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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Astronomy, the study of the physical Universe beyond our Earth, 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). Most compelling are statistics compiled by the American Institute of Physics revealing 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 (Prather, Slater & Adams, 2004; Partridge & Greenstein, 2003). For most non-science college students, introductory astronomy presents a singular opportunity to grasp the meaning and value of scientific inquiry, and to motivate a sense of wonder and appreciation for the larger Universe around them.

Education research suggests that most students enter the science classroom on that first day with a very real curiosity about the course topic (Redish, Saul & Steinberg 1998). However, despite this curiosity most students complete their science class with only a negligible gain in understanding of the core topics commonly taught (Deming, 2002; Prather, Bailey & Slater, 2003). Most painful to astronomy educators, we observe that some students finish the course with an aversion to a science (as also found by Redish, 1998) that once inspired their curiosity and wonder.

Many studies have concluded that the educational systems in the United States and some other industrialized nations are missing opportunities to serve their students' science education needs. Studies such as *A Nation at Risk* (National Commission for Excellence in Education, 1983) and more recently *Trends in Third International Mathematics and Science Study, TIMSS 2003* (Gonzales *et al.* 2003) demonstrate the need for corrective action. While much of the focus has been on pre-college (K-12) education, there is considerable evidence that colleges and universities could do a better job of preparing future scientists and producing a scientifically literate public. Much of this evidence comes from the related field of physics, in studies such as those by Laws (1997), Redish and Steinberg (1999), and Crouch and Mazur (2001). Further evidence is seen in national studies such as *Shaping the Future* from the National Science Foundation (1996).

Surveys have shown (Fraknoi, 2001; Walczyk & Ramsey, 2003; Zeilik, 2002) that introductory astronomy as well as physics are still overwhelmingly taught using the traditional lecture format (didactic lecture and demonstration), although this is now often supplemented with generous audiovisual and some computer-assisted instruction.
A formidable body of research has demonstrated that lecture-based instruction is largely ineffective (Dykstra, Boyle & Monarch, 1992; Halloun & Hestenes, 1985a; Hestenes, Wells & Swackhamer, 1992; McDermott, 1984; McDermott, 1991).

From science education research, the view is clearly emerging that student understanding is improved when researched-based teaching strategies are employed that are based on cognitive learning theory and active learning (Bonwell & Eison, 1991). The call has gone out from the astronomy education community (Straits & Wilke, 2003), as well as the science community as a whole (Walczyk & Ramsey, 2003) encouraging learner-centered instructional approaches. As Alexander (2005) points out, however, “implementing a learner-centered approach can be a difficult task.” Students are often more comfortable in their familiar passive role, and the increased demand on individuals for a responsible role in their own learning can lead to confusion and frustration (Straits & Wilke, 2003). Astronomy instructors today face a complex and difficult situation. If we are to be successful in promoting greater conceptual understanding in our students, we must utilize the best ideas from science education research.

Implementing active learning in the classroom requires considerable time and effort by astronomy instructors. Overall lack of resources such as teaching assistants, and limited time and pedagogic expertise for developing new instructional materials for themselves mean that faculty need materials that they can easily incorporate into their existing classes. Bailey, Prather and Slater, (2003) conclude that the development of research-based pedagogically sound curriculum materials is perhaps the greatest need in astronomy education today. Our study is aimed squarely at addressing this need.

In this investigation we seek to apply the currently most successful model of learning, broadly known as constructivism (cf. Section 2.3) to the development and testing of a strategy of in-class astronomy conceptual exercises. We hypothesize that these exercises will help students structure their own knowledge in line with accepted scientific explanations. As detailed in later chapters, the development of these conceptual exercises, called ranking tasks, along with the systematic measurement of their effectiveness helps fill a need for research-based curriculum materials largely absent in the teaching of introductory astronomy.

1.2 Ranking Tasks

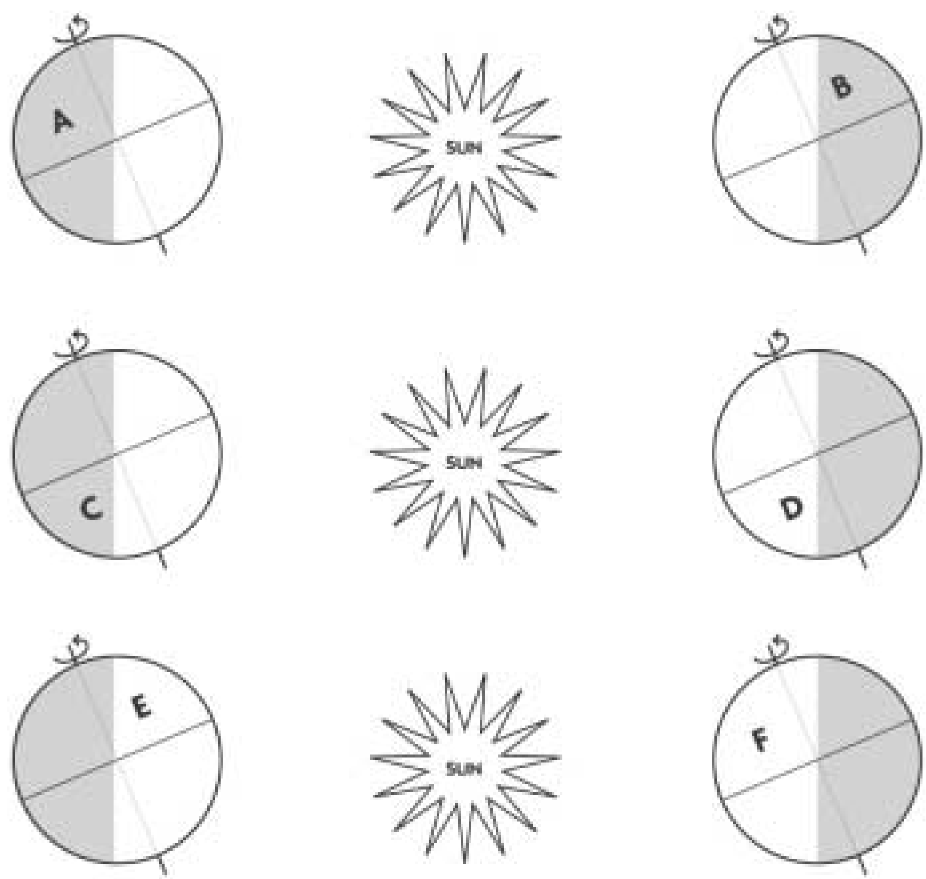
Ranking tasks (Maloney, 1987) are a novel type of conceptual exercise, unfamiliar to most students, in which learners are presented with (usually) pictures or diagrams that describe four to eight slightly different variations of a basic physical situation. Each situation in a ranking task includes different values for the variables involved, often including data that is not important to the task. 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.

An example astronomy ranking task is shown in Figure 1 on the following page.

Figure 1

Example Ranking Task Exercise

Description: In the figure below six different locations (A - F) on Earth are shown during a particular time of the year. Note that each location is the same distance away from the equator.



Ranking Instructions: Imagine that you placed identical glasses of water at each location (A - F). Rank the temperature (from coolest to hottest) of the water in each glass at the end of a full 24 hour day.

Ranking Order: Coolest 1 ____ 2 ____ 3 ____ 4 ____ 5____ 6____ Hottest

Or, the temperature of each glass of water would be the same. ________ (indicate with check markmark).

Carefully explain your reasoning for ranking this way: ____________________________

____

The format of ranking tasks is unfamiliar to students, and challenges them with a puzzle in which the path to solution is not immediately obvious. The multiple scenarios, as shown in Figure 1, engage students' minds and force them to think more deeply about the critical features of each situation and the step-by-step process needed to compare the situations and derive a ranking solution. A great advantage of ranking tasks is that their structure makes it difficult for students to rely strictly on memorized answers and mechanical formula substitution.

Ranking tasks can be presented to students as a series of increasingly complex situations, and can also represent the situations in a variety of different ways. For example, various situations may be presented as photographs, line diagrams, graphs, or tables of data. By changing the representation, we hypothesize that ranking tasks may require students to develop mental schema that are more flexible and robust, in dealing with a variety of aspects and applications of a particular concept as compared to conventional tutorial approaches. In this study, we use ranking tasks as collaborative team in-class activities, thereby encouraging active social interaction which research (Johnson, Johnson & Smith, 1998; Johnson, Johnson & Holubec, 1994; Johnson, Johnson & Smith, 1991) indicates promotes learning.

An important feature of ranking tasks is to ask students to explain how they solved the task. This requires the student to identify key variables, organize their mental steps, and structure their response using appropriate language into a (hopefully) coherent verbal procedure. Research indicates that this narrative explanation is a significant metacognitive learning process (Livingston,1996). In addition, it helps the instructor quickly identify cases where the student is employing one of many alternative conceptions (cf. Section 2.5) common in astronomy.

Our study hypothesized (and later concluded) that adding a program of collaborative ranking task exercises to traditional lecture-based instruction would significantly improve introductory astronomy student understanding.

1.3 Motivation for the Study

In their 2003 survey of the state of astronomy education, Bailey, Prather and Slater (2003) conclude that the "largest piece of astronomy education research that is missing still today is the practice–theory connection". This shortcoming in astronomy education research (AER) is also observed by Taylor, Barker and Jones, (2003) who noted that "developing research-based pedagogically sound curriculum materials for use in the astronomy classroom has been largely unexplored."

As discussed further in Section 2.4, the literature reflects a very limited amount of research aimed at developing teaching interventions for the astronomy classroom that are based on cognitive theory. Even rarer are interventions that have been empirically tested for effectiveness. The primary motivation for this investigation of ranking tasks is to address these two major gaps in current research.

The lack of empirically tested curriculum materials designed for the introductory astronomy classroom may be further compounded by limited pedagogical content knowledge of some astronomy instructors. As defined by Shulman (1987), pedagogical content knowledge includes

> “. . . the most regularly taught topics in one's subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations - in a word, the ways of representing the subject that make it comprehensible to others. . .(I)t also includes an understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to learning.” (p. 9)

Introductory astronomy is often taught by graduate students, research-oriented astronomers, and physics professors. These instructors have varying levels of pedagogical content knowledge in astronomy. In non-research institutions, a survey found that only 20% of astronomy instructors hold graduate degrees in astronomy. The majority of instructors are trained in physics and teach other classes besides astronomy (Fraknoi, 2001).

As discussed in Section 1.1, surveys have found that introductory astronomy and physics are still most often taught using traditional lecture-based instruction. This is true despite the large body of research showing such traditional instruction to be less effective than most instructors believe. For example, the weakness of traditional instruction in developing conceptual understanding by focusing on teaching equations in physics was demonstrated by Dykstra (1992) and Viiri (1996). They found that students could often “plug-and-chug” values into force and motion mathematical problems and get good grades, but lacked an underlying conception of the nature of Newtonian physics. I believe that similar difficulties occur with mathematical concepts in the astronomy classroom.

These factors – namely lack of astronomy-specific classroom materials, the level of pedagogical content knowledge of many stand-in astronomy instructors, and marginal effectiveness of traditional lecture-based instruction - provide the motivation for investigating ranking tasks as effective and easy-to-implement classroom curriculum material to help astronomy students learn.

1.4 RESEARCH QUESTIONS & STUDY LIMITATIONS

Earlier sections described (1) the shortage of research based curriculum materials for use in the astronomy classroom, and (2) the current lack of quantitative measures of the effectiveness of astronomy interventions in promoting student learning. To address these needs in astronomy pedagogy, this investigation addresses four fundamental questions:

1. Does a research-based program of astronomy ranking task exercises result in student conceptual gains when used as collaborative in-class activities in conjunction with traditional lecture-based instruction?

2. Do ranking task exercises differentially affect students by gender or their initial knowledge level of introductory astronomy topics?

3. How do ranking tasks exercises affect the depth of student understanding of selected introductory astronomy topics as demonstrated through the quality of student written answers to free-response questions?

4. To what extent do students perceive the ranking task exercises to be valuable in the introductory astronomy classroom?

Limitations of the Study

The research questions were framed taking into account a number of practical constraints and limitations in this education research. The main effect being investigated was comparing the ranking task treatment to traditional instruction (lecture). However, we decided that it was impractical to completely isolate these two factors. The single large class size made it impossible to break into two entirely separate groups – consisting of one group receiving traditional instruction followed by ranking task exercises, while a second group simply receiving additional lecture time. Over the eight key astronomy topics being investigated, we decided that repeatedly breaking the class into separate groups would be impractical from a teaching resource standpoint and unacceptably disruptive to students.

As a result of these considerations, we framed the research questions to study the effect of adding ranking tasks to traditional instruction. Indeed, we believe that this would be the most common strategy for incorporating these active learning activities into the classroom. This practical constraint on the experimental design means that we cannot say conclusively whether ranking tasks rather than additional lecture time led to gains in student understanding. However, we believe that most gains after the ranking tasks can be attributed to the conceptual exercises because of the significant prior research that demonstrates the limited gains from extended lecture time on task. In recognizing this limitation, we identify in Section 5.5 (Recommendations for Further Study) the need to investigate this time on task question.

1.5 DEFINITIONS

Throughout the study, a number of terms are used which are often presented in educational research literature with a variety of slightly different meanings. Many of these terms are discussed in greater detail in Chp 2 - Review of the Literature. These brief definitions are offered for the convenience of the reader:

1. Conceptual exercise: an intellectual exercise that usually presents a set of facts and conditions that require a qualitative analysis for determining a method of solution; often focusing on one or two aspects of a concept in a particular context – and which cannot be solved by simply by plugging numbers into an equation and finding a numerical value.

2. Effect size: in the context of this study, a quantitative measure of learning gains between experimental treatments.

3. Meta-analysis: a summary of previous research that uses common quantitative methods (such as effect size) to compare outcomes across a wide range of studies in an attempt to generalize conclusions.

4. Mental model: a qualitative representation that can be visualized mentally (Vosniadou & Brewer, 1992) and which helps people recognize, explain, and predict phenomena that they encounter. It may consist of declarative knowledge (i.e. propositions and schemas), visual imagery, procedural knowledge, rules and assumptions (Kyllonen & Shute, 1989.)

5. Alternative conceptions: operationally defined as explanations of phenomena derived from everyday experience which differ from accepted scientific explanations. The term refers to intuitive, experience-based explanations constructed by learners to make sense of a broad range of natural phenomena.

6. Scaffolding: refers to the strategy of carefully structuring and sequencing learning experiences from simple to more complex - providing support and help to the novice, then withdrawing that guidance as the learner constructs more robust knowledge.

7. Traditional Instruction: operationally defined in this investigation as consisting of pre-class student readings, didactic lecture, instructor-centered demonstrations, and limited instructor-led questioning of students.

1.6 Responsibilities of Study Team Members & Participants

In this section I describe the duties and responsibilities for the various individuals and groups who participated in this research. These include the following:

- David W. Hudgins – author of this thesis
- Dr. D.J. Grayson - UNISA Promoter
- Dr. D.P. Smits – UNISA Co-Promoter
- Dr. E.E. Prather – U. of Arizona, Co-Promoter
- Various members of the CAPER Team (Conceptual Astronomy & Physics Education Research) at the University of Arizona. Major participants were Dr. Prather and Dr. Tim Slater, and PhD students Eric Brogt and Erin Dokter.
- 280 undergraduate astronomy students – participants at Rockhurst University and University of Arizona.

In broad terms, I acted as principal investigator. My duties were to define the original research questions, investigate the literature, draft the experimental procedures, define the theoretical framework for the astronomy ranking tasks, draft the majority of the original twelve sets of astronomy ranking task exercises, draft the various assessment tests including the scoring rubric for Level of Understanding, and conduct a portion of the overall pilot studies with two of my introductory astronomy classes at Rockhurst University in Kansas City. During the main data collection phase conducted in Dr. Prather's astronomy class at the University of Arizona, I monitored and assisted in data collection in two classes. Following data collection, I was entirely responsible for data analysis, summarizing results, and interpreting results for their implications in teaching and for astronomy education research. I was also responsible for presenting results of this research as invited speaker at two major professional conferences, the 206th Meeting of the American Astronomical Society in Minneapolis, and the 2005 Summer Meeting of the American Association of Physics Teachers in Salt Lake City.

All this said, the contributions of other members of this research group have molded the high quality of the final research effort.

As Promoter for this thesis, Dr. Grayson provided great direction to the original scope of the research, and defined the high standards and expectations required. From Proposal to this final Thesis, Dr. Grayson acted as senior navigator and technical consultant, heavily contributing to the entire review process with suggestions, comments, corrections, and often difficult questions regarding my draft work.

Dr. Prather's role was absolutely critical to this study. His duties were to act as my day-to-day guide and mentor in the development of the ranking tasks, suggesting refinements to my draft ideas for an experimental method to create a practical research plan, assisted with the pilot studies and reviewed and guided improvements to both the original Ranking tasks and the draft testing instruments. Dr. Prather then volunteered his introductory astronomy class of 250 students, conducting the two experimental treatments and overseeing data collection. As my Local Supervisor and Co-Promoter, Dr. Prather also contributed heavily to the entire review process.

Dr. Smits was my UNISA Co-promoter for the study, a degreed astronomer who contributed in the review process of the original ranking tasks and extensively later in review of the final thesis.

