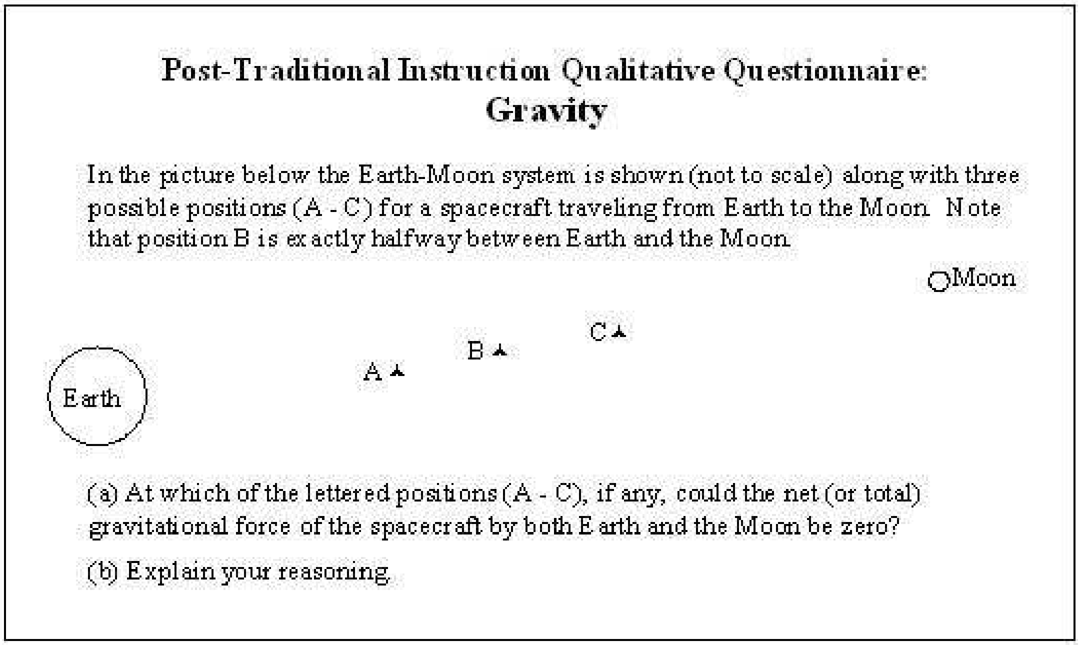


Figure 2. Sample qualitative questionnaire concerning gravity.

These written student narratives were analyzed qualitatively as described by Stemler (2001) using a level-of-understanding rubric defining five levels of student understanding. These levels were based on the student's use of scientific language, identification of critical variables, and conceptual linkages. The rubric that we developed for this analysis is presented in Table 1.

Table 1. Rubric for scoring student level of understanding from narrative responses.

Level of Student Understanding	Description
Level 5: Expert	Complex and accurate, student demonstrates a grasp of all relative concepts. Includes naming of critical variables and correctly describing how essential variables and rules affect the outcome of the phenomena. A robust general process described with correct scientific language.
Level 4: Functional	Yielding correct solution, but a briefer (but generally correct) description of major variables and interactions. Somewhat short of demonstrating a robust general process.
Level 3: Near functional	Student description identifies two or more relevant variables and relationships of relevant concepts but omits describing at least one essential element of knowledge. Description sometimes shows some minor confusion in language or terms but often still results in correct solution. However, the student description suggests a limited conceptual understanding that does not have the depth or flexibility to deal with small changes in the format or presentation of the problem.
Level 2: Subfunctional	Student explanation correctly identifies at least one relevant variable, but only portions of the component concepts are demonstrated. Important interrelationships of variables are not suggested by student narrative, and the student's description may include significant misapplication of language, contradictions, or simplifications of logic.
Level 1: Unstructured/alternative	Student may identify one relevant variable, but he or she does not describe or appear to recognize any of the component concepts. Or, the student describes an alternative model not based on science studies.

The rubric was tested for reliability and repeatability in terms of the consistency of scoring student level of understanding. Three experienced astronomy instructors used the rubric to each independently score pairs of Post–Traditional Instruction and Post–Ranking Task narrative responses from a sample of 15 students. T tests showed that there was no statistical difference in scoring student responses among the instructors. This test demonstrated the interrater reliability of the scoring process using the rubric. Ultimately one author (Hudgins) scored all Post–Traditional Instruction and Post–Ranking Task student responses (approximately 180) for a quantitative measure of level of understanding.