Several members of the CAPER Team at the University of Arizona (which includes Dr. Prather) also assisted in this study. Dr. Tim Slater, along with two PhD students, Erin Dokter and Eric Brogt provided helpful reviews of all the astronomy ranking tasks and assessment tests as part of the pilot studies. In addition, the two doctoral students acted as teaching assistants in Dr. Prather's introductory astronomy class; they carried out the day-to-day data collection for the formal portion of the study that took place at the University of Arizona. The raw data collected by these PhD students was then delivered to the author for analysis.

Lastly, the undergraduate student participants in this study included (1) my two small astronomy classes of thirty students at Rockhurst University who contributed in the pilot studies as focus group reviewers of the ranking tasks and assessment tests; and (2) Dr. Prather's introductory astronomy class of 250 students at the University of Arizona who were the primary experimental subjects in this research.

1.7 Theoretical Framework & Design of Astronomy Ranking Tasks

Theoretical framework

The theoretical framework on which we base the design and instructional strategies of collaborative "ranking task" exercises is strongly influenced by the cognitive theories broadly known as constructivism and schema theory. In broad terms, the constructivist model holds that learners actively construct new knowledge by fashioning it to meet their own needs and capacities and integrating it into their existing cognitive structure (University of Mass. Physics Education Research Group website, 2001). Schema theory views organized knowledge as an elaborate network of abstract mental structures which represent one's understanding of the world. Howard (1987) described it as "a mental representation of a set of related concepts."

The basic idea of the schema theory of learning is that as students receive incoming information, they organize it into a sort of framework or plan (Stein & Trabasso, 1982) around their previously developed schemata, or "networks of connected ideas" (Slavin, 1988). Schema theory includes the importance of visual imagery combined with additional knowledge structures that are actively organized (rightly or wrongly) by the mind into an elaborate network of rules, propositions, word lists, categorization concepts, and procedural knowledge.

The most important implication of schema theory is the role of prior knowledge in processing. In order for learners to be able to effectively process information, their existing schemas related to the new content need to be activated. Research by schema theorists indicates that abstract concepts are best understood after a foundation of concrete, relevant information has been established (Schallert, 1982).

Schema theory suggests a number of considerations that should be incorporated in the design of ranking tasks. The first is the idea of constructing knowledge as a process of building from the familiar to the unfamiliar, from the concrete to the abstract. Several instructional strategies logically follow from schema theory. Armbruster (1996) encourages the use of analogies and comparisons in order to draw attention to learners' existing schema and to help them make connections between existing schema and the new information. Similarly, Price and Driscoll (1997) suggest that instruction should use "realistic, familiar scenarios in teaching problem-solving rather than more conventional abstract contexts."

Further design strategies follow from schema theory with the related idea of scaffolding. Bruner (1960) noticed the success of teaching highly structured bodies of knowledge like the physical sciences by starting with simple, intuitive ideas which – after being mastered - are connected with other knowledge in a step by step fashion to eventual mastery of a complex body of knowledge. Clement (1988) describes a way to help students grasp abstract concepts by creating a series of analogies (bridges) starting with concrete and familiar concepts that become more abstract.

With these ideas regarding schema theory in mind, we hypothesize that the effectiveness of ranking tasks as learning tools can be improved by designing the exercises so that they are presented to students in very carefully structured sets that accomplish the scaffolding described above.

Lastly, additional ideas in learning theory that we have applied to the design of our astronomy ranking tasks include presenting the various physical situations in different representations (e.g. pictures, schematics, graphs, tables). Having students translate between representations helps them link knowledge types and relate the knowledge to physical experience (Dufresne, Gerace & Leonard, 1997). Price and Driscoll (1997) report that schema-building experiences from multiple perspectives are needed to help learners develop functional problem-solving schemas that they can successfully use to solve unfamiliar problems.

<u>Design Features of Astronomy Ranking Tasks</u>

Our design of astronomy ranking tasks is based on the general model for curriculum development described by Driver and Oldham (1986) which draws on four main types of input:

(1) decisions on content;

(2) information on students' prior ideas or alternative frameworks;

(3) perspectives on the learning process – i.e., the constructivist model and schema theory;

(4) practical knowledge of our students and university classroom environment.

The design features of our astronomy ranking tasks were motivated by schema theory and the general model for curriculum development described above. These design features incorporate pedagogical content knowledge as described by Shulman (1986) and Grayson (2004) in that they are topic-specific, use powerful analogies, confront common alternative concepts, and employ instructional strategies and comparisons with every-day experience that we have found successful in previous astronomy classroom experience.

We developed ranking tasks as structured sets of conceptual exercises for each of a dozen introductory astronomy topics initially investigated in this study. Each topical set of ranking tasks incorporated the design features described below.

1. Scaffolding: Each set of ranking tasks begins by tying a major element of the subject astronomy topic to an idea within the common everyday experience of the student. That is, it starts with familiar concepts and builds up to more complex applications. Frequently, it may first be necessary to *remind* students of what they probably already know before introducing new material. The material must be sequenced in a step by step manner so that it is easily grasped by the student. This scaffolding takes the student through increasingly complex and complete cognitive models of the concept, re-organizing existing knowledge, and introducing new language.

For each of the introductory astronomy topics investigated in this study we created a set of ranking tasks consisting of five exercises. This number provides three or four ranking tasks per topic to be utilized in-class as 20 minute collaborative activities, plus one or two additional ranking tasks for homework or later tests.

2. Conceptual to mathematical progression: The series of ranking task exercises provides repeated exposure to the concept at increasingly complex levels. In particular, the ranking tasks first focus on qualitative (non-mathematical) situations in order to promote conceptual analysis and deeper thinking by the student - rather than rote formula solution. As appropriate, later exercises require mathematical solutions.

3. Multiple formats of presentation: We designed the astronomy ranking tasks within a 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, re-enforcing a more cohesive, robust, and versatile schemata or mental model. This more robust understanding enables students to be successful in solving increasingly complex problems.

Each set of astronomy ranking tasks consisted of five exercises that typically include three or four different presentation formats. We focused on using a variety of illustrative diagrams because some researchers (Hegarty & Just, 1993; Sharp *et al.* 1995) report the positive effects of graphical diagrams on the construction of mental models. Their research suggests that the creation of dynamic images constitute the frame of reference for construction of the generalized mental model.

4. Elicit common alternative conceptions: ranking tasks should incorporate design features that elicit and enable confrontation of known or suspected alternative conceptions held by students.

5. Limit physical situations to 6 situations: Based on our experience in the pilot studies (cf. Section 3.7), we limit the number of different physical situations presented in our astronomy ranking tasks to a maximum of six. Without this limitation, the ranking task becomes needlessly complicated by bookkeeping activities.

6. Incorporate distracters: In moderation, we found it useful to incorporate distracters within the ranking tasks exercises in order to require students to discriminate between relevant and non-relevant information. Distracters can include attractive but ultimately irrelevant numerical data which improve critical thinking skills by honing students' filtering process.

7. Require student narrative explanations: Finally, as suggested by Maloney (1987), each ranking task asks students to explain the reasoning underlying their ranking order. Their response requires students to identify the factors or rules that they are considering, and to integrate those ideas into a cohesive argument in the appropriate language of science. According to Vygotsky-based social constructivism theory, we hypothesize that this rehearsal and re-enforcement strengthens the students' mental schema.

8. Use as in-class collaborative activities: ranking tasks are easily incorporated into routine classroom activities as collaborative exercises. Incorporation of this feature is motivated by research (Cooper *et al.* 1990; Bonwell & Eison, 1991; Mazur, 1996) which shows that collaborative social groups facilitate learning by enabling students to test knowledge, associate and organize with other knowledge, and gain insight from the perspectives of others.

1.8 Organization of the Study

Chapter 1 has provided an introduction to the research conducted in this study. This included the background of the study, definition of ranking tasks, motivation for the study, the research questions, limitations of the study, definition of terms, responsibilities of study team members and participants, the theoretical framework and design of astronomy ranking tasks, and this summary of the organization of the study.

Chapter 2 presents a review of the related literature beginning with the development and research on ranking tasks, followed by research on constructivist pedagogy, astronomy education research, alternative conceptions and the role of conceptual change, and closes with a discussion of schema theory and mental models.

Chapter 3 describes the methods, instruments and procedures of the study. Included in this chapter are a description of the participants, experimental design, statistical design, pilot studies, and data analysis.

Chapter 4 describes the results of the statistical tests and other analyses used to investigate the research questions.

Chapter 5 discusses the results of the study as they relate to the research questions, discusses the educational implications that follow from this investigation, and presents suggestions for future research.

CHAPTER 2

REVIEW OF THE LITERATURE

2.1 Introduction

In the previous chapter I presented a background and motivation for this study, definition of ranking tasks, the research questions, definitions, responsibilities of the study team members, a discussion of the theoretical framework and design of astronomy ranking tasks, and summary of the organization of the study.

In this chapter I review and summarize the literature essential to this study. This review of the literature has two goals. First, to provide an historical background on ranking tasks as they have been implemented in physics education. Secondly, this chapter defines and characterizes the theoretical framework of key learning theory that drives the design features and classroom implementation of our astronomy ranking task exercises. Thus, key topics included in this literature review include a history of ranking task conceptual exercises, constructivism, conceptual change, scaffolding, historical perspective of astronomy education research, alternative conceptions, schema theory and mental models.

2.2 Ranking Tasks

Ranking tasks are such a new format of conceptual exercise that the literature describing their development and use in the classroom is limited. Ranking tasks seem to have been first described by Maloney (1987), and are based on a technique called rule assessment originated by Siegler (1976). Ranking tasks have been applied in the physics classroom where they can be used as diagnostic pretests, pre and posttests to assess lab effect, and homework. Ranking tasks were described as particularly useful as collaborative in-class exercises by Maloney and Friedel (1996) and Maloney (1987). For example, Maloney presented students with five situations of carts with various masses and speeds traveling on a horizontal table and impacting identical wood blocks, and asked students to rank the situations by how far the wood blocks would be moved. Maloney then observed that when working in collaborative groups on ranking tasks, physics students found that they had to be able to first describe and agree on a conceptual basis for solving the exercise, including a step-by-step process, before doing any calculations.

Constructivist theory (see Section. 2.3) argues that in student collaborative activities, the verbalization and negotiation of ideas is an essential part of learning in that it re-enforces the plausibility of students' developing mental model. Verbalization of the conceptual strategy (by discussion with peers and written explanation normally required in the ranking task) using the language of science is essential to learning (Lefrancois,1994).

Specific examples of the physics applications of ranking tasks are well demonstrated by O'Kuma, Maloney, and Hieggelke (2000) in their book on this topic. They point out in a qualitative way the advantages of ranking tasks as tutorial exercises. For example, ranking tasks demand more than simple memorized responses from students. They are forced into deeper thinking than simply picking the best response from multiple-choice questions. Importantly, the required explanatory response provides a window into students' thought processes. O'Kuma *et. al.* argue that the multiple presentations of a physical situation require students to "engage in a comparison reasoning process that they are seldom required to do."

In their paper on ranking tasks, Maloney and Friedel (1996) place considerable emphasis on the design of the exercise in order to reveal possible student conceptual strategies and anticipated student misconceptions. This requirement resulted in their physics ranking tasks presenting a rather large number of physical situations (usually eight) in each ranking task exercise. Another common feature of previous work in development of physics ranking tasks (e.g., O'Kuma, Maloney & Hieggelke, 2000) has been the heavy emphasis on formula application for solution. Perhaps this reflects the traditional focus in physics textbooks which emphasizes numerical solutions as demonstrations of understanding.

At this time, I find no evidence in the literature that there have been any quantitative studies of the effectiveness of ranking tasks as aids to student learning.

2.3 Constructivism

A central idea to the design of the ranking task curriculum materials developed and tested in this study (and in the interpretation of results) is the constructivist model of learning. The constructivist model holds that learners actively construct new knowledge by fashioning it to meet their own needs and capacities and integrating it into their existing cognitive structure (Yeager, 1991). Modern constructivist pedagogy holds that learning is an interpretive and iterative process in which new learning is given meaning in terms of a students' previous knowledge (von Glasersfeld, 1981; Roth, 1994).

Constructivism is a theory of learning that can be traced to the eighteenth century and the work of Giambattista Vico who held that humans can only clearly understand what they themselves construct from their own experience. Major contemporaries who have developed the contemporary model of constructivism as a theory of learning and its educational impact include Jean Piaget, John Dewey, Lev Vygotsky, Jerome Bruner, and Ernst von Glaserfeld (Kearsley, 1999). They propose that learners actively construct knowledge and that this construction of knowledge takes place in a social context heavily influenced by language and social expectation. The success of constructivist theory in modern education is due to von Glasersfeld's interpretation of Piaget's work in terms of a "radical constructivist epistemology" (von Glasersfeld, 1974). By radical constructivism von Glasersfeld defines "a theory of knowledge in which knowledge does not reflect an 'objective' onto logical reality, but exclusively an ordering and organization of a world constituted by our experience" within the constraints of reality (von Glasersfeld, 1984, p. 24). Further, von Glasersfeld describes his 'radical constructivism' as having two parts:

- Learners construct new knowledge on the foundations of their existing knowledge.
- The knowledge they create tells us nothing about reality, it only helps learners to function successfully.

Various types of constructivism have emerged, and depending on the author you may get different interpretations. Ernest (1995) points out that "there are as many varieties of constructivism as there are researchers". Cunningham and Duffy (1996) identified two major similarities that are the foundation of all constructivist theories. They are that "learning is an active process of constructing rather than acquiring knowledge and instruction is a process of supporting that construction rather that communicating knowledge." (Cunningham & Duffy, 1996, p.172).

Two major varieties of constructivism have evolved, called social constructivism and cognitive constructivism. While each approach has its own emphasis and variations, they share several central themes:

(1) Knowledge is constructed in the learners mind, not transmitted directly.

(2) Prior knowledge and social context (language) significantly impacts the learning process.

(3) Initial learning is based on simple cognitive or mental models, and is only deeply learned when organized into a more extensive global context by integration with prior knowledge.

(4) Building useful cognitive structure requires effort and purposeful activity by the learner.

Implications of Constructivism to Teaching

Constructivism focuses on the role of the active learner. In contrast to this idea of learning, the dominant teaching approach utilized thirty years ago among educators in the science classroom was the objectivist model. This is often referred to as traditional instruction. Traditional instruction proposed that knowledge can be conveyed by the teacher through language, and that students somehow absorb that knowledge directly. The objectivist teaching method involves more or less passive lecture and demonstrations (Hendry, 1996). Across the range of epistemological theories, objectivism and constructivism represent opposite extremes.

The constructivist theory of learning focuses on the manner in which the learner constructs useful knowledge, yet it does not specifically identify instructional strategies. As observed by von Glasersfeld (1992):

> "Constructivism does not claim to have made earth-shaking inventions in the area of education; it merely claims to provide a solid conceptual basis for some of the things that, until now, inspired teachers had to do without theoretical foundation."

The constructivist view does, however, suggest a number of principles which are useful in guiding the design of curriculum materials and structuring the learning environment. Several of these guidelines include the following which are especially relevant to this ranking task study:

1. Students must be active participants in their own learning. The educators' task is to provide meaningful, authentic activities to help students construct understanding and knowledge. (von Glaserfeld, 1995)

2. Apply the idea of scaffolding to the structure of curriculum material. That is, begin with the intuitive/simple concepts and proceed step-by-step with exercises that reinforce previous concepts and link those ideas with new ones. (Bruner, 1960; Wood, Bruner & Ross, 1976; Reigeluth & Stein (1983). Similarly, Lee (2000) recommends that instructional methods utilize a dynamic environment in which students are actively engaged through a series of questions. If answered incorrectly, the instructor guides them with a series of hints to facilitate solving more complex problems.

3. Skills and knowledge are best acquired in context. Educators must create instructional materials that engage students in applying new knowledge in a variety of contexts. (Berryman, 1989; Lave, 1988; Lave & Wenger, 1990). This situated cognition holds that learning is inseparable from the activity , context, and culture in which it developed (Brown, Collins & Duguid, 1989; Greeno, 1998)

4. "Conceptual understanding is influenced by the prior knowledge brought by students to learning situations. This prior knowledge [when incorrect] is labeled….as 'preconceptions', …'alternative frameworks, or 'misconceptions'" (Kinnear, 1994)

5. By anticipating and diagnosing misconceptions (cf. Section 2.4), educators can adopt instructional strategies that make students aware of conflicts or inconsistencies in their thinking. Students must experience some disequilibrium

in their current cognitive model before they are able to move to a new level of understanding (Driscoll, 2000).

6. Instructional strategies are more effective and learning is promoted when students work in collaborative groups. This peer interaction and negotiation encourages students to test and expand their mental model on particular issues (Savery & Duffy, 1996; Wilson, 1996; Driscoll, 2000).

In conclusion, the goal of constructivist-based instruction is nicely described by Confrey (1990) as facilitating the building of a learner's cognitive model to include or satisfy these features: (1) internal consistency, (2) successfully integrates a variety of concepts so that it explains several different phenomena, and (3) can be verbally described in words or through use of pictures by the student.

Scaffolding

An important aspect of constructivism relative to this study is the evolution of Vygotsky's concept of the Zone of Proximal Development into a successful instructional strategy now known as scaffolding. Bruner (1960) noticed the success of teaching highly structured bodies of knowledge like physical sciences by starting with simple, intuitive ideas which – after being mastered - are connected with other knowledge in a step by step fashion to eventual mastery of a complex body of knowledge. Wood, Bruner and Ross (1976) later coined the term scaffolding to describe this instructional stategy.

Graves and Braaten (1996) define scaffolding as the process by which an expert provides temporary support to learners to "help bridge the gap between what [the learner] know[s] and can do and what [he or she] need[s] to accomplish in order to succeed at a particular learning task”. After completion of this task, a learner is better able to make the connection between prior knowledge and new information. Scaffolding helps this happen through an instructional strategy in which the teacher directly, or through carefully designed sequence of curriculum materials, engages the student with leading questions or conceptual exercises that enable the student to organize prior knowledge with new information. (Brickmore-Brand, 1990).

In their classic text on teaching and learning, Bransford, Brown and Cocking (2000) describe how scaffolding instruction using computer technology “enables learners to do more advanced activities and to engage in more advanced thinking and problem solving than they could without such help.” They describe how this cognitive technology was first used to help students learn mathematics (Pea, 1985) and writing (Pea & Kurland, 1987), and the current widespread use of computerized scaffolded instruction to promote learning in the sciences and mathematics.

In the 1980’s research had accumulated supporting various aspects of scaffolding as an instructional approach. In particular, the classic work “*The Elaboration Theory of Instruction*” by Reigeluth and Stein (1983) is notable. These authors propose that course material be organized from intuitive/simple to more complex – in a manner that reinforces previous concepts and links to new ones – to achieve a rich breadth and depth of understanding. This idea is fundamental in the design of astronomy ranking tasks investigated in this study.

2.4 Astronomy Education Research

Over the past twenty years, astronomy education research (AER) has emerged as a distinct field of scholarly inquiry in which astronomers and education researchers are actively engaged. Prior to this, however, astronomy educators benefited from and relied almost entirely on the older and more extensive literature of physics education research (PER) as the primary source of insights into common issues and educational strategies.

As presented by McDermott and Redish (1999) in their bibliography, the roots of PER extend back to the 1970's and strongly follow the emergence of constructivism as the dominant paradigm of learning theory. While McDermott's bibliography identifies 224 key research papers in the field of physics, a similar bibliography of the highly dispersed AER literature by Bailey, Prather, and Slater (2003) finds only 37 papers during the same time period (1977 – 1999). Further, the great bulk (almost 80%) of AER papers have been published in only the last ten years.

Focus of Astronomy Education Research

The predominant theme in AER over the past two decades has been the study of alternative conceptions (cf. Section 2.5) and the resulting reasoning difficulties with astronomical phenomena that students bring to the classroom prior to instruction. For example, students have inaccurate ideas about the shape of the Earth (Nussbaum & Novak ,1976), phases of the Moon (Sharp, 1996; Stahley, Krockover & Shepardson,1999), planetary motion (Tregust & Smith, 1989), seasons (Baxter, 1989; Atwood & Atwood, 1996), and cosmology (Prather, Slater & Offerdahl, 2002). These studies clearly document and illustrate how students' pre-instructional conceptions are poised to interfere with instruction.

Since the 1990's, the emphasis in astronomy education (along with general educational psychology) has been toward recognition of the importance of cognitive processes and the implications of cognitive science research in classroom teaching strategies. AER expanded to include research into the conceptual framework underlying student understanding, and general quantitative measurement of astronomy knowledge. These studies include Sadler's (1998) Project Star Astronomy Concept Inventory, and Zeilik's Astronomy Diagnostic Test (described by Hufnagel & Deming, 2000). These two researchers, Sadler and Zeilik, have been called the two founding fathers in astronomy education (T. Slater and G. Brissenden, private communication 14 Oct. 2004)

In most recent years, AER has just begun to address a notable void in the pedagogy - with the development of specific teaching strategies and (more rarely) quantitative measurement of their effectiveness in teaching astronomy core topics. These rare instances include, for example, methods of collaborative group learning (Adams and Slater, 1998; Skala *et al.* 2000; Zeilik, 1998; Adams & Slater 2002), and a modest number of other specific teaching strategies and curricula such as historical approaches (Sneider & Ohadi, 1998; Abbd-El-Khalic, 1999), a method to overcome astronomy misconceptions (Comins, 2000), the nature of evidence and theories in science (Brickhouse *et al.* 2000), and the classroom use of new curriculum materials called Astronomy Lecture-Tutorials (Adams, Prather & Slater, 2002).

In their surveys of the state of astronomy education (Wall, 1973; Bailey, Prather & Slater, 2003; Taylor, Barker & Jones, 2003), the authors identified much needed areas of astronomy education research to include the following:

- Development of research-based and pedagogically sound curriculum materials for use in the astronomy classroom.
- Quantitative evaluation of existing and new instructional strategies.
- Gender and ethnicity factors effecting astronomy learning.
- Effective methods for preparing astronomy teachers at all levels.

2.5 Alternative Conceptions & Conceptual Change

Introduction & Terminology

A principal idea of constructivism is that learners must build their own scientific knowledge and understanding in a step-by-step fashion in which they interpret and integrate new knowledge in the context of what they already understand. This initial knowledge state is therefore critical to subsequent learning. Importantly, education research has widely documented that students come into the science classroom with knowledge they have constructed about the physical world that is often inconsistent with modern scientific explanations. This pre-existing knowledge is based on personal observation in their everyday life in which they have generated an intuitive, experience-based explanation which students use to make sense of a wide range of natural phenomena. Resnick and Chi (1988) observe that

> “We cannot teach directly, in the sense of putting fully formed knowledge into people's heads; yet it is our charge to help people construct powerful and scientifically correct interpretations of the world. We must take into account learners' existing conceptions, yet at the same time help them to alter fundamentally their scientific misconceptions.”

There has been considerable research into the role of these “existing conceptions” in science education, and a diversity of terminology has developed. Many of these terms are often used almost interchangeably in the literature, and authors often intend slightly different meanings.

Examples of general terminology referring to students’ pre-existing ideas include “preconceptions” (McDermott, 1998), “previous idea” (Duit, 2004), as well as “existing conception”, “spontaneous conceptions”, “implicit theories”, “theories in action”, and “alternative framework” (Driver & Easley, 1978). All of these terms are rather neutral in nature, and avoid implying a negative perspective of this complex cognitive behavior. The use of different terminology may also reflect varying theoretical positions within the field of research.

Other terminology referring to “existing conceptions” further include the meaning that the students’ original conception is inconsistent with modern scientific explanation. These inconsistent concepts have been called “misconceptions” (Helm, 1983), “false conceptions” (Fischer & Lipson, 1986), “conceptual errors”, “naïve conceptions” (Champagne, Klopfer & Anderson, 1980), and finally “alternative conceptions” (Driver, 1981; Driver & Easley, 1978; Dykstra, Boyle & Monarch, 1992; Hewson & Hewson, 2003).

For this investigation, I will use the term alternative conceptions to refer to students' intuitive pre-existing beliefs concerning natural phenomena that were derived from everyday experience – and which differ from accepted scientific beliefs.

Alternative Conceptions – a Central Theme of PER/AER

From the allied fields of physics and astronomy education research, the literature reveals two consistent themes in regard to alternative conceptions. First, that students bring a multitude of their own experience-based ideas about the natural world to the classroom. A second major theme in PER and AER is that these alternative conceptions are often very resistive to change to a scientific view using traditional instruction such as lecture, demonstrations, and end-of-chapter type exercises. Hestenes, Wells and Swackhamer (1992) showed that traditional instruction produced little change in students' alternative conceptions about force and motion. Similar conclusions about the difficulty of overcoming students' alternative concepts through traditional instruction are found throughout the literature (Driver *et al*. 1994; Maloney, 1990; Atwood & Atwood, 1996; Comins, 2000).

In regard to the difficulties that alternative conceptions often pose to new learning - is the quote by Mark Twain…

> "It's not what you don't know that hurts you, it's what you know that just ain't so!".
>
> – from *Adventures of Huckleberry Finn*

<u>Role of Conceptual Change Theory in Alternative Conceptions</u>

The idea of conceptual change is essential to discussion of educational strategies for dealing with alternative conceptions. Within AER, a classic study and educational film is Schneps and Sadler's (1985) "A Private Universe". After demonstrating common astronomy alternative conceptions held by even highly educated new college graduates, the film focuses on a bright high school student, Heather. The major part of the film follows the difficult process of conceptual change that Heather undergoes in trying to understand the phenomena of seasons. The film shows powerfully how her intuitive alternative conceptions about fundamental science concepts are resistive to change despite dogged effort to instill the correct concept. Even after lengthy instruction, Heather's conception undergoes a major shift but never comes completely inline with scientific thinking.

The evolution of Heather's concept about the seasons as shown in "A Private Universe" illustrates the slow shift or restructuring of existing knowledge that distinguishes conceptual change from other types of learning (e.g., acquiring declarative or factual information). Learning for conceptual change is not just memorizing new facts or skills. In conceptual change an existing conception must be fundamentally modified or even replaced to enable students to gain a scientific understanding of a phenomena.

The origins of conceptual change theory goes to a group of science education researchers at Cornell University who developed a theory of conceptual change (Posner *et al.* 1982) and expanded by Hewson (1981,1982). This theory was based on Piaget's ideas about disequilibrium and accommodation, in which a new conception is likely to be adopted by the learner if it seems to offer better solutions to the problem.

The following conditions for conceptual change are described by Posner *et al.* (1982), and Strike and Posner (1992):

1. Dissatisfaction with the currently held conception.
2. The alternative conception must be understandable by the learner.
3. The alternative conception must seem plausible or credible to the learner.
4. The alternative conception must seem fruitful or useful in a variety of situations.

The second central concept in conceptual change theory is the idea of *conceptual ecology,* which Hewson (1992) describes as "the context in which the conceptual change occurs, that influences the change, and gives it meaning". The interaction within these contexts for a learner will raise or lower the *status* of conceptions (Hewson, Beeth & Thorley, 1998).

The theory of conceptual change proposed by Posner *et al.*, with its central ideas of status and conceptual ecology, is "currently the most widely accepted and influential theory of its kind" and has guided much research and instructional strategies (Davis, 2001).

Implications of Alternative Conceptions on Teaching Astronomy

The importance of recognizing student's alternative concepts in designing instructional strategies and materials is a clear and direct consequence of constructivist learning theory (Von Glasersfeld, 1992). Alternative conceptions impede new learning. Schank (1991) explained it this way:

> "When you learn new things, as you are all the time, the new knowledge must perturb the system in order to find its place in memory in relation to what is already there. Does it amplify old knowledge, or contradict it? The mind needs to resolve these questions as new knowledge appears, getting reminded of what it already knows or believes each time some new experience occurs. This process of reminding and comparison is a critical part of learning."

In the constructivist view, when students encounter something new, they try to match or compare it with something that is already in their memory. As a result, conceptions derived from their everyday experience can lead them astray from understanding or accepting a scientific model of astronomical phenomena. Common examples of alternative conceptions in astronomy include the following:

- The seasons are caused by the Earth being closer or farther from the Sun at different times of the year;

- The phases of the Moon are caused by a shadow – perhaps the Earth or a cloud – passing over the Moon;

- The Big Bang was an explosion of pre-existing material into pre-existing space.

Each of these alternative conceptions is based on primitive conceptions being misapplied to more complex phenomena (Prather, 2002 and 2004; DiSessa, 1993). For example, the warm and cold seasons are most easily explained by the general rule that "close means more". That is, more heat means the Earth must be closer to the Sun. Similarly, students are initially compelled to implement the general rule that "you can't create something from nothing" to derail their grasp of the scientific implications of the Big Bang.

DiSessa (1988, 1993) called primitive conceptions resulting from one's experiences and observations in the real world "phenomenological primitives" or "p-prims". An important feature of diSessa's concept is that p-prims are highly robust and resistant to change. An effective strategy for restructuring alternative conceptions when students confuse related but distinct physics concepts is described by Grayson (1996, 2004) as "concept substitution" and by Jung (1993) as "reinterpretation". Let me provide an example how this strategy might be applied in introductory astronomy. Instead of challenging a students' alternative conception that the phases of the Moon are caused by the shadow of the Earth, the teacher provides the following concept substitution: the idea that the dark portion of the Moon is in shadow is not wrong at all – but the shadow is not caused by the Earth, but is the shadowy side of the Moon which is only half-illuminated by the Sun.

An extensive body of education research has shown that before real learning takes place, students' alternative conceptions about the natural world must be directly confronted and reconciled with the scientific view. Without this reconciliation, students may memorize a conceptual response that they narrowly apply in school, but retain another framework that they apply to the real world – promptly forgetting the scientific concept – or at best viewing it as obtuse and incomprehensible.

Science education scholars have over the years identified many common student alternative conceptions about the physical world, and to varying degrees advocated diagnostic and instructional strategies. An example is the Hewson and Hewson (2003) study of 100 high school science students in South Africa. Half the students were taught using traditional science instruction and materials. The other half were taught with an instructional strategy designed to acknowledge and address students' prior concepts, and incorporate principles for conceptual change. Pre and posttests were used to measure conceptual change in the experimental and control groups. Results showed a significantly greater improvement in learning in the experimental group, and researchers concluded that this gain was due to the instructional strategy and materials that specifically dealt with the learners' alternative conceptions.

Other examples of research regarding alternative conceptions and instructional strategies include Dykstra (2002); Laws (1991); Sokoloff and Thornton (1997); Thornton (1996, 1997); Goldberg (1997); Duit, Treagust and Mansfield (1996); Goldberg and Bendell (1995); Driver and Ericson (1983). In a broader context, a classification framework for integrating research into student conceptual difficulties from various domains is described by Grayson, Anderson and Crossley (2001). Of particular import to this investigation on ranking tasks is the extensive listing of astronomy alternative conceptions identified by Slater and Adams (2003).

2.6 Schema Theory & Mental Models

Schema theory is a view of constructivism developed in its modern form by Anderson (1984). Schema theory views organized knowledge as an elaborate network of abstract mental structures which represent a person's understanding of the world. Howard (1987) described it as "a mental representation of a set of related concepts." The basic idea of this theory of learning is that as students receive incoming information, they organize it around their previously developed schemata, or "networks of connected ideas" (Slavin, 1988).

Schema theory incorporates Piaget's model of the knowledge development process, involving the idea of accreting new information, tuning a primitive construct, and continually restructuring into a more accurate mental model (Driscoll, 1994). New information is often added, subtracted, ignored, or transformed depending on how the learner views the schema and the relation of new information to the schema. Stein and Trabasso (1982) describe schema as a sort of framework, or plan. A schema is a "script" which is used to guide encoding, organization, and retrieval of information.

A term related to schema theory in epistemology is the concept of *mental models.* The idea is believed to have been originated by Craik (1943) in *The Nature of Explanation*. Mental models is a handy and intuitive term that loosely refers to an internal construct or representation that people use to explain specific phenomena or use to anticipate events (Gentner & Stevens, 1983). In literature today, the idea of mental models most often refers to declarative knowledge with an image or picture constructed in the mind that a student uses to explain or make predictions regarding a situation or phenomena (Wilson & Watola, 2004).

While handy as a general reference to the mental structure that constitutes knowledge about a particular topic, the various definitions of *mental model* that I find in literature strike me as rather nebulous. These definitions lack the clarity and specifics that educators need in practical application of this concept for understanding the process of learning or nature of knowledge. As a result, in this investigation of ranking tasks I find that schema theory presents a more useful model of cognition - because it is based around the importance of visual imagery combined with additional knowledge structures that are actively organized (rightly or wrongly) by the mind into an elaborate network of rules, propositions, word lists, categorization concepts, and procedural knowledge.

Schema theory is also a useful model of cognition for our study of ranking tasks because it seems to successfully provide a useful framework for explaining students' knowledge structures, ability to recall information, and the widespread phenomena in the physical sciences of alternative conceptions (Price & Driscoll, 1997; Widmayer, 2000).

CHAPTER 3

METHODS AND PROCEDURES

3.1 Introduction

This section provides details about the methods and procedures of the study. It describes the development of the ranking task instruments, test participants, experimental treatments, data collection instruments, measurements, experimental design, general procedures of the study, and data analysis.

3.2 Participants

Participants in this study were 285 college students at the University of Arizona (a major southwestern US doctoral-granting research university) and Rockhurst University (a mid-western private liberal-arts college). The participants were enrolled in one-semester introductory astronomy courses during the Spring and Fall semesters of 2004. Prior to data collection, pilot studies with draft astronomy ranking tasks were conducted with two small astronomy classes (N = 30) at Rockhurst University (Spring of 2004), and with a group (N=5) of astronomy graduate students (Spring and Summer of 2004) at the University of Arizona. These pilot studies tested early ranking task exercise designs and the various data collection procedures. Following the pilot studies, the source of all data reported were 250 undergraduate introductory astronomy students enrolled at the University of Arizona during the Fall (August – December) of 2004. Approximately 95% of the student participants were non-science majors.

All student participants in this study were volunteers. Prior to the start of the study, the goals and research method were fully explained to all participants. Students were advised that results of this study would be published in professional journals. Students were assured privacy of various assessment test scores in compliance with the Human Subjects Policies of the respective universities. Students were asked to sign an informed-consent release before participating, and they were allowed to exercise their right to not participate in the study without consequence. With these assurances, none of the students declined to participate in the study. Thus it is fair to say that results were obtained from a representative sample of introductory astronomy students.