In summary, the level-of-understanding rubric provided an independent numeric score for comparison with the multiple-choice test results. In addition, this qualitative analysis provided a window into student conceptual change resulting from the ranking-task treatments, as discussed in the Results section.

4.4 Student Attitude Survey

A Likert scale survey form was developed and given to all student participants at the end of the semester to investigate their attitudes about using ranking tasks as part of their instruction. The survey form addressed student impressions regarding ranking tasks, how well these exercises contributed to their learning while working in collaborative groups, and whether they believed that ranking tasks enhanced their understanding of course material. After the Likert scale questions, the survey asked students to describe their overall experience with ranking tasks using a free-response question.

5. RESULTS

5.1 Quantitative Assessment Using Multiple-Choice Questions

As described in the previous section, we measured student understanding of eight key introductory astronomy topics at three points in the instructional process: Preinstruction, Post–Traditional Instruction, and Post–Ranking Task. Based on research into the effectiveness of traditional lecture-based instruction, we anticipated that there would only be modest gains from Preinstruction to Post–Traditional Instruction. In fact, with an average sample size of 131 students, across each of the eight astronomy topics, we observed an average preinstruction score of 32% correct, rising to an average of 61% correct after traditional instruction. These results agree closely with previous research on gains by introductory astronomy students after traditional instruction (Prather et al. 2004). Although statistically significant (alpha < 0.05), these gains demonstrate once again that even the best lecture-based instruction is far less effective in promoting student understanding of astronomy topics than we teachers would like to believe.

Our first research question was whether implementing a research-based program of astronomy ranking-task exercises results in student conceptual gains when used as collaborative activities in conjunction with traditional lecture-based instruction. In Figure 3, we present results of the three treatments across each of eight astronomy topics. On average, it shows that test scores rose from 32% (preinstruction) to 61% after traditional instruction, increasing to 77% after students completed the collaborative ranking-task exercises. Using the standard course-grading rubric, the ranking tasks helped students improve their understanding over these eight topics an equivalent of 1 1/2 letter grades.

In this experiment, we assessed ranking tasks as a supplement to traditional instruction because we believe that this will be the most common strategy for implementing these conceptual exercises in an existing classroom. However, in this one-group design, we cannot say conclusively that the gains reported here are due strictly to incorporating a program of ranking tasks. We recognize that perhaps some gains might result from simply extending the lecture. Yet significant prior research demonstrates that the very limited gains in student understanding occur by longer lecture time. As a result, we assert that the rise in test scores from 61% to 77% is a very substantial and positive gain. This gain is especially notable if one considers that students in this study received no credit toward their final grade for working through the ranking tasks. Sadly, we observe that there is always a certain fraction of students who remain unmotivated to intellectually engage during such classroom exercises.