3.3 Treatments

The research questions seek to measure the change in student understanding of eight key astronomy concepts resulting from two instructional treatments as compared to the students' pre-course understanding.

Treatment #1 is traditional instruction which is defined as consisting of pre-lecture student assigned reading, lecture by an experienced astronomy instructor, in-class demonstrations, and instructor-led questions. The experimental course consisted of twice-weekly 75 minute sessions. For each of the eight introductory astronomy topics studied, traditional instruction (lecture, demonstrations, questions) focused on key elements of the topic, and took about 40 minutes of class time. The remainder of the class consisted of 20 to 25 minutes of Treatment #2 (see below), or other collaborative activities plus homework review and administrative activities.

Treatment #2 added collaborative ranking task exercises to the traditional instruction. Over the course of the the semester, for eight key introductory astronomy topics the instruction was supplemented with collaborative ranking task exercises. Early in the semester, before traditional instruction on the first studied topic (Motion of the Sky) students were given special training to introduce them to the ranking task format. This initial training was done using examples and practice exercises done interactively with the instructor until students demonstrated a good understanding of the exercise format and expectations. In later use, three or four ranking task exercises were completed during a single class session by students in small collaborative groups immediately after Treatment #1, and the associated Post-Traditional Instruction (P-TI) testing.

3.4 Experimental Design

The study used a one-group repeated measures design. This design maximized the sample size, and enabled more powerful statistical analysis by using paired data of individual students. Confounding variables were controlled because the characteristic the study measures (i.e., knowledge about eight selected astronomy concepts) is very resistant to change outside the effect of the two experimental treatments (Gall, Borg & Gall, 1996). The research questions concerning the effect of ranking tasks on student understanding utilized the two variations of a 28 question multiple-choice assessment instrument (described in Section 3.5) as pre and post-tests. The research question concerning how ranking tasks affect students' evolving knowledge structure utilized a qualitative questionnaire (cf. Section 3.5) and subsequent analysis of student responses using the rubric as described in Section. 3.7.

The research question concerning student attitudes toward their use of ranking tasks is based on student responses to the Likert-scale student attitude survey presented in Appendix E.

3.5 Research Instruments & Data Collection

Data collection instruments include a pre-course instrument, four post-treatment instruments including multiple-choice questions and free-response questions, and a Likert-scale style student attitude survey which was completed at the end of the 4 month study period.

To investigate the four research questions (cf. Section 1.5), the astronomy topic areas were divided into two groups. Group A consisted of the following five topics: Motion of the Sky, The Seasons, Orbital Motion – Kepler's Laws, Doppler Shift, and Magnitude-Distance Relationships. Students' understanding of these topics from Group A were assessed quantitatively using multiple-choice assessment tests. Group B consisted of three additional topics: Phases of the Moon, Gravity, and Luminosity of Stars. Students' understanding of Group B topics were assessed by both quantitative multiple-choice tests and by qualitative instruments with free-response questions for the students.

A bank of 28 multiple choice questions was created consisting of three or four questions for each of the eight key astronomy concepts covered in this study. These 28 questions were culled largely from previously published evaluation instruments, and selected to address the commonly taught aspects of the eight astronomy concepts covered in this study. Questions were selected from the Astronomy Diagnostic Test (Zeilik, 2003), from Prather, Slater, and Adams (2004), and from Seeds (2004).

Pretest Instrument & Data Collection

Initial assessment of students' knowledge base was measured using the 28-item multiple choice Pretest presented in Appendix B. Within the test, questions were structured to prevent situations where one multiple-choice question might provide clues to a related question. The Pretest was administered at the start of the first day of class. A small group of students who did not report to class until the second session took the Pretest in that second class.

The data collected were student ID number, gender, Pretest question number, and student responses.

Post-Traditional Instruction Instruments & Data Collection

The P-TI test for each of the five astronomy topics identified as Topic Group A above consisted of the corresponding three to four multiple choice questions for each topic which were used one to ten weeks earlier in the Pretest.

The P-TI instruments for the three astronomy topics in Topic Group B consisted of the three to four multiple choice questions for each topic plus a qualitative questionnaire of free-response questions. The multiple-choice test was given to half the class, and the qualitative questionnaire was given to the other half of the class. The qualitative questionnaire consisted of a typical “end of chapter” problem coupled to a free-response question seeking to assess the strategy used by the student in solving that exercise and to assess the depth of understanding of the concepts involved. See Appendix C for the P-TI multiple-choice assessment test and the qualitative questionnaire.

Data collected on the multiple-choice test and the qualitative questionnaire were student ID, gender, P-TI question number and student responses. Additional data collected on the qualitative questionnaire were individual student responses to the sample exercise and to the open-ended questions. Students were asked to solve a conceptual question on the astronomy topic, and then to explain their reasoning process for their answer.

Post-Ranking Task Instruments & Data Collection

The Post-Ranking Task (P-RT) test for each of the five astronomy topics identified as Topic Group A consisted of three to four multiple-choice questions similar in concept to those used in the Pretest. However, the questions were carefully reworded and new variable values substituted so that students had to re-analyze the exercise.

For Topic Group B, the P-RT instruments included the revised multiple-choice questions as described above, plus a revised qualitative questionnaire. Half the class received the multiple-choice questionnaire and half received a qualitative questionnaire similar to the P-TI instrument, but with a revised “end of chapter” type exercise. See Appendix D for the P-RT multiple-choice test and the qualitative questionnaire.

Data collected on the multiple-choice test were student ID, gender, P-RT question number and student responses. Additional data collected on the qualitative questionnaire were individual student responses to the sample exercise and to the free-response question.

Student Attitude Survey

A Likert-scale survey form was developed and given to all participants at the end of the semester to investigate their attitudes about using ranking tasks as part of the instructional method. The survey form addressed student impressions in using ranking tasks, how well these exercises worked in collaborative groups, and whether students believed that ranking task exercises helped them in learning the course material. After the Likert-scale questions, the survey asked students to describe their overall experience with ranking tasks using a free-response question. The student attitude survey form is presented in Appendix E.

3.6 Procedures

In the months prior to data collection with the experimental group, I monitored classes (in the Spring 2004) taught by the instructor (Dr. Prather) who was to later conduct the experimental treatments. In follow-up discussions, we defined what would constitute the traditional instruction to be used throughout the study. We agreed that traditional instruction would include those elements currently expected by university students for a lecture-based course. As a result of these discussions, we defined traditional instruction as including these main elements:

- Student pre-class reading assignment;
- Didactic lecture using carefully prepared MS PowerPoint visual aids (summery bullet slides of key ideas and definition, illustrations of the phenomena, and presenting example problems)
- Demonstrating solutions to example problems.
- Limited instructor-oriented questioning of individual students, and answering specific student-initiated questions by instructor.

For each of the eight astronomy topics studied in this investigation, this traditional instruction occupied about 40 minutes of a 75 minute class period.

Because this was the style of instruction that both Dr. Prather and I use in our classroom routine, I was confident that the traditional instruction treatment would be consistently applied over the eight astronomy topics studied in this investigation.

Prior to the beginning of the data collection period (Fall semester, 2004), the instructor (Dr. Prather) who conducted the experimental class and data collection was provided with the following:

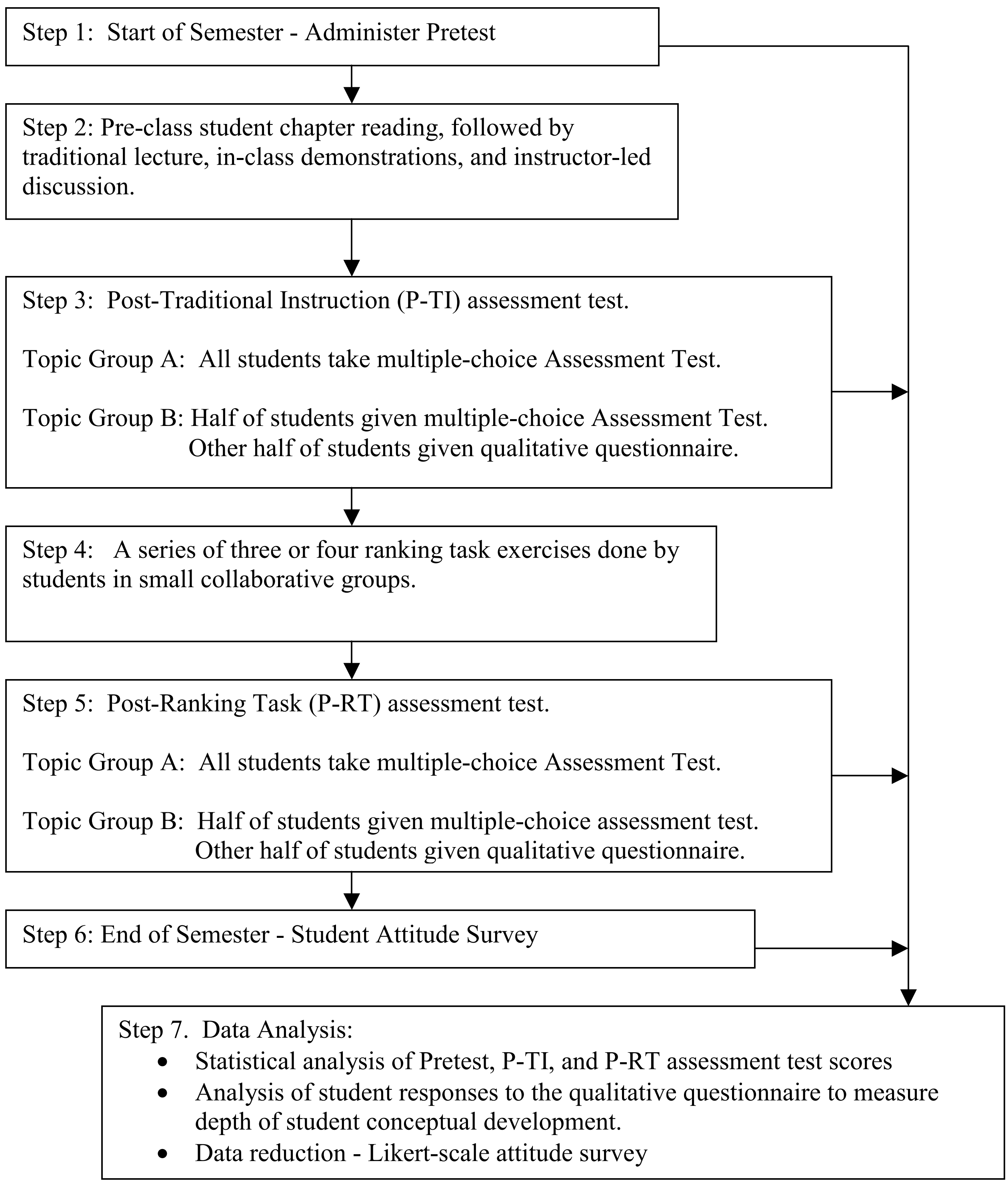
- Ranking task sets (four to five exercises each) for the eight key introductory astronomy topics selected for the investigation;
- Multiple-choice assessment tests for each of the eight topics (P-TI and P-RT versions).

- Qualitative questions (P-TI and P-RT versions) for each of three topics in astronomy topics Group B.
- Likert-scale student attitude survey

The basic steps of the research procedure employed over the course of the four month data collection period are shown in Figure 2 on the next page. A discussion of this procedure then follows.

Figure 2: General Experimental Procedure:

Astronomy Ranking Task Study



Step 1: Administer Pretest

In the first class session, the instructor explained the purpose of the research project and the confidentiality aspects of student participation. Students were advised that they could participate or opt out without consequence. It was also carefully explained to the students that the purpose of the study was to determine the effectiveness of ranking task exercises as a learning tool. Most importantly, student test scores done as part of the study had no impact on individual students' final grade in the class.

After normal first day of class orientation, all students took the Pretest. This test measured individual student knowledge base for each of the eight astronomy topics prior to course instruction. The scored Pretest was not returned to students, and students were asked to avoid discussing Pretest questions later among themselves. Once completed, we observed little continued interest by students in the Pretest, and conclude that there was no general effort to memorize the questions or answers.

Step 2: Traditional Instruction

Traditional Instruction includes pre-class reading assignments, followed by traditional lecture from an experienced astronomy instructor, in-class demonstrations, and instructor-led discussion. (See earlier discussion in this chapter.)

Step 3: Post-Traditional Instruction Assessment Test

After traditional instruction on each of the eight studied astronomy topics, students immediately took the multiple-choice P-TI assessment test. However, in the case of topic

Group B, half of the students (randomized) took the P-TI qualitative questionnaire instead of the multiple-choice assessment test. This testing took from eight to ten minutes, with the qualitative questionnaire requiring slightly more time than the multiple-choice test. As test forms were collected, students were reminded that their individual scores did not affect their course grade but were essential to the validity of the research. Tests were later scored and results recorded. However, tests were not returned to students nor correct answers discussed with them. Because, I believe, the short tests did not affect their grade, we observed no effort or interest by students in later discussing their responses.

I believe it unlikely that whether a student took the P-TI multiple-choice assessment test or the qualitative questionnaire would affect their knowledge level. More importantly, however, in the end our ANOVA statistical analysis required "matched pairs" of student scores thereby eliminating this potential problem in our results.

Step 4: Collaborative Ranking Task Exercises

Immediately after the P-TI assessment test (for each of the eight astronomy topics investigated in this study), the instructor directed students to work on the first ranking task exercise. Students sitting in the large lecture hall broke into self-formed collaborative groups of two or three students, and then worked together to complete the three or four paper and pencil ranking task exercises which had been handed out. The researchers observed considerable and often animated discussion within groups as they worked through the exercises. The teaching assistants often aided groups as requested.

Although students worked in small collaborative groups, each student recorded individual answers to the ranking task exercises. Student responses were collected and student given participation credit in order to maintain class motivation, but no data were collected from the ranking task exercises. After gathering the paper and pencil ranking task exercises, the instructor generally did not review answers unless specifically (and rarely) requested by a student. While this review was not considered a priority during the course of the study, I later concluded that this strategy probably reduced somewhat the full potential gains from ranking tasks. See discussion about this later in Section 5.4.

Step 5: Post-Ranking Task Assessment Test

After completing the collaborative ranking task exercises, students immediately took the multiple-choice P-RT assessment test. However, in the case of topic Group B, half of the students (randomized) took the P-RT qualitative questionnaire instead of the multiple-choice assessment test. This testing took about ten minutes, with the qualitative questionnaire requiring more time than the multiple-choice test. As the paper test forms were collected, students were reminded that their individual scores did not affect their course grade – but were essential to the validity of the research. Tests were later scored and results recorded in an Excel spreadsheet. However, tests were not returned to students nor were correct answers discussed with them.

Step 6: Student Attitude Survey

In the class following the last of the eight key astronomy topics investigated in this study, a Likert-scale student attitude survey (cf. Appendix E) was administered to all participants. Students included their student ID numbers on the survey form in order to receive daily participation credit toward their course grade. However, these identification numbers were clipped off the form by teaching assistants immediately after recording attendance. Student responses to the five Likert-scale questions were then recorded in an Excel file. Student narrative responses and comments were retained on the paper form for later study.

3.7 Early Project Development & Pilot Studies

In the early Spring of 2004 we selected eleven key topics commonly included in introductory astronomy courses as candidates for use in our investigation of ranking tasks. These topics were drawn from survey studies by Brissenden *et al*. (1999), and by Slater *et al.* (2001), and included the following:

1. Motion of the sky
2. The Seasons
3. Phases of the Moon
4. Kepler's Laws
5. Gravity
6. Luminosity of stars
7. Doppler shift
8. Apparent & absolute magnitude
9. Stellar parallax
10. Scale of astronomical objects
11. Evolution of stars

Following this selection of astronomy topics we began drafting topical sets of ranking task exercises guided by education research and the design features described in Section 1.7.

During the Spring and Summer of 2004, we conducted pilot studies of these draft ranking tasks using three groups of students. These pilot test groups included the author's two introductory astronomy classes of 15 students each at Rockhurst University, and a group of five graduate students and staff research assistants associated with the Conceptual Astronomy and Physics Education Research (CAPER) Team at the University of Arizona (cf. Section 1.6). My students worked during regular class periods, and the CAPER Team met in special sessions. These pilot tests groups were instructed and familiarized with the form of the ranking tasks, and then asked to work in collaborative groups to solve the exercises and provide feedback (both oral and written) regarding any difficulties the group encountered to Dr. Prather and to the author. As I drafted the various pre and post-test assessment instruments to be used in the study, Dr. Prather and the CAPER Team reviewed this testing material - and provided valuable written feedback.

The pilot studies enabled us to finalize a set of eight ranking tasks to be used in this study. The selected ranking task topics were items 1 through 8 listed above. This number constitutes a moderately large sample of key astronomy topics from which to draw general conclusions, but was workable within the total resources and practical schedule constraints of the study. Two topics (scale of astronomical objects, and stellar evolution) were pilot tested but were later discarded because we felt these topics relied heavily on memorization rather than more complex conceptual understanding. We believe that ranking tasks developed around such topics may have less benefit than more complex conceptual subjects. In addition, we also dropped the topic of star parallax because of its limited complexity and heavy reliance on a simple linear calculation.