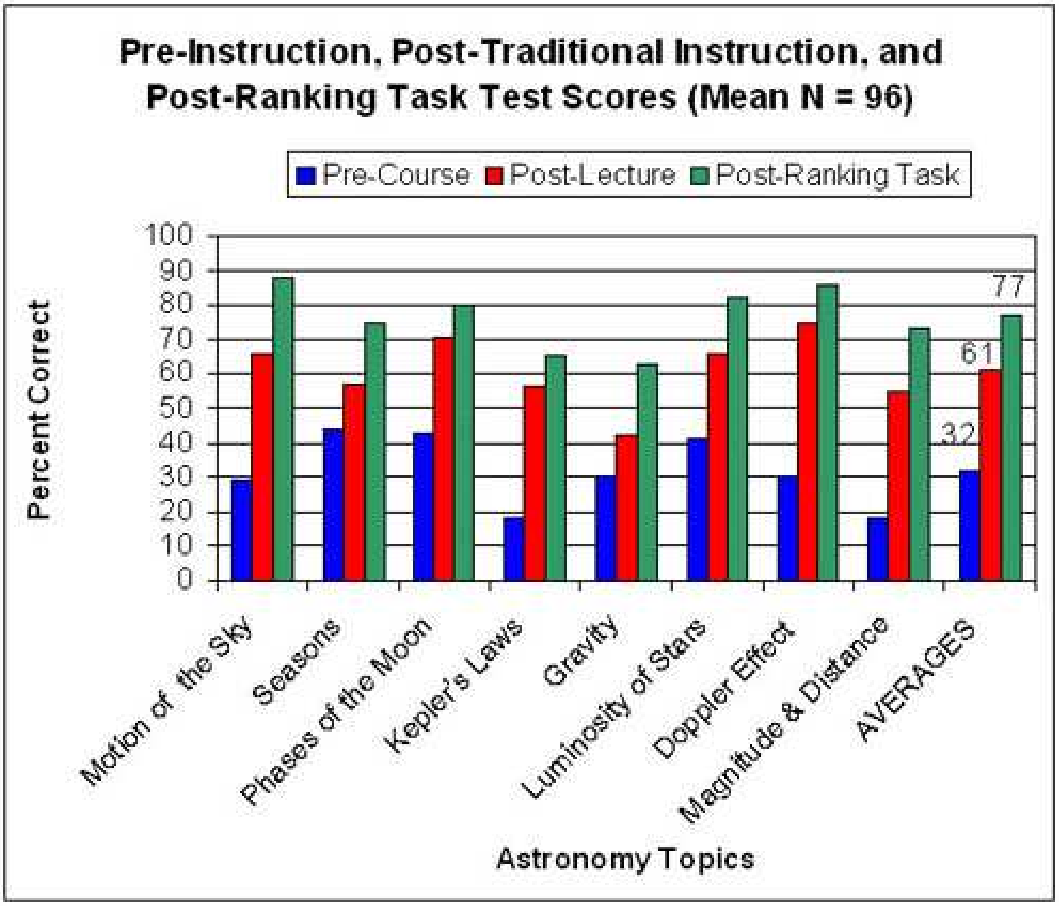


Figure 3. Preinstruction, Post–Traditional Instruction, and Post–Ranking Task test scores across eight astronomy topics.

A series of mixed-factors analyses of variance (ANOVAs) were performed on student scores from Preinstruction, Post–Traditional Instruction, and Post–Ranking Task tests (repeated factors) for each of the eight astronomy topics in this investigation. The ANOVA was followed by calculation of least significant differences (LSD) between the Post–Traditional Instruction and Post–Ranking Task test scores in order to test student gain between the two treatments. The ANOVA and LSD tests show that student mean test scores rose significantly after traditional lecture-based instruction (as one would hope). Most important to the research questions in this study, test scores across all eight astronomy topics also rose very significantly ($p < 0.05$) after the ranking-task treatment.

Our second research question was whether the gains resulting from adding collaborative ranking-task exercises to traditional instruction were sufficient to justify implementing them into the introductory astronomy classroom. These inferential statistics tell us that the test scores after the ranking-task treatment are statistically different from the Post–Traditional Instruction scores. However, a better measure of test score gains is needed to actually answer this research question.

A useful metric often reported in educational research is the average normalized gain (<g>) first described by Hovland, Lumsdaine, & Sheffield (1955). This is defined as the ratio of the actual average gain compared to the maximum possible gain, or

$$\langle g \rangle = G_{actual} / G_{maximum} = (\%\langle S_f \rangle - \%\langle S_i \rangle) / (100 - \%\langle S_i \rangle).$$

The average normalized gain is useful because it provides a standard way to compare results across metastudies of treatment effects (Becker 2000; Hake 1999). Figure 4 presents the normalized gains resulting from traditional instruction and from the ranking-task exercises across the eight studied astronomy topics. Averages across all topics are presented at the far right of the figure.

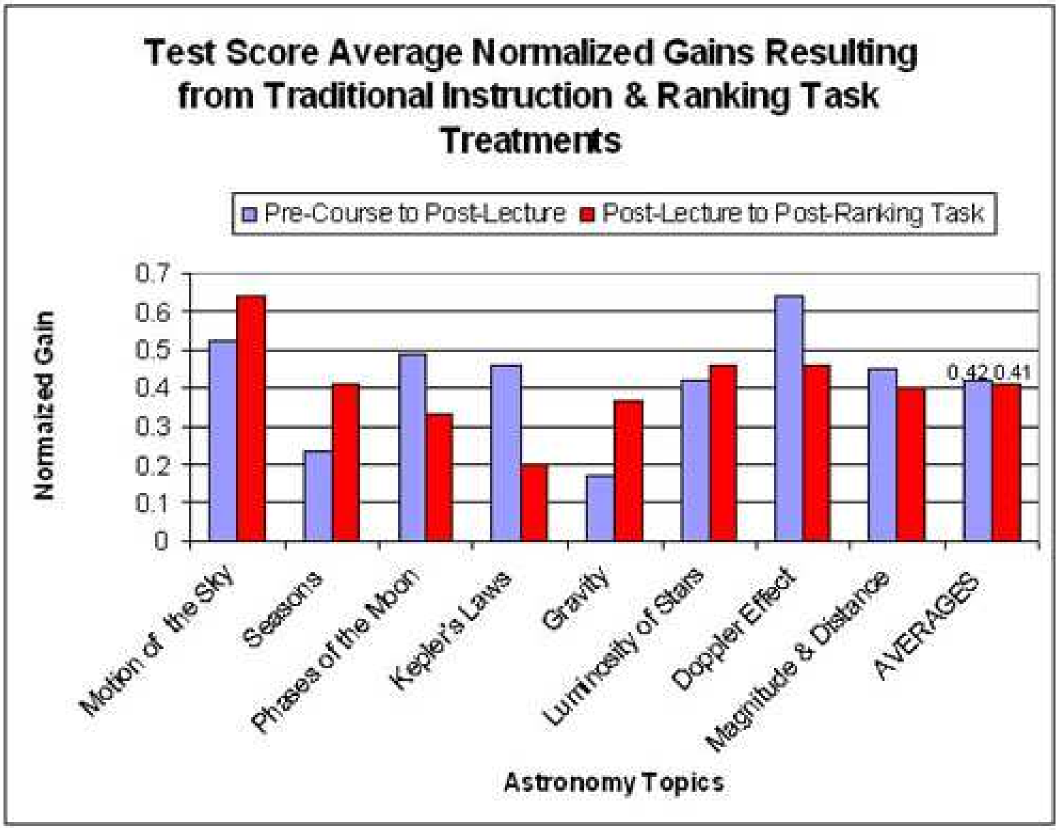


Figure 4. Normalized gain in test scores when ranking-task exercises are added to traditional instruction in this study of eight key astronomy topics.

As shown in Figure 4, an especially interesting conclusion of this study is that the average normalized gain resulting from the ranking-task treatment (<g> = 0.41) is statistically equal to the earlier gain (<g> = 0.42), which resulted from the various approaches incorporated in traditional instruction. We find this result astonishing. Put another way, this investigation shows that the gains from three collaborative ranking-task exercises completed by students working collaboratively in a large lecture class for 20 minutes produced a gain in understanding equivalent to the entire array of carefully prepared traditional instruction that preceded the ranking tasks.

As a result, we assert that student understanding is very significantly improved when a research-based program of collaborative ranking-task exercises is incorporated in the classroom with traditional lecture-based instruction.

5.2 Qualitative Assessment Using Free-Response Questionnaire

Our first research question asked whether a program of collaborative astronomy ranking-task exercises results in student conceptual gains when used as a supplement to traditional lecture-based instruction. As a cross-check of results from the multiple-choice assessment tests, we sought to investigate student conceptual change in a more qualitative way. For three of the eight astronomy topics, we therefore posed a conceptual question to half of the students (matched pairs; $N = 29$) that required both a word-based solution and a narrative explanation describing how the student reasoned about the conceptual exercise. These free-response questions were posed for both Post–Traditional Instruction and Post–Ranking Task. Student responses were scored for level of understanding using the rubric described in section 4.3.

Averaging across all three astronomy topics, the student level of understanding scores rose from 2.6 (Post–Traditional Instruction) to 3.6 after the ranking-task treatment ($N = 114$). For each topic, a *t*-test showed that this increase was significant (alpha = 0.05). This result from the qualitative assessment portion of our study agrees with results from the quantitative portion using the multiple-choice tests. Both assessment methods conclude that student understanding increased significantly after completing the ranking-task exercises.

Table 2 is provided to illustrate the typical evolution of student understanding from Post–Traditional Instruction to Post-Ranking Task. Actual responses are presented from two students (pseudonyms are used) demonstrating their understanding of the phases of the Moon and gravity. A brief discussion of the student responses is also provided.