During the pilot studies, the various assessment tests went through a slow evolution as a consensus was reached regarding the exact form of the multiple-choice tests and the free-response qualitative questions. Importantly, from student responses to the qualitative questions I developed a draft rubric for categorizing five levels of student understanding. This rubric was based on the degree to which component concepts, the language of science, and structural relationships were described by the student in their written responses.

From the pilot studies we were able to identify and correct several shortcomings in the original design of our ranking tasks. The pilot studies revealed these three design issues:

1. Our early astronomy ranking tasks focused too heavily and too quickly on on mathematical solution. Perhaps this resulted from the many physics ranking task examples we had seen previously, and which we initially adapted as a model. In the pilot studies we found, however, that students struggled when initially confronted with computation-based ranking tasks. After this initial stumble, we observed students then struggle to build the more robust knowledge structure that we hypothesize ranking tasks facilitate. As a result of these difficulties, we made a fundamental change in the design of the ranking tasks. We were careful to begin each set of ranking tasks with a familiar and non-mathematical concept, then scaffolded to more complex and mathematical exercises as appropriate to the topic.

2. We found that great care must be taken in the design of diagrams and illustrations to assure that all aspects of figures are properly scaled, or clearly marked when not to scale. Students view figures and diagrams very literally, often reading more into the illustration than we had intended. Figures must be clear and unambiguous to learners.

3. While other references (e.g., O'Kuma, Maloney & Hieggelke, 2000) describe ranking tasks with often eight physical situations, our pilot study leads us to conclude that no more than six situations should be presented to students. While a larger number of situations make it easier to identify student thought processes, we found that students quickly lost motivation if faced with long bookkeeping activities. Therefore we established a design limit of six physical situations to our astronomy ranking tasks.

3.8 Data Analysis

Hypothesis Testing of the Ranking Task Main Effect

The primary focus of the study was to determine if student understanding of eight key astronomy topics was improved by adding a series of in-class collaborative ranking task exercises to traditional lecture-based instruction, and to measure that Main Effect, if any. Student understanding was assessed by a Pretest, and multiple-choice tests both post TI and post-RT administered for each of the eight astronomy topics.

The null hypothesis is that mean student scores on the Pretest, P-TI and P-RT assessment tests will be equal:

$$Ho: \mu_{Pre} = \mu_{P\text{-}TI} = \mu_{P\text{-}RT}$$

While the alternative hypothesis is:

$$Ha: \mu_{P\text{-}RT} > \mu_{P\text{-}TI} > \mu_{Pre}$$

Using a standard statistical package, SPSS Ver 12.0, descriptive and inferential statistics were developed and hypothesis testing performed. Specifically, a series of mixed-factors ANOVA was performed on student scores from Pretest, P-TI, and P-RT assessment tests (repeated-factors) for each of the eight topics covered. Gender was the between-groups factor. A significance level of alpha = 0.05 was established prior to significance testing.

The repeated measure designs, where participants participate in all levels of the independent variable (e.g., Pretest, P-TI, and P-RT), allowed participants to serve as their own controls. Analyzing the data with the repeated measure factor effectively reduced the error variance that would be found if the independent variable was tested using the basic between groups approach.

Because this analysis of variance involves three treatments, the ANOVA was followed by calculation of post hoc Least Significant Differences (LSD). The most important of these (the main effect) were between the P-TI and P-RT test scores - in order to test student gains between the two treatments.

Although the repeated measure (Time of Testing, Pretest, P-TI, and P-RT) and gender (between groups factor) were simultaneously analyzed in this series of mixed-factors ANOVA, gender differences are reported separately in this study.

Finally, a second series of mixed factors ANOVA were performed on the data. In these analyses, upper versus lower Pretest score student groups based on the median split were calculated to form the between subjects factor. Time of Testing (P-TI and P-RT) was the repeated factor.

Determining Effect Size Using Standard Education Research Measures

To fully answer the first research question (cf. Section 1.4 - concerning the effect on student understanding of adding a program of astronomy ranking task exercises to traditional lecture-based instruction) requires more than the inferential statistics described above. We are interested in not only do ranking tasks increase student understanding, but to what degree do these exercises help, if any? An intervention could be statistically significant, but the gains so slight that they are not worthwhile as a practical matter in the classroom.

To actually measure the effect of ranking tasks, the study calculated several metrics commonly used in education research (Zelik & Morris, 2004; Cohen, 1988) from the descriptive statistics and ANOVA described above. These standard education research metrics include partial eta^2, average normalized gain <g>, and Cohen's d. (cf. Section 4.4).

Gauging Student Conceptual Development From Free Response Questions

The primary measure of student understanding of the eight astronomy topics was through the multiple-choice assessment tests administered as a pretest, and after the two study treatments. However, we sought to investigate conceptual change resulting from the ranking tasks in a second and different way which we had hoped would provide additional insight. With this goal, for each of three astronomy topics in Group B (Lunar Phases, Gravity, and Luminosity of Stars) we asked a number of students (N=30) to solve a typical end-of-chapter problem, and to then explain in a written narrative (i.e., free response) how they solved the problem.

These written narratives were then analyzed qualitatively as described by Stemler (2001) in a process that yields a numeric score which is then suitable for comparative studies. This analysis of narrative text was described by Berelson (1952) as "a research technique for the objective, systematic, and quantitative description of the manifest content of communication". Gall, Borg, and Gall (1996) describe this analysis as "a research technique for making inferences by systematically and objectively identifying specified characteristics within a text."

Data analysis of student narrative answers to free-response questions involved developing a system of coding based on our earlier pilot studies and the testing of our draft ranking task exercises. This system of coding took the form of a rubric (See Table 1 on next page) that defines a student's level of conceptual understanding into five categories described as "Unstructured/Alternative" to "Expert". These levels are described by the identification of component concepts, use of language, and the structure or integration of conceptual relationships demonstrated by students in their responses.

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 Component Concepts*. Includes naming of relevant 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 the Component Concepts, but omits describing at least one essential element of knowledge. Description sometimes shows some minor confusion in language or terms, but sometimes 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: Sub-functional	Student explanation correctly identifies at least one relevant variable, but only portions of the Component Concepts are demonstrated. Important inter-relationships 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/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.

Definition: Component Concepts – knowledge of the concepts, phenomena and principles involved and how they relate to one another - as required for construction of an integrated and robust mental model of the subject topic.

For our research topic of Star Luminosity the Component Concepts include (1) understanding and interpretation of H-R diagrams, and (2) ability to apply the general relationship Luminosity = f(Temp, Surface Area or "size").

For our research topic of Gravity the Component Concepts include (1) F_g is the same on each body, (2) gravity decreases with distance, but never becomes zero, (3) Gravity obeys an inverse square law, (4) F_g = f(mass, distance), (5) force vectors – opposing equal forces cancel for net result of zero, (6) the mass of the Earth is greater than the mass of the Moon.

For our research topic of Lunar Phases the Component Concepts include (1) the Moon is always ½ lit by the Sun, (2) as the Moon orbits the Earth each month, the illuminated area of the Moon slowly changes, (3) from our vantage point here on Earth, the amount of the sunlit portion of the Moon that is visible to us changes from night to night depending on the Sun-Earth-Moon geometry, (4) the Moon is above Earth's horizon at some time during both daylight hours and at night.

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 P-TI and P-RT 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 testing demonstrated the inter-rater reliability of the scoring process using the rubric, and ultimately the author scored all P-TI and P-RT student responses (approximately 180) for a quantitative measure of Level of Understanding.

The analysis of student narrative explanations using the Level of Understanding rubric provided an independent measure of the robustness of student understanding after each of the experimental treatments. We viewed this analysis as a valuable cross-check of results from the purely quantitative multiple-choice assessment tests. Student narrative responses to the qualitative questionnaire were later found to provide interesting insights into subtle changes in conceptual understanding between the traditional instruction and ranking task treatments.

Analysis of Student Attitude Survey

The fourth Research Question (see Section. 1.4) asked “To what extent do students perceive the value of ranking tasks exercises in the introductory astronomy classroom? To address this question, a survey was conducted at the end of the study consisting of two parts.

The first part of the survey presented students with four positive statements regarding the usefulness of ranking tasks, and a Likert-scale of five levels A through E to indicate the degree that the student either agreed or disagreed with the statement. For data analysis, student responses were transferred to an Excel spreadsheet as a numeric with 5 meaning they strongly agree and 1 meaning the student strongly disagrees.

Data from the Excel spreadsheet were reduced to descriptive statistics (percentage responses) for levels within each attitude statement. In the course of this analysis a small problem was discovered in the design of our Likert-scale survey form which resulted in discarding about 12% of the data. This is discussed in Section 4.8.

The second part of the Student Attitude Survey posed a free-response question asking for student comments on their overall experience with the astronomy ranking tasks. Analysis consisted of grouping comments into positive and negative major categories, and counting the number of occurrences of repeated common ideas expressed in the narratives. This analysis highlighted a number of unexpected issues that are discussed in Section 4.8.

CHAPTER 4

RESULTS

4.1 Introduction

This research was conducted to answer the question of whether adding a program of ranking task exercises to traditional lecture-based instruction produces a higher levels of understanding by university students over eight key introductory astronomy concepts. In this research, better understanding was measured as gain in conceptual test scores from a Pretest (at start of semester) to P-TI, and finally to P-RT.

It was our hypothesis, based on results from cognitive science and how people learn and limited literature on the use of ranking tasks in the physics classroom, that a program of ranking task exercises added to traditional lecture-based instruction would produce significantly greater gains by introductory astronomy students on conceptual tests as compared to only traditional lecture-based instruction. In addition, this research investigated (1) gender effects, (2) the effect of student initial astronomy knowledge base on the effectiveness of ranking tasks, (3) a qualitative measure of student conceptual models after study treatments, and (4) students' perceived value of ranking task exercises in the introductory astronomy classroom.

Recall that approximately 280 introductory astronomy students at two four-year universities participated in this study. Ranking task curriculum materials were designed and pilot tested on eight key astronomy topics (motion of the sky, seasons, phases of the

Moon, Kepler's Laws, gravity, luminosity of stars, Doppler effect, and star magnitude & distance). At the start of the semester students were pre-tested using a 28 item multiple-choice conceptual test covering these eight astronomy topics. Students were then post-tested after traditional instruction (P-TI) and after completion of the collaborative ranking task exercises (P-RT). In addition, a sample group of students completed a qualitative questionnaire asking them to explain their strategy for solving conceptual exercises in three of the eight study topics. Finally, a Likert-scale attitude survey about ranking tasks was administered at the end of the semester to all students.

4.2 Descriptive Statistics: Pretest, Post-Traditional Instruction, & Post-Ranking Task Student Test Scores

The primary study group was an introductory astronomy class at the University of Arizona consisting of 253 students. On the first day of class, 211 students took the Pretest as a measure of their astronomy knowledge prior to the start of the course. Eight astronomy topics were included in the study. Three topics (Motion of the Sky, Gravity, and Star Luminosity) were investigated using both multiple-choice questions and a qualitative (free-response) questionnaire. For the remaining five topics investigated in the study we gathered Pretest, P-TI, and P-RT matched-pair data sets (students participating in all three tests) for the multiple-choice assessment tests. The average sample size was 131 participants for each test.

Table 2 below presents overall descriptive statistics of results of the Pretest, P-TI, and P-RT test scores on each of the eight key astronomy topics. The table reports the sample size, mean, and standard deviation of assessment test scores along with averages across the eight studied topics.

Note that in Table 2 below the standard deviation (SD) of student scores within various topics are sometimes larger than the mean. This frequently happens when it is possible for scores to be zero, as was the case for many students on the Pretest.

Table 2
Descriptive statistics of Pretest, P-TI, and P-RT assessment scores for multiple-choice questions on eight key astronomy topics.

		Pretest	Pretest	P-TI	P-TI	P-RT	P-RT
Topic	**N**	**% Items Correct**	**SD %**	**% Items Correct**	**SD%**	**% Items Correct**	**SD%**
Motion of the Sky	148	29	24	66	29	88	19
Seasons	148	44	28	57	27	75	27
Phases of the Moon	31	43	18	71	23	80	25
Kepler's Laws	120	18	20	56	26	65	26
Gravity	45	30	26	42	19	63	19
Luminosity of Stars	38	41	30	66	29	82	23
Doppler Effect	128	30	33	75	30	86	25
Magnitude & Distance	111	18	23	55	35	73	27
Averages	**96**	**32**	**25**	**61**	**27**	**77**	**24**

Figure 3 below presents graphically the mean test scores for the Pretest, P-TI, and P-RT for each of the eight studied astronomy topics which were presented earlier in Table 2. Note that the standard errors for each datum point are smaller than the resolution of the figure.

Figure 3

Study results of Pretest, P-TI, and P_RT Assessment Test Scores for each of the eight key astronomy topics.

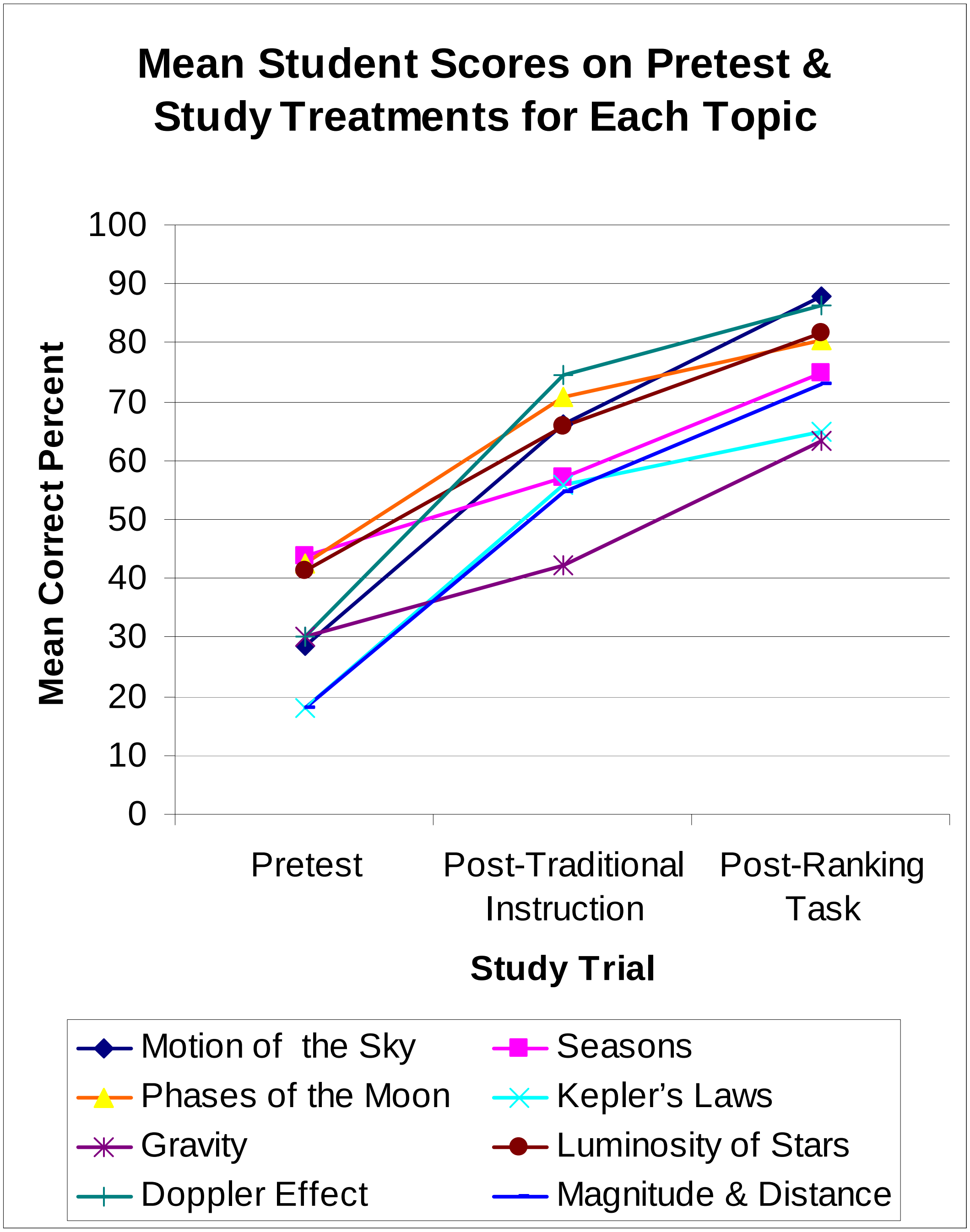
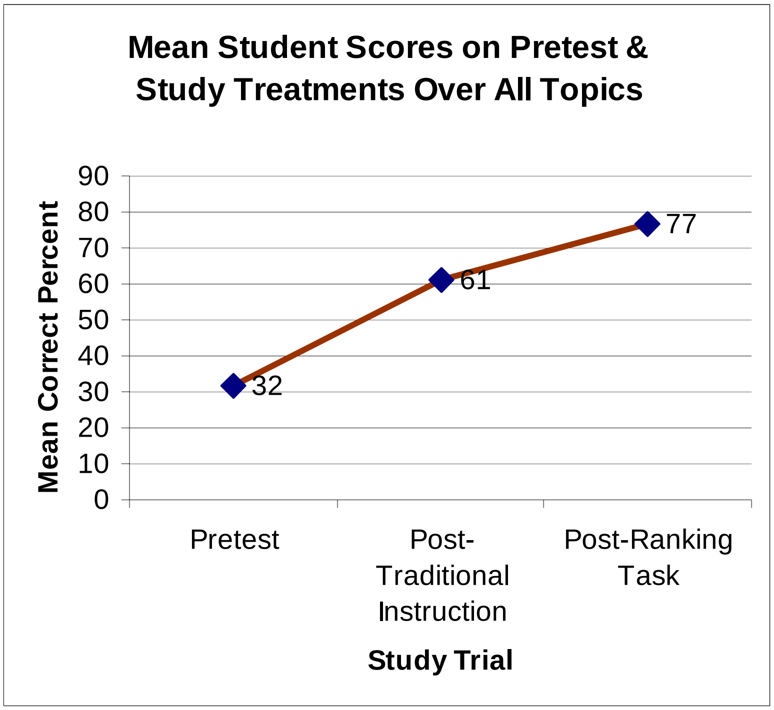


Figure 4 below shows the average Pretest, P-TI, and P-RT test scores across all eight astronomy topics.