Table 2. Examples of Post–Traditional Instruction and Post–Ranking Task narratives by two students concerning gravity and phases of the Moon.

Post–Traditional Instruction	Post–Ranking Task
Chris (explaining phases of the Moon): "The Moon goes through phases because it is rotating around the Earth, allowing more or less of the illuminated light to be seen each preceding day." **Analysis:** Student correctly refers to motion around the Earth and changing amount of "illuminated light to be seen." However, key ideas that the Moon is always half lit and that the changing angle at which we see the Moon with respect to the Sun determines the phase we see are not expressed. There is a partial framework of ideas, but it is not cohesive.	**Chris (explaining phases of the Moon):** "The Moon goes through phases because half the Moon is lit at all times by the Sun, but we on Earth can only see part of the lit surface, so as the Moon orbits the Earth we see more or less of the lit surface." **Analysis:** After the ranking tasks, the student correctly mentions important language and ideas ("orbit," "Moon is half lit," "as Moon orbits Earth we see more or less of the lit surface"). This reflects a more complete conceptualization of key ideas.
Jennifer (explaining at what location between the Earth and Moon the net gravitational force on a spaceship becomes zero as it travels between the two bodies): "Halfway, because exactly halfway causes the Moon's and Earth's gravitational pulls to cancel out." **Analysis:** The student realizes that both the Earth and Moon exert a gravitational force on the spaceship. However, she does not recognize how the differences in mass between the two bodies vary that force with distance. Thus, her answer is incorrect.	**Jennifer (explaining at what location between the Earth and Moon the net gravitational force on a spaceship becomes zero as it travels between the two bodies):** "Closer to the Moon than to the Earth. Because Earth has a greater force on the spaceship than the Moon. But when the spaceship is closer to the Moon, the Earth loses some force while the Moon gains some, until their strengths become equal. And this is closer to the Moon." **Analysis:** The student now recognizes that the Earth exerts a greater gravitational force on the spaceship compared with the Moon, suggesting that she recognizes that mass is a critical factor. She sees that distance is also important and that gravitational force from each body depends on the distance. She correctly recognizes that there is a balance point closer to the Moon to satisfy both conditions, demonstrating a more complete model of the phenomenon.

Asking students to explain their problem-solving strategy in a free-response narrative gave us an unexpected insight into the development of their schema. In their written responses to a question that relied heavily on spatial relationships and visual imagery, we observed a substantial increase in the frequency of diagrams or sketches in student responses in their Post–Ranking Task explanation when compared with their earlier Post–Traditional Instruction explanation. This was demonstrated most clearly in student free-responses explaining the phases of the Moon. During the lecture, students were exposed to a variety of visual representations of this phenomenon. In their Post–Traditional Instruction narratives, only 10% of students used visual representations to express their understanding. However, after the ranking-task exercises, 27% of students added a diagram to their explanation. We interpret the more frequent use of diagrams to indicate that the ranking tasks enabled a greater number of students to construct a useful visual representation of the phenomena as part of their mental model.

Despite the positive conceptual gain observed in this study, the free-response questionnaire also reveals the fragile nature of student understanding (both Post–Traditional Instruction and Post–Ranking Task). After both treatments, we observed that the degree of sophistication in most student responses remained below a level that demonstrated a true mastery of the content.

5.3 Student Attitudes about Ranking Tasks

Our final research question asked about the perceived value that introductory astronomy students attribute to the ranking-task exercises. At the end of the study, 132 students completed the Likert scale attitude survey. This survey revealed that 83% of students believed that ranking tasks contributed positively to their learning, and 72% thought that the exercises helped them on tests. Overall, about 16% of students gave responses that tended toward a negative attitude about ranking tasks—a figure that agrees with previous studies that report a similar fraction of non–science major students who simply prefer a passive role in science class rather than participating in active-engagement activities (e.g., 15% negative reported in use of personal classroom transponder devices by Dokter et al., 2004).

In a free-response question included in the attitude survey, students were asked to describe their overall impression of the astronomy ranking tasks developed in this study. Because 83% of students reported that ranking tasks helped them learn, there were frequent general responses such as "ranking tasks helped me think," "gave good practice," and "I learn better like this in a group." But many students provided more useful elaboration and insight, such as these representative quotes:

> ". . . they helped us learn more ways to solve a problem, and show . . . more possible scenarios of the subject matter."