Figure 4
Mean Pretest, P-TI, and P-RT test scores for eight astronomy topics.



The data in Figures 3 and 4 suggest that students' test scores rose consistently between each treatment. Mean scores of 32% for the Pretest and 61% for P-TI, rose to 77% after the collaborative ranking task exercises.

4.3 Statistics & Hypothesis Testing: Ranking Task Exercises Main Effect

A series of mixed-factors ANOVA were performed on student scores from Pretest, P-TI, and P-RT tests (repeated-factors) for each of the eight astronomy topics in this investigation.

Repeated measure designs, where participants participate in all levels of the independent variable (e.g., Pretest, P-TI, and P-RT test scores), allow participants to serve as their own controls. Analyzing the data using a repeated-measures ANOVA effectively reduces the error variance that would be found if the independent variable was tested using the basic between groups ANOVA.

Because this analysis of variance involves three treatments, the ANOVA was followed by calculation of Least Significant Differences (LSD) between the P-TI and P-RT test scores in order to test student gain between the two treatments. A significance level of $p = 0.05$ was established prior to significance testing.

Table 3 on the next page presents the results of the inferential statistics for the study main effect, i.e., the effect of the ranking task exercises on student understanding. Table 3 shows the Pretest, P-TI, and P-RT test scores along with results of the ANOVA and LSD tests of the three treatments across each of the eight studied astronomy topics. It presents various ANOVA metrics including degrees-of-freedom (df), F-values, p-values, along with effect size (partial eta^2), and LSD significance results expressed as z-scores and resulting p-values.

Table 3
Results of repeated-factors ANOVA & Least Significant Difference Tests (LSD) of Pretest, P-TI, and P-RT assessment test scores on eight key astronomy topics.

Topic	**N**	**Pretest (% Items Correct)**	**Pretest vs. P-TI LSD alpha=0.05**	**P-TI (% Items Correct)**	**P-TI vs. P-RT LSD Alpha=0.05**	**P-RT (% Items Correct)**	**Omni-bus df**	**Omni-bus F**	**Omnibus p-value**	**P-RT vs P-TI: Partial eta^2**
Motion of the Sky	148	29	$Z > 1.96$ $p < 0.05$	66	$Z > 1.96$ $p < 0.05$	88	2, 292	252	<0.001	0.33
Seasons	148	44	$Z > 1.96$ $p < 0.05$	57	$Z > 1.96$ $p < 0.05$	75	2, 292	58	<0.001	0.22
Phases of the Moon	31	43	$Z > 1.96$ $p < 0.05$	71	$Z > 1.96$ $p < 0.05$	80	2, 58	28	<0.001	0.15
Kepler's Laws	120	18	$Z > 1.96$ $p < 0.05$	56	$Z > 1.96$ $p < 0.05$	65	2, 236	154	<0.001	0.09
Gravity	45	30	$Z > 1.96$ $p < 0.05$	42	$Z > 1.96$ $p < 0.05$	63	2, 86	30	<0.001	0.45
Lumi-nosity of Stars	38	41	$Z > 1.96$ $p < 0.05$	66	$Z > 1.96$ $p < 0.05$	82	2, 72	26	<0.001	0.20
Doppler Effect	128	30	$Z > 1.96$ $p < 0.05$	75	$Z > 1.96$ $p < 0.05$	86	2, 252	179	<0.001	0.09
Magni-tude & Distance	111	18	$Z > 1.96$ $p < 0.05$	55	$Z > 1.96$ $p < 0.05$	73	2, 218	137	<0.001	0.22

The omnibus data shown in Table 3 are an essential part of the ANOVA, presenting a comparison of the extremes of the three sets of data (i.e., Pretest vs. P-RT). For each of the eight astronomy topics, the omnibus F test yielded very large F values. The omnibus degrees-of-freedom (df) is presented because it is this factor along with the omnibus F-values that determine the omnibus p-value associate with each of the eight astronomy topics.

The omnibus p-values in Table 3 demonstrates that there is a very large statistical difference ($p < 0.001$) between Pretest and P-RT test scores, as expected. While these results may seem obvious, for statistical completeness this omnibus test must carefully be done prior to the two LSD tests.

In Table 3, the LSD tests show that for each of the eight astronomy topics, a comparison of Pretest vs P-TI test scores and P-TI vs. P-RT test scores yields a calculated Z-value of greater than 1.96. This means that in each case, the p-value is less than 0.05. Of critical importance to this study, the LSD test demonstrates that there is a significant statistical difference between the P-TI and P-RT test scores.

The last column in Table 3 shows the P-TI vs P-RT partial eta^2 effect sizes across the eight astronomy topics. These effect sizes can be described as moderate to large (Cohen, 1988).

In summary, the ANOVA and LSD tests show that student mean test scores rose significantly after Traditional Instruction (as one would hope). More important to this study, test scores across all eight astronomy topics rose very significantly after the ranking task treatment. As a result, for each of the eight astronomy topics, I reject the null hypothesis ($\mu_{Pretest} = \mu_{P-TI} = \mu_{P-RT}$) and accept the alternative hypothesis that ranking tasks significantly raise student assessment test scores ($\mu_{P-RT} > \mu_{P-TI} > \mu_{Pretest}$) beyond the gains made as a result of traditional instruction.

4.4 Effect Size Measures

In this section I present common measures of effect size often reported in educational research. Effect size is a name given to a number of indices that measure the magnitude of treatment effects. Unlike significance tests, these indices are independent of sample size. Effect size measures are useful as the common currency of meta-analysis studies that summarize the findings across multiple studies into a specific area of research. (Becker, 2000)

As metrics of merit, we use partial eta^2, average normalized gain, and Cohen's d. There is some controversy about how to compute effect sizes when study groups are dependant, which is the case in this study where we have matched groups or repeated measures – also called a correlated design. However, these are useful standard measures that are often quoted in the literature (Zeilik & Morris, 2004).

Partial Eta^2

An unbiased measure of effect size in repeated measures designs referenced by Cohen (1988) is the partial eta^2 which is obtained as part of the ANOVA, as presented in Table 3 above. Cohen (hesitantly) describes partial eta^2 > 0.08 as a moderate effect, and partial eta^2 > 0.14 as a large effect. Using these definitions, the ANOVA partial eta^2 values shown in Table 3 comparing the P-RT vs. P-TI treatments show generally large effect sizes attributed to the ranking task exercises for Motion of the Sky, Seasons, Phases of the Moon, Gravity, Luminosity of Stars, and Star Magnitude/Distance topics. For the Doppler Effect and Kepler's Laws topics, the ranking tasks produced moderate effects.

Averaging across all eight astronomy topics, the mean partial eta^2 is 0.22 which Cohen describes as a large effect. Thus we assert that the ranking task treatment had a large effect in producing gains in student understanding scores compared to traditional instruction alone.

<u>Average Normalized Gain</u>

A second effect size measure often found in education research is normalized gain <g> (Hake, 1999; Hovland, Lumsdaine & Sheffield 1949). This is defined as the ratio of the actual average gain compared to the maximum possible gain. The average normalized gain is

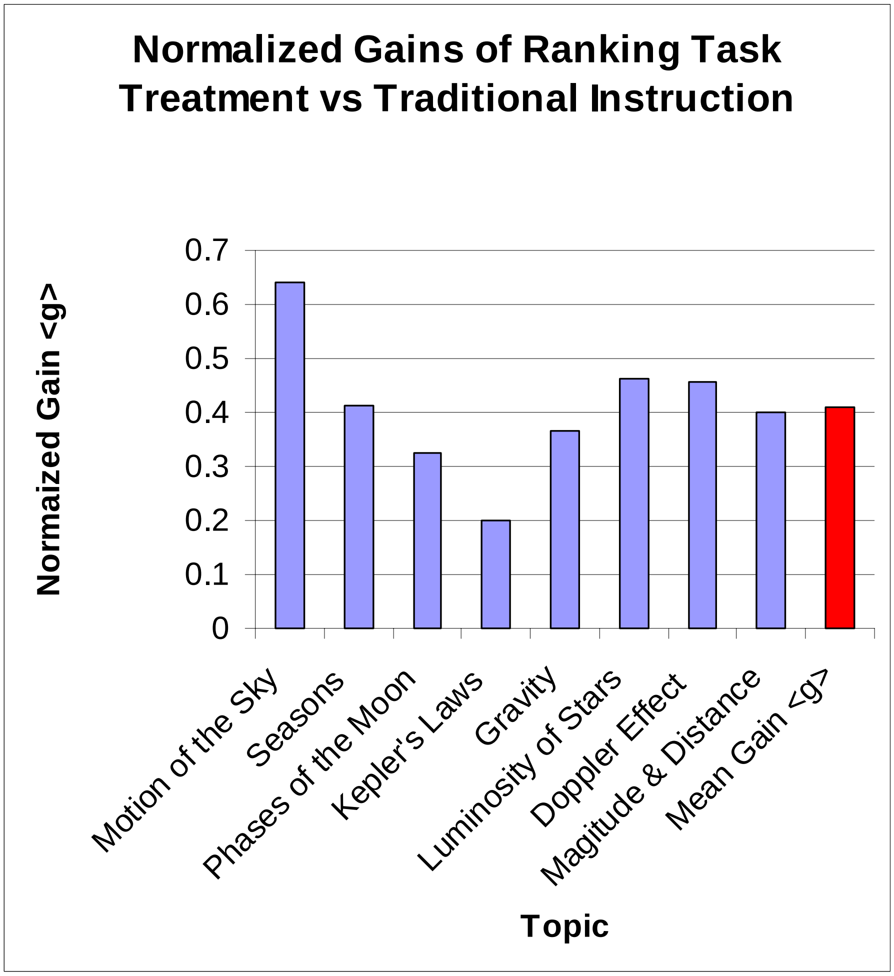
$$\langle g \rangle = G_{actual} / G_{maximum} = (\%\langle S_f \rangle - \%\langle S_i \rangle)/ (100 - \%\langle S_i \rangle)$$

Table 4 presents the average normalized gain <g> between student P-TI and P-RT test scores on each of the eight studied astronomy topics. Figure 5 presents the normalized gains in a bar graph for easier comparison.

Table 4
Descriptive statistics for normalized gain in test scores when ranking task exercises are added to traditional instruction.

Topic	**N**	**P-TI**	**P-RT**	**Normalized Gain < g>**
		% Items Correct	**% Items Correct**	
Motion of the Sky	148	66	88	0.64
Seasons	148	57	75	0.41
Phases of the Moon	31	71	80	0.33
Kepler's Laws	120	56	65	0.20
Gravity	45	42	63	0.37
Luminosity of Stars	38	66	82	0.46
Doppler Effect	128	75	86	0.46
Magnitude & Distance	111	55	73	0.40
Averages	**96**	**61**	**77**	**0.41 +- 0.13**

Figure 5
Normalized gain in test scores when ranking task exercises are added to traditional instruction in this study of eight key astronomy topics.



Earlier we found that for each of the eight studied astronomy topics, the addition of ranking task exercises to traditional instruction significantly improved test scores (cf. Section. 4.3). As shown in Figure 5 above, we also see that ranking tasks resulted in normalized gains ranging from <g> = 0.20 to <g> = 0.64. Across the eight studied astronomy topics, the mean normalized gain <g> was 0.41 +/- 0.13. This is described by Hake (1999) as a moderate gain. Importantly, however, the ceiling effects described by

Meltzer (2005) and Hekler (2004) tend to falsely minimize the test score gains actually resulting from the ranking task treatments. This ceiling effect refers increasing difficulty of further gains in P-RT test scores when scores are already high (61% correct) in the earlier P-TI scores. Meltzer points out that "higher pretest scores tend to result in smaller absolute gains, all else being equal." We therefore assert that the normalized gains shown here are highly significant, and large by any measure commonly used in education research.

<u>Cohen's d Effect Size</u>

Another common effect size measure recommended (Hake, 2001) and commonly found in education research is Cohen's d. This measure is defined (Cohen, 1988) as

$$d = (\langle\%post\rangle - \langle\%pre\rangle) / [(sd_{pre}^2 + sd_{post}^2)/2]^{0.5}$$

This measure is basically the difference in means divided by the pooled standard deviation.

Results of the Cohen's d effect size measure for P-TI vs. P-RT are presented in Table 5 below.

Table 5
Cohen's d effect size comparing P-RT test scores with P-TI test scores over eight key astronomy topics.

Topic	**N**	**P-TI**	**P-RT**	**Cohen's d Effect Size**	**Description of Effect Size** (Note 1)
		% Items Correct	**% Items Correct**		
Motion of the Sky	148	66	88	0.88	Large
Seasons	148	57	75	.66	Moderately Large
Phases of the Moon	31	71	80	0.40	Medium
Kepler's Laws	120	56	65	0.34	Medium
Gravity	45	42	63	1.12	Large
Luminosity of Stars	38	66	82	0.60	Moderately Large
Doppler Effect	128	75	86	0.42	Medium
Magnitude & Distance	111	55	73	0.58	Moderately Large
Averages	**96**	**61**	**77**	**0.62 +- 0.264 SD**	**Moderately large**

Note1: Defined as by Cohen (1988) as effect size =0.1 small effect, 0.3 – 0.5 as medium effect, 0.5 –0.8 moderately large effect, and >0.8 as a large effect.

It is worthwhile noting that Cohen's d assumes a comparison of independent groups. Because this study design actually compares matched pairs (the same students taking both the P-TI and P-RT tests), the verbal descriptions (e.g., small, moderate, large effect) suggested by Cohen (1988) tend to understate the effect size when Cohen's d is applied to matched pairs - as in this study.

Zeilik and Morris (2004) report that "In education research, effect sizes of 0.1 or less are considered small and of no practical import; 0.3 are considered medium and have practical significance; and 0.5 or greater are considered large (see Cohen 1988)". Using these definitions, results presented in Table 5 show a mean Cohen's d of 0.62, considered large in education research. This further supports our assertion that the effect of the ranking task exercises is highly significant, and large by any measure commonly used in education research.

4.5 Statistics & Hypothesis Testing: Gender Effects

Our second research question (cf. Section 1.4) asked if Astronomy ranking tasks differentially affected student test scores by gender. Table 6 presents descriptive statistics of student test scores by gender for each of the eight astronomy topics.

Table 6
Descriptive statistics by gender for Pretest, P-TI, and P-RT assessment test scores on eight key astronomy topics.

			Pretest	**Pretest**	**P-TI**	**P-TI**	**P-RT**	**P-RT**
Topic	**M or F**	**N**	**% Items Correct**	**SD %**	**% Items Correct**	**SD %**	**% Items Correct**	**SD %**
Motion of the Sky	M	86	29	23	72	28	87	20
	F	62	28	25	61	30	89	19
Seasons	M	83	43	27	60	27	78	25
	F	65	45	30	54	26	71	30
Phases of the Moon	M	19	40	19	71	21	82	23
	F	12	46	18	71	28	79	28
Kepler's Laws	M	69	21	20	55	27	67	27
	F	51	15	18	57	25	62	24
Gravity	M	26	34	26	39	20	64	20
	F	19	26	24	45	18	63	17
Luminosity of Stars	M	19	40	34	67	27	84	20
	F	19	42	27	65	32	79	25
Doppler Effect	M	76	35	37	79	27	87	25.0
	F	52	25	27	70	33	86	25
Magnitude & Distance	M	63	16	22	58	38	74	28
	F	48	18	24	51	31	72	26.0
Averages	**M**	**55**	**32**	**26**	**63**	**27**	**78**	**24**
	F	**41**	**31**	**24**	**59**	**28**	**75**	**24**

The results presented in Table 6 show that male and female mean test scores differed by only a few percent within each of the three assessment tests (Pretest, P-TI, and P-RT). T-tests of these results show that across all eight astronomy topics there is no statistical difference between gender scores for the Pretest, P-TI or P-RT.

Gender differences were assessed for each topic in the series of repeated measures ANOVAs reported earlier. These results are shown in Table 7.

Table 7
Differential effects of ranking tasks by gender via repeated factors ANOVA.