> "Some concepts discussed in class are difficult to understand because I've never had to think in astronomy terms. The ranking tasks helped me understand the concepts in my own terms, rather than just being told a right or wrong answer."

> "I like how the exercises started with a simple idea that I knew (like the hot plates), then went on to more complex things like the brightness of stars."

> "The order of the ranking tasks was just right for your brain to make connections between concepts and how they are related."

> "Ranking tasks definitely helped me in conceptualizing. Because the [astronomy] ideas are so abstract, using pictures and real life things are a big help."

6. CONCLUSIONS AND IMPLICATIONS FOR TEACHING

6.1 Merits of this Study in Astronomy Education Research

We believe that the results of this investigation have important implications for astronomy education research and the teaching community. It responds to the call for the development of research-based and pedagogically sound curriculum materials. Further, this research demonstrates that research on teaching and learning can be done in effectively in large lecture astronomy courses and that such research can move our community forward by establishing a standard of assessment for interventions proposed for "Astronomy 101" instruction.

Our approach was to investigate the effectiveness of both the traditional instruction and ranking-task treatments across a moderately large number (eight) of different core astronomy topics. We expected (and saw) that students held widely varying degrees of preinstruction knowledge about different astronomy topics. For example, there was almost no initial understanding of Kepler’s laws and magnitude/distance relationships, but a significant portion of students began the course with a partial understanding of the seasons and phases of the Moon. We also expected (and saw) that the effectiveness of the intervention, as measured by normalized gains, varied by topic across the two treatments. Lecture produced only small gains in student understanding about gravity and seasons when compared with the larger gains resulting from the ranking tasks. However, for Kepler’s laws, we saw that lecture produced larger normalized gains than the ranking-task treatment. By investigating a moderately large sample of eight different topics, we assert that our general results and averages are representative of the effect of lecture-based traditional instruction and the ranking-task intervention over a broad range of key introductory astronomy topics.

6.2 Implications for Teaching

We summarize our conclusions and implications for teaching.

6.2.1 Ranking tasks help students learn.

The central implication of this study is the compelling experimental evidence from which we assert that implementing a research-based program of astronomy ranking-task exercises results in significant student conceptual gains when used as collaborative activities in conjunction with traditional lecture-based instruction. These gains in understanding are demonstrated by average multiple-choice test scores rising from 31% correct on the preinstruction test, to 61% after traditional instruction, to 77% after the ranking-task treatment. The Post–Ranking Task normalized gain (Hake 1999) was not only substantial, but also we find it impressive that this gain was statistically equal to the gain from the entire previous program of traditional instruction.

Results from the multiple-choice assessment tests were cross-checked and confirmed by qualitative analysis of student responses when asked to explain how they reasoned about sample exercises concerning three astronomy topics. After the ranking-task treatment, students more frequently correctly identified critical concepts, properly used specialized language, and added diagrams and sketches that we assert demonstrates more robust understanding of the astronomy topic.

6.2.2 Students think that the astronomy ranking tasks help them.

The attitude survey clearly showed that the great majority of students (83%) thought that ranking tasks helped them learn.

6.2.3 Ranking tasks can be successfully designed for implementation into the Astro 101 classroom.

Although surveys have shown that lecture remains the key instructional component in most college science classrooms (Fraknoi 2001; Walczyk & Ramsey 2003; Zeilik 2002), education research shows that a traditional lecture has only limited effectiveness in promoting learning. Our study found that a suite of well-designed ranking-task exercises can be easily incorporated into both small and large introductory astronomy classrooms. The exercises require only minimal training of instructors and students in their use, and they do not require radical changes in classroom protocol. After a brief lecture (15–20 minutes), we found that students were able to form groups quickly on a daily basis. These collaborative groups could then successfully complete a series of three or four ranking-task exercises in 15–20 minutes. More challenging ranking tasks could then be incorporated into homework assignments.

Proper introduction of the raking task format is essential to success. Almost all students found the format of the ranking tasks quite novel, and we observed both positive and negative first reactions. For many students, the lack of "hints" typical of multiple-choice questions, or the lack of a clear mathematical algorithm that they could simply "plug and chug" into to solve problems, was found to be an obstacle at first. We introduced students to the ranking-task format with a number of simple examples from everyday life, such as ranking photographs of several people by age. Students must be shown how to record their answer, particularly when two or more of the situations are equal. After a little practice, students had little difficulty with the format.