Topic	**df**	**F**	**p-value**	**Partial eta^2**
Motion of the Sky	2, 292	3.7	0.05	0.03
Seasons	2, 292	1.7	0.18	0.01
Phases of the Moon	2, 58	0.38	0.69	0.01
Kepler’s Laws	2, 236	1.5	0.24	0.01
Gravity	2, 86	1.1	0.36	0.02
Luminosity of Stars	2, 72	0.19	0.83	0.01
Doppler Effect	2, 252	0.34	0.72	0.00
Magnitude & Distance	2, 218	0.87	0.87	0.01

Table 7 presents ANOVA results where p-values for each astronomy topic are calculated from the degrees-of-freedom (df) and the F value. Notice that for seven of the eight astronomy topics, the p-value was greater than 0.05 and therefore not statistically significant. In a single case (Motion of the Sky), the p-value of a gender interaction barely reached significance at the 0.05 level. However, with eight topics this could be expected from chance alone. Based on the large p values (> 0.05) shown in Table 7 for seven of the eight astronomy topics, we assert that there is no difference in P-TI to P-RT gains related to gender, and that both genders benefited equally from the ranking task exercises.

4.6 Statistics and Hypothesis Testing: Post-Ranking Task Scores vs. Upper/Lower Pretest Scores

Our second research question (cf. Section 1.4) asked whether ranking task exercises differentially benefited students who scored in the upper or lower median Pretest groups. Put another way, is there a difference in the benefits that ranking task exercises provide to students depending on their initial knowledge state (as measured by the Pretest score) over the eight astronomy topics at the beginning of the course?

Table 8 below divides the participants into Upper Median and Lower Median groups based on their Pretest scores. The table also presents descriptive statistics on the Upper Median and Lower Median groups P-TI and P-RT test scores by astronomy topic.

Table 8
Descriptive statistics by upper and lower median split on student Pretest scores.

			P-TI	P-TI	P-RT	P-RT
Topic	**Upper or Lower**	**N**	**% Items Correct**	**SD %**	**% Items Correct**	**SD %**
Motion of the Sky	U L	47 101	72 65	30 28	85 89	20 19
Seasons	U L	62 86	65 52	26 26	78 73	26 26
Phases of the Moon	U L	18 13	67 77	26 19	83 779	21 30
Kepler's Laws	U L	69 51	54 58	27 24	65 65	25 27
Gravity	U L	35 10	44 33	19 17	63 65	20 18
Luminosity of Stars	U L	13 25	72 63	23 32	72 83	22 24
Doppler Effect	U L	66 62	80 70	29 31	87 85	25 25
Magnitude & Distance	U L	46 65	60 52	34 35	73 73	34 35
Averages	**U** **L**	**45** **52**	**64** **59**	**27** **27**	**76** **76**	**24** **25**

Across all topics, the Upper Median group P-RT scores rose by 12% over their P-TI scores, while the Lower Median group rose by 17%. From these raw descriptive statistics it is tempting to infer that ranking task exercises benefit the Lower Median students more than the Upper Median students. To gain a deeper insight into this issue we performed a repeated-factors ANOVA of the two groups comparing their P-TI and P-RT test scores. The results are shown in Table 9 that follows.

Table 9
Differential effects of ranking tasks by upper/lower median groups Pretest scores via repeated factors ANOVA

Topic	**df**	**F**	**p-value**	**Partial eta^2**
Motion of the Sky	1, 146	4.3	0.05	0.03
Seasons	1, 146	1.9	0.18	0.01
Phases of the Moon	1, 29	0.57	0.34	0.02
Kepler's Laws	1, 118	0.44	0.44	0.00
Gravity	1, 43	2.8	0.10	0.06
Luminosity of Stars	1, 36	1.3	0.26	0.04
Doppler Effect	1, 126	1.7	0.20	0.01
Magnitude & Distance	1, 109	1.9	0.17	0.02

Table 9 presents ANOVA results where p-values for each astronomy topic are calculated from the degrees-of-freedom (df) and the F value. Notice that for seven of the eight astronomy topics, the p-value was greater than 0.05 and therefore not statistically significant. In a single case (Motion of the Sky), the p-value of an upper/lower group interaction barely reached significance at the 0.05 level. However, with eight topics this could be expected from chance alone. Based on the large p values (> 0.05) shown in Table 9 for seven of the eight astronomy topics, we assert that ranking task exercises equally benefited both the upper median Pretest student group and the lower median Pretest group.

4.7 Statistics & Hypothesis Testing: Qualitative Measures of Student Understanding

The primary measures of student understanding that we used after the two treatments (P-TI and P-RT) were the multiple-choice assessment tests described in Section 3.4. In addition, however, our third research question (cf. Section 1.4) concerns measurement of changes to the depth of student understanding between the P-TI and P-RT treatments as reflected by students' answers to free-response questions. To study this, for three of the eight astronomy topics, a sub-set of students completed a qualitative questionnaire (free-response questions) in which they were presented a sample exercise and asked to explain their process for solving that exercise. The three topics selected for this additional investigation were phases of the moon, gravity, and luminosity of stars.

Level of Understanding as Measured by Rubric

Using the rubric described in Table 1, an analysis (as described by Stemler, 2001) was performed on the student narrative responses. The P-TI and P-RT responses were classified using the five level scale of Level of Understanding (described as Unstructured/Alternative Conception to Expert levels).

Because of varying class attendance and the random selection of students to complete the free-response questionnaire, this phase of the study compared a mean of 29 matched pairs (meaning the same student took both tests) of P-TI and P-RT Level of Understanding scores for each of the three astronomy topics.

Table 10 below presents descriptive statistics and the results of the paired t-test comparing P-TI to P-RT Level of Understanding scores.

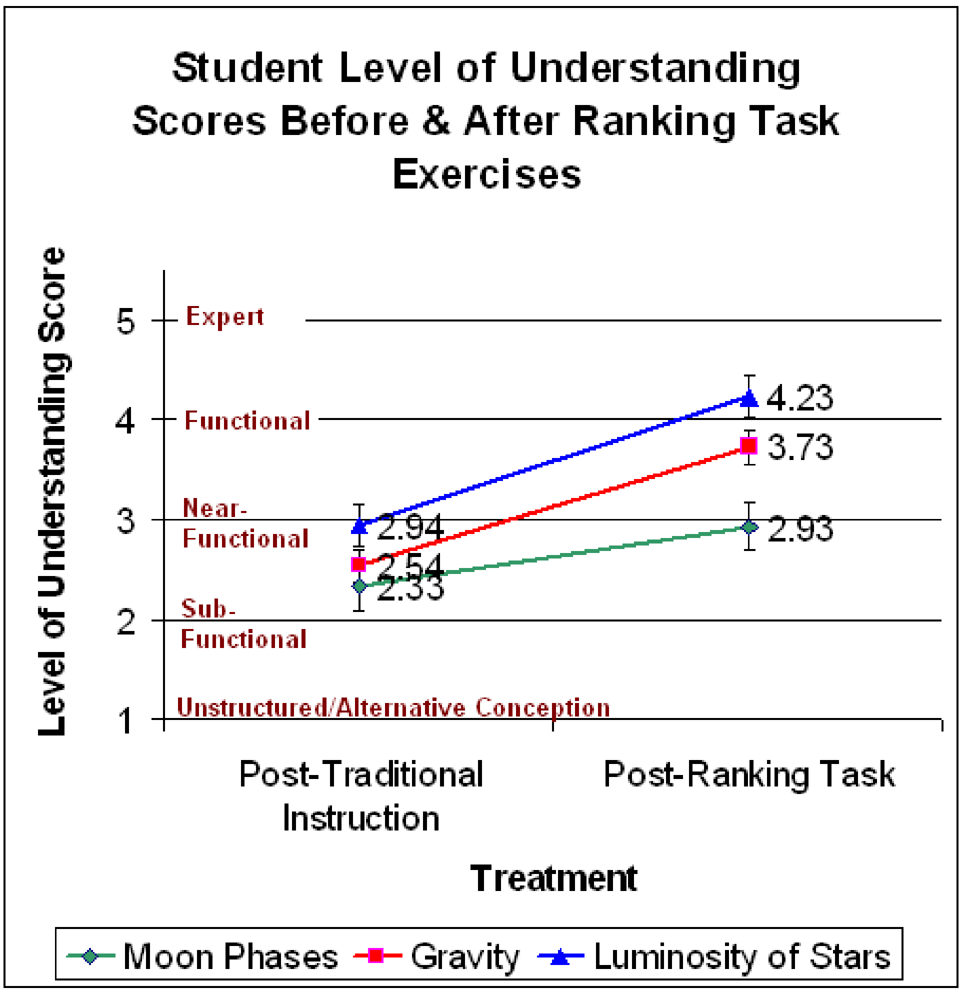
Table 10
Descriptive statistics and hypothesis test (paired t-test) of student Level of Understanding P-TI and P-RT scores on three astronomy topics..

		P-TI	**P-TI**	**P-RT**	**P-RT**			
Topic	**N**	**Level of Understanding Score**	**SD**	**Level of Understanding Score**	**SD**	**t**	**df**	**p-value**
Moon Phases	30	2.3	1.2	2.9	1.4	2.4	29	.022
Gravity	26	2.5	0.91	3.7	0.83	5.1	25	<.001
Luminosity Of Stars	31	2.9	1.2	4.2	1.1	5.2	30	<.001
Averages	29	**2.6**		**3.6**				

Across all three astronomy topics, the Level of Understanding scores rose from an average of 2.6 (P-TI) to 3.6 (P-RT). A t-test was performed that compared P-TI to P-RT scores for each of the three astronomy topics. The p-value resulting from the t score and degree-of-freedom (df) for each topic is shown in the last column in Table 10. These very low p-values tell us that for each of the three astronomy topics, the student Level of Understanding score rose significantly (alpha = 0.05) after the ranking task exercises.

The results of the qualitative questionnaire agree with the quantitative multiple-choice tests to the extent that student understanding did increase substantially after the ranking task exercises. However, results from the qualitative questionnaire suggests that student Level of Understanding still did not reach as high a level as we desire as educators. Descriptively, the P-TI Level of Understanding could be described as just below Near-Functional rising to just below Functional after the ranking task exercises. This is shown graphically in Figure 6 for each of the three astronomy topics.

Figure 6
Mean student P-TI and P-RT Level of Understanding scores for three astronomy topics.



Level of Understanding as Indicated by Individual Student Responses

Although the Level of Understanding Rubric enabled us to interpret narrative responses into a numeric measure, I found that simply reading and comparing individual student's responses before and after the ranking task treatment was enlightening. Three cases of student responses and analyses are presented in Tables 11a, b, and c.

Table 11a
Analyses of narrative responses from Student Sharon regarding phases of the Moon.

Post-Traditional Instruction	Post-Ranking Task
Sharon: (Explaining phases of the Moon) "The moon rotates on its axis around Earth. So as we look up into the sky depending on the position of the Moon in respect to the Earth we are only able to see pieces of the Moon's lit surface." Analysis: Student alludes to motion of the Moon ("rotates on its axis") but does not link to the idea of orbital motion. Student correctly refers to seeing "pieces" of the "lit surface" but does not mention the Sun at all, or the critical relationship in the changing Sun – Moon angle as seen from a viewer on Earth. Some key ideas are mentioned, but are not structured into a cohesive framework.	Sharon: (Explaining phases of the Moon) "The Moon goes through phases because it rotates on its orbit around the Earth, and during its rotation we are only able to see parts of the Moon's lit surface due to the position of the Moon in respect to the Sun." Analysis: After the ranking tasks the student correctly mentions important language ("orbit"), and also identifies the critical concept that the position of the Moon relative to the Sun changes the "Moon's lit surface" that we see. This is a more fully developed conceptualization of the phenomena.
Conceptual Exercise: Would a waxing gibbous Moon ever be above the horizon during the daytime (6AM to 6PM)? Sharon: "Yes it would depending on if it is that phase on a particular day." Analysis: While "yes" is correct, the line of reasoning demonstrates no evidence of structure or recognition of key ideas.	Conceptual Exercise: Would a waxing gibbous Moon ever be above the horizon during the daytime (6AM to 6PM)? Sharon: "Yes, because it is highest in the sky at 6PM. So if we subtract 6 hours it means the Moon rose at 3PM – so is visible in the daytime." Analysis: Student now demonstrates a fully working schema. She is now able to predict at what time this Moon is highest in the sky, recognizes that 6 hours earlier it was rising (3 PM), and consequently that this Moon phase is above the horizon during the day.

Table 11b
Analyses of narrative responses from Student Chris regarding 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 proceeding 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 that 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 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 full conceptualization of key ideas.
Conceptual Exercise: Would a waxing gibbous Moon ever be above the horizon during the daytime (6AM to 6PM)? Chris: “Yes, because it will be highest in the sky around 3 AM.” Analysis: While “yes” is correct, the line of reasoning does not follow logically. Further, the statement that “it will be highest n the sky at 3 AM” is incorrect. This response indicates that partial understanding has taken place after traditional instruction, but the schema is still fundamentally incomplete.	Conceptual Exercise: Would a waxing gibbous Moon ever be above the horizon during the daytime (6AM to 6PM)? Chris: “Yes, because at 9 PM it should be highest in the sky. It should have risen at 3 PM and therefore would have been visible during the daytime. Analysis: The prediction of the location of the Moon in the sky at both times is exactly correct, and leads to a logical conclusion. This response demonstrates a strong working model of the phenomena after the Ranking task exercises.

Table 11c
Analyses of narrative responses from Student Sarah regarding phases of the Moon.

Post-Traditional Instruction	**Post-Ranking Task**
Sarah: (Explaining phases of the Moon) "Because at any time we can only see one face of the Moon from the Earth. How much of the Moon we see is affected by how much of the Moon is lit, or how much of the visible side to us is lit, Since half of the Moon is always lit, but not necessarily the half that we see." Analysis: Student clearly recognizes that "half the Moon is always lit", and the amount lit of the side of the Moon visible to us changes. All of these are correct ideas. However, she does not refer to other critical ideas that the Moon is in motion around the Earth and that this causes changes in the way the Sun illuminates the visible side of the Moon. This response indicates a strong beginning to understanding, but a full understanding is not demonstrated.	Sarah: (Explaining phases of the Moon) "The Moon is always half lit by the Sun. Depending on its position relative to Earth and Sun, we can see only a portion of the lit part of the Moon. That portion we see causes us to see phases." Analysis: After the ranking tasks the student correctly mentions important language and ideas ("Moon is always half lit", what we se depends on Moon's "position relative to earth and Sun".) This response indicates a clear conceptualization of key ideas.
Conceptual Exercise: Would a waxing gibbous Moon ever be above the horizon during the daytime (6AM to 6PM)? Sarah: "No, because this phase only occurs when the Sun illuminates it during our nighttime. This phase would be highest in the sky around 9 PM." Analysis: Interestingly, the student can correctly predict the time of day when the moon would be highest in the sky while in this phase, using a formula-based strategy taught in traditional instruction. However, this strategy does not seem linked to an overall conceptualization of Moon phases because she does not "run the clock backwards" to visualize the Moon still in the sky 6 hours earlier at 3 PM – during the daytime. She has constructed a partial model, but not yet robust in structure.	Conceptual Exercise: Would a waxing gibbous Moon ever be above the horizon during the daytime (6AM to 6PM)? Sarah: "This phase is highest in the sky at 9 PM, therefore rising 6 hours earlier at 3 PM and setting 12 hours later at 3 AM. So yes, it would be visible for some short time between 3 PM and 6 Pm in the daytime. Analysis: After the ranking tasks, the students model is much more robust, showing an understanding that after calculating the time when the Moon is highest in the sky, the times of rising and setting are easily extrapolated. This response demonstrates a strong working model of the phenomena.

In the study topic Phases of the Moon, thirty students provided narrative answers to the free-response questions. A small proportion of students had clearly reached a competent level of understanding after traditional instruction. This obviously carried on through the ranking task treatment. Also, a very small group of students completed traditional instruction without any demonstrated understanding, and revealed no gain even after the ranking tasks. The great majority of students, however, showed marked increases in conceptual understanding of lunar phases after the ranking tasks as demonstrated by the quality of their responses.

4.8 Student Attitudes about Ranking Tasks

The final research question (cf. Section 1.4) asked about the perceived value that introductory astronomy students attribute to the ranking task exercises. The Likert-scale attitude survey used in this study addressed four areas of student perception regarding ranking tasks: (1) contribution to general interest in the course, (2) were ranking tasks an enjoyable part of the classroom experience, (3) did they help my learning, and (4) did they help me prepare for tests.

In addition to the attitude survey, a final free-response question asked students to comment on their overall experience in using ranking tasks, and how it affected their learning. The attitude survey was completed by 132 students at the end of the study.

Results of Likert-scale Survey

A problem was found in the format of our Likert-scale attitude survey that resulted in the loss of a small amount of data. While reviewing student responses, we found 16 questionnaires (12%) in which students replied with strong responses (either positive or negative) to the open-ended question regarding ranking tasks – but scored the Likert-scale in an exactly opposite manner. Further examination revealed four additional questionnaires where students had circled A through E responses on the Likert scale, then later erased or marked out the initial response and then transposed their answers to the exact opposite range of the scale.

It became apparent that the design of our Likert-scale survey form asked for student responses in a counter-intuitive manner – which led to an error in some of the data collection. For example, students were asked if they agreed with the statement "Ranking tasks were an enjoyable part of the classroom experience" using a scale of A through E. A majority of our students view the letter "A" as representing a positive, while an "E" was thought to be analogous to a grade of "F" and so decidedly negative. Unfortunately, the design of the survey form we adapted for this study used an "A" to mean a negative response which confused some students.