Additional considerations in design and classroom implementation. Some additional observations from our pilot studies and the main data collection phase that we believe should be considered when designing and implementing ranking tasks include the following:

a) In selecting astronomy topics for ranking tasks, we found that the nature of these conceptual exercises is more suited to some topics than to others. We first looked for topics in which the student must consider the interaction of several variables in predicting an outcome, paying special attention to situations of equality—that is, when particular combinations of variables can produce the same outcome. These include, for example, luminosity of stars, magnitude-distance relationships, Kepler's laws, and phases of the Moon. Computational topics such as these are easily represented as ranking exercises. In addition, we found ranking tasks also compatible with astronomy topics that involve categorization (e.g., scale of objects in the universe) and process sequences (e.g., evolution of stars). In contrast, we found it more difficult to create ranking tasks on topics based heavily on declarative knowledge (e.g., names of the various planets, astronomy history).
b) As in any conceptual exercise, avoid wording that is overly technical or possibly ambiguous. In our scaffolded series of ranking tasks, we found that special care was needed when there were only slight changes in wording or directions from one exercise to the next. In our pilot studies, students often asked for critical wording changes to be underlined or highlighted. However, there is arguably great value in requiring students to read each exercise carefully.
c) About 12% of students reported that they found the ranking tasks somewhat repetitive in nature. We conclude that it is important to design as much variety as possible within each ranking-task set—for example, changing the method of presentation (diagrams, graphs, photographs) and mixing up both everyday and astronomical applications that demonstrate the concept.
d) Maintaining student motivation is important to keeping them engaged in the learning process. After the collaborative ranking-task activities, instructors should always include a brief time to review

"correct" answers with students. In addition, we found it useful to randomly have students read aloud their narrative explanations for their rankings as required in the exercises. We observed that this review maintains interest by spurring discussion and resolving friendly disputes within study groups. Alternatively, a hard-copy answer sheet available in the classroom or online might be substituted. However, posting solutions would provide less intellectual engagement during class time once students realized that all the answers would be available after class. Further, future students may come to class with the solutions you have posted if the ranking tasks are not significantly changed. In the end, students may resort to memorizing the answers of the solutions rather than trying to complete the ranking tasks themselves.

e) Motivation is further encouraged by including the more challenging ranking tasks as homework assignments, followed by discussion in class. Finally, it is important that ranking tasks appear regularly on quizzes and exams in order to illustrate to students that these activities are a central component of the course and that the ideas developed are important, as illustrated by the assessments used.

f) As first observed by Maloney (1987), we also found that development of effective ranking-task exercises is very much an iterative task. In our investigation, while students learned from the ranking tasks, we also learned along with them how to best design and use these exercises in the astronomy classroom. It usually took about three iterations in the design and classroom implementation of a ranking task in order to achieve the optimal learning outcome.

6.2.4 Publication of additional astronomy ranking tasks.

We are investigating the publication of the ranking tasks developed in this study and an expanded list of topics suited to the Astro 101 classroom. We hope that these will be available within the next year. Please contact the first author (david.hudgins@rockhurst.edu) for updates on this publication.

6.3 Future Research

Further questions for future research include the following:

1. How does the efficacy of collaborative ranking tasks used in conjunction with short lectures compare with an equivalent increase in "time on task" using traditional instruction?
2. Topics in introductory astronomy often (1) involve the interaction of variables (e.g., gravity, orbital period, star luminosity) or (2) can be more narrative or procedural in nature (e.g., evolution of stars, scale of objects in the universe, the nature of light). Is ranking tasks equally effective in promoting learning for these two types of astronomy topics?
3. Does gender or the level of student initial knowledge state about astronomy affect learning gains from ranking-task exercises?

We note that further testing of this curriculum material is needed to ensure portability to other student demographics and by instructors less familiar with the teaching strategy.

In conclusion, we have provided examples of a new learner-centered instructional strategy for introductory astronomy courses, namely ranking tasks, which we have shown to be effective in increasing student understanding of key concepts. We believe that this work has made a contribution to addressing the needs in the astronomy education community identified at the beginning of this article–namely, the need for research-based curriculum and the evaluation of new instructional materials and teaching approaches.

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APPENDIX

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