We believe that this counter-intuitive survey design led approximately 12% of students toward responses that were markedly counter to their written comments later in the questionnaire. In the end, in 16 cases where the evidence was very compelling to support this misunderstanding of the instructions, we discarded those questionable responses from the survey results.

Student responses (N = 116) to the Likert-scale attitude survey are presented in Figure 7. A separate bar graph is provided for each of the attitude statements that we measured.

Figure 7
Results of student attitude survey regarding the Astronomy ranking task exercises in this study.

The responses presented in Figure 7 show a consistency in student attitude absent of polarization that might make interpretation difficult (Sclove, 2001).Over the four areas of student opinion, 67% of the participants expressed a positive perception (Agree or Strongly Agree") of ranking tasks, 17% were neutral, and 16% tended toward a negative perception. Most importantly, 83% of students felt that ranking tasks helped them learn the course material. Overall we find that student responses indicate that they feel the ranking tasks to be a positive addition to their learning experience.

Student written responses to the free-response question included in the attitude survey provided further insight into students' perceptions about their experience with ranking tasks.

Student Written Comments

The student attitude survey included a final question that asked students to describe their overall impression about the astronomy ranking tasks during the semester. A total of 111 students provided a written response to this question.

Because 83% of the participants reported in the Likert-scale survey that ranking tasks helped them learn, it was not surprising to see many positive comments. In general there were many comments like ranking tasks "helped me think" or "gave good practice", or "I learn better working with a group and talking".

Along with general positive responses, some students provided useful elaboration as characterized by examples provided below:

> "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."
>
> "Ranking tasks helped me understand, especially how they started easy and progressively became more complex."
>
> "…they helped us learn more ways to solve a problem, and show… more possible scenarios of the subject matter."
>
> "Ranking tasks definitely helped me in conceptualizing. Because the (astronomy) ideas are so abstract, using pictures and real life things are a big help."
>
> "Ranking tasks were useful, especially by starting with something we know (like the hot plates) and then going to harder questions."
>
> "I like [ranking tasks] because they are logical rather than just math - which is what I like to do, think logical [*sic*]."
>
> "The order of the ranking tasks was just right for your brain to make connections between concepts and how they are related."

"I like that after the ranking task, there was an explanation part just to be sure everyone [in the group] understood what they were doing."

"The pictures really helped me understand the concepts better."

"I enjoyed having to think in a different way."

"I like how the exercises started with a simple idea that I knew, then went on to specifics like the brightness of stars.

Some comments by students were of a conflicted nature, yet provided useful information. Several complained that ranking tasks were repetitive or "boring", such as:

"…[ranking tasks] were a little redundant, but the drill helped me understand."

"The exercises were very repetitive. They probably helped students who were having difficulty, but for me they were very repetitive."

"…..helpful, but a little repetitive. We had to answer the same question over and over."

"Helped reinforce material from lecture, but the predictable format got old after a while."

Other student complaints related to shortcomings in our classroom procedures in using ranking tasks. Specific procedural problems included not always reviewing correct answers in class, and not specifically featuring ranking tasks on later tests. Student comments included….

> "The ranking tasks were not always fun, but I learned a great deal from them. But answers should have been posted because we didn't go over all of them in class."

> "If we could review the exercises after doing them in class, then this would double our understanding."

> "My understanding was greatly increased, but I would have benefited from having an answer sheet.

> " [Ranking tasks are] helpful, but we should go over the answers in class."

> "I didn't see ranking task questions on the test."

> "…..they were not helpful for tests"

Finally, according to the Likert-scale survey almost 16% of the students had somewhat to strong negative perceptions toward ranking tasks. These negative comments were often short on specifics, but are enlightening nevertheless:

"[ranking tasks] did not teach anything".

"I don't like having to explain after every obvious question."

"I hate them!"

"….obviously a star is brighter close up, so why ask?"

"[Ranking tasks] helped, but I was just not always however {sic} in a mood to do them."

<u>Summary of Student Comments</u>

One hundred eleven students responded to the question "Please describe your overall experience with the ranking task exercises, including how then exercises affected your understanding of course concepts." Very often, student comments addressed several areas, stating that they were helpful, and then adding additional observations – both positive and negative. In rank order, their responses can be categorized as follows:

83% (92 responses) – Very positive (but often non-specific) comments that ranking tasks "help them learn", "added interest to the classroom", or they "enjoyed" them, or "they made me think".

12% (13 responses) – stated that the ranking task format was “repetitive” and as a result sometimes “boring”.

9% (10 responses) – stated that ranking tasks helped them study for exams.

8% (9 responses) – stated that they found it helpful that ranking tasks began with simple and familiar physical situations, and then progressed to more complex ones.

6% (7 responses) – made negative but non-specific statements such as “didn’t like them”, or ranking tasks were “not fun”.

5% (6 responses) – mentioned that they were frustrated that ranking tasks were not always reviewed later in class, or that an answer sheet was not provided for later study.

4% (4 responses) – stated that ranking tasks did not seem helpful in studying for tests, or that tests did not include any ranking tasks.

Totals exceed 100% because many students made several observations. A discussion of these results in the context of each research question is presented in the next chapter.

4.9 SUMMARY OF RESULTS

In summary, this study produced the following results regarding the use of ranking tasks as an additional intervention to traditional instruction in the astronomy classroom:

- Across a sample of eight introductory topics, student test scores rose from 32% correct on the Pretest, to 61% correct after Traditional Instruction, to 77% correct after the collaborative ranking task exercises.

- Statistical tests (ANOVA and Least Significant Differences) show that the rise in test scores from P-TI to P-RT is significant at the 0.05 level. That is, the ranking task exercises produced improved student understanding (as measured by the assessment tests) to a high level of confidence.

- Three measures of effect size commonly reported in education research are presented in this study. An unbiased measure of effect size referenced by Cohen (1988) is partial eta^2. Over the eight topics in this study the mean partial eta^2 is 0.22, which Cohen describes as a large effect. A second effect size measure often found in education research is normalized gain <g> (Hake, 1999). Across the eight astronomy topics in this study the mean normalized gain was 0.41, which Hake describes as a medium gain. The third measure of effect size often found in education research is Cohen's d (Cohen, 1988). Across the eight astronomy topics covered in this study, the mean Cohen's d effect size was 0.62 which Cohen describes as moderately large.

- All three measures of effect size reported in this study agree that ranking tasks have a moderately large to large effect on student understanding of the eight key astronomy topics.

- A mixed-factors ANOVA showed that the ranking task intervention produced no gender effects at the 0.05 level. That is, both genders benefited equally from the ranking task exercises.

- A repeated factor ANOVA showed that at the 0.05 significance level there was no effect based on student Pretest scores (a measure of initial astronomy content knowledge) and score gains following the ranking task exercises. In other words, the ranking task exercises equally benefited both the upper and lower median Pretest groups. Also, both groups achieved the same level of understanding after the ranking task exercises.

- Using free-response questions, an example exercise for students to solve and explain, and content analysis of narrative responses, the study found across three astronomy topics that student Level of Understanding rose from 2.6 to 3.6 after the ranking task exercises based on a five-level rubric. A t-test showed this was a significant increase. While these scores are a sign of increased student understanding, the level of sophistication and completeness in many student responses remained below a desired level.

The Likert-scale survey of student attitudes about the ranking tasks found that 67% of students reported a positive response to the exercises, 17% neutral, and about 16% somewhat to strongly negative. Significantly, within the negative responses the primary factors were revealed to be certain classroom procedures rather than the ranking tasks themselves. Specifically, students were frustrated when correct answers were not provided after class, and when no ranking tasks appeared on later tests. These issues, and others, are later addressed in Section 5.4 - Implications for Teaching.

CHAPTER 5

SUMMARY AND DISCUSSION

5.1 Introduction

This chapter provides a summary of the goals and methodology of the study, followed by a discussion of results and conclusions of this investigation as they relate to each of the four original research questions. The chapter then presents implications of the study on teaching introductory astronomy, and closes with recommendations for future research.

5.2 Summary of Study Goals & Methodology

This study was conducted to measure the effect on student understanding of incorporating a program of ranking task exercises into a traditional lecture-based introductory astronomy classroom. The study applied results of research on teaching and learning to the design of ranking task conceptual exercises. These exercises are focused on eight key topics most frequently taught in introductory astronomy.

The primary goal of the study was to quantify student conceptual gains using current research methods and measures from the field of education research. These include Hake's average normalized gains, and effect size measures including partial eta square and Cohen's d. A strength of this research is the large sample size one-group, pretest-posttest experimental design using paired data on individual students. This enabled robust statistical analysis of the ranking task main effect. Using these statistical measures, we further investigated whether ranking tasks differentially affected student performance by gender, or by student initial knowledge state about astronomy. Finally, the study sought to measure student's perceived value of ranking tasks as a learning aid.

Prior to data collection, pilot studies (cf. Section 3.7) were conducted with two small astronomy classes (about thirty students) at Rockhurst University to assess the initial design of the materials and procedures to be used in the formal stages of the study. The results of the pilot studies were used to inform final design modifications in order to assure our research materials best suited the needs of students and classroom for our study. After the pilot studies, our formal research was done with approximately 250 volunteer introductory astronomy students enrolled at the University of Arizona Fall (August – December) Semester 2004.

A Pretest of student knowledge over the eight studied astronomy topics was assessed by administering a 28 item multiple-choice test on the first day of class prior to any instruction. In later classes, following traditional instruction (consisting of pre-class reading, lecture, and in-class instructor-based demonstrations) on each of the studied topics, students took a three or four item multiple choice post-test (referred to as the P-TI test) covering only the topic on that day's instruction. In addition, for a sample of three topics, one-half of the students answered a qualitative questionnaire with free-response questions asking the student to explain the method they used in solving a sample conceptual exercise.

After the P-TI tests, students worked in collaborative groups for approximately twenty minutes to work through a set of four or five ranking task exercises developed for each astronomy topic. This was followed immediately by a three or four question multiple-choice P-RT assessment test. In the case of three of the eight studied astronomy topics, one-half of the students answered a qualitative questionnaire with free-response questions asking the student to explain the method they used in solving a sample conceptual exercise.

In order to analyze the level of understanding demonstrated by students in their narrative answers to the free-response qualitative questionnaire described above, a rubric was designed (cf. Section 3.8). This rubric described five Levels of Understanding for the astronomy topics based on use of scientific language, identifications of critical variables, and conceptual linkages. The rubric enabled the researchers to reduce students' narrative responses to a metric that could be used for comparative study. Descriptive statistics of students pre-test and the two post-test scores were presented in Section 4.2 for each of the eight astronomy topics. Hypothesis testing was conducted (cf. Section 4.3) using a repeated measure analysis of variance (ANOVA) to analyze interactions of the ranking tasks, gender, and Pretest scores. To quantify performance gains and to aid in comparison with other research, the study calculated common effect size measures including partial eta-square, average normalized gain (Hake, 1999), and Cohen's d. These results were presented in Section 4.4.

The last phase of the study addressed the issue of student attitudes about the astronomy ranking tasks after a semester of experience with this new form of conceptual exercise. On the last day of class, students completed a Likert-style attitude survey designed to assess students' perceived value of the ranking task exercises. The survey questions sought to determine if students felt that (1) the ranking task exercises contributed to their interest in the course, (2) helped them learn, (3) helped prepare them for tests, and (4) made the class more enjoyable.

5.3 Discussion of Results

Research Question #1

The first research question asked "What is the effect on student understanding of adding a constructivist-based program of ranking task exercises to traditional lecture-based instruction of selected introductory astronomy topics?"

To more thoroughly test the hypothesis that a program of ranking task exercises will substantially benefit students in their understanding of astronomy concepts, this study undertook to test this idea across eight concept areas. This moderately large number of topics was selected in order to include examples of two general types of astronomy topics: first, those that are largely calculation-based (e.g., Kepler's Laws, Gravity, Luminosity of stars, and magnitude/distance relationships), and secondly, visually difficult or concept-imagery based topics (e.g., motion of the sky, seasons, phases of the moon, and Doppler effect).

Results reported in Section 4.2 showed that for each of the eight studied astronomy topics, student post-test scores rose after completing the ranking task exercises beyond their performance after traditional instruction. Overall, average test scores rose from 31% on the Pretest to 61% after Traditional Instruction to 77% after the ranking task treatment. Hypothesis testing using ANOVA and Least Significant Difference Tests (cf. Section 4.3) showed that for each astronomy topic the ranking tasks significantly improved student scores, with an average partial eta-square effect size of 0.219. This is described by Cohen (1988) as a large effect. Using the traditional classroom grading scheme, the gains from astronomy ranking tasks amount to a one and one-half letter grade improvement in student test scores. Based on our informal discussion with students, they consider this a substantial improvement.

In Section 4.3 we report that student test score gains following the ranking task treatment are statistically significant, and that these gains are large by any measure commonly used in education research. For example, Table 4 in that chapter shows that the average normalized gain (Hake, 1999) after the ranking task treatment was <g> = 0.408 across all astronomy topics. It is interesting to compare the ranking task normalized gain (<g> = 0.41) with the earlier traditional instruction normalized gain (<g> = 0.43). These gains are shown to be statistically equal, evidence of the significant impact of the ranking tasks on student learning.

Other effect size metrics also show significant understanding gains as a result of the ranking task treatment. Another common effect size measure presented in education research, Cohen's d, is shown in Table 5 to average 0.62. This is described by Cohen (1988) as moderately large. However, Cohen's d admittedly understates effect size when applied to matched pairs of data as we have in this study. The descriptors that Cohen developed were applied to two-group experimental designs – those using independent control and experimental groups – resulting in more uncertainty in homogeneity of the groups and resulting statistics.

Based on these data, we assert that the education research-based program of ranking tasks exercises substantially improved (<g> = 0.418 +/- 0.13) student understanding of the eight key astronomy topics studied in this investigation beyond their understanding after traditional instruction.

Research Question #2

The second research question asked "Do ranking task exercises differentially affect (1) students by gender, or (2) by their initial knowledge state about astronomy?"

The results are clear in regard to gender differences in test scores after the ranking task exercises. Descriptive statistics presented in Table 6 show that averaging over all eight astronomy topics, test scores never differed by more than two or three percent between male and female students.

We asserted earlier (Research Question #1) that ranking tasks substantially improved overall student understanding. In addition, the repeated factors ANOVA (cf. Table 7) demonstrates that both male and female students benefited equally from the ranking tasks. With this large sample size, these results showing no gender differences are compelling and not unexpected.

The second part of Research Question #2 asked “Do astronomy ranking tasks benefit students differently depending on their initial astronomy knowledge state as measured by the pretest scores?” To answer this question students were divided into two groups (upper median and lower median) for each of the eight astronomy topics based on their Pretest scores in each topic. The repeated factors ANOVA (Table 9) showed an upper vs. lower Pretest group P-TI and P-RT test scores main effect with an average p-value of only 0.22 over the eight astronomy topics. This large p-value is not statistically significant. Thus the ranking task exercises were shown to equally benefit the upper and lower median Pretest score groups.

Research Question #3

The third research question asked “How do ranking tasks exercises affect the depth of student understanding of selected introductory astronomy topics as demonstrated through the quality of student written answers to free-response questions?”

The purpose of this question was to measure the progression of student understanding from a different and perhaps useful perspective compared to numeric test scores. We studied this question across three of the eight astronomy topics included in the main study. We presented students (as matched pairs, P-TI and P-RT) with a conceptual exercise centered on each of the three astronomy topics. The questionnaire asked students to solve the exercise, and to then carefully explain the reasoning behind their problem solving approach. We believe that student writing, as investigated in this portion of the study, is a good indicator of their thinking and clarity of their understanding.

As described in the Introduction above, student narrative responses were classified into a five-level rubric from Unstructured/Misconception (Level 1) through Expert (Level 5) by analysis suggested by Stemler (2001). The study found that for each of the three topics, the ranking task treatment resulted in a more sophisticated solution strategy as indicated by the rubric-defined Level of Understanding. Table 10 showed that after the ranking task treatment, the students' average Level of Understanding scores rose to 3.63 from 2.60 after traditional instruction. Paired t-tests showed that these gains were statistically significant for each of the three astronomy topics.

During this portion of the study, we observed an interesting change in students' use of diagrams to illustrate their free-response answers in explaining the phases of the Moon. After traditional instruction, only 7% of students included a diagram in their narrative explanations. But after the ranking task treatment, this rose to 27% of students explaining the phases of the Moon using both narrative and diagrams. We interpret this increased use of diagrams as reflecting stronger visual imagery by students as their schema develops.

How could we describe this change in students' depth of understanding? The ranking task gain typically amounted to an increased recognition of one variable plus some additional demonstrated use of the language of science or imagery related to the astronomy topic. For example, in explaining the phases of the Moon, these two students (whose names have been changed) from the study demonstrate typical levels of understanding after traditional instruction and after ranking tasks:

> Richard (P-TI): "The illumination of the Moon comes from the Sun. As the Earth rotates so does the Moon, so we see only certain phases of the Moon at certain times of the month."

> Richard (P-RT): "The Moon goes through phases because the Sun lights up the Moon. As the Moon orbits the earth, it lights up from the Sun at different angles which causes the different phases." [Student also added a small diagram showing Moon orbiting Earth, with Moon figures correctly half illuminated by the Sun.]

Notice that after ranking tasks, student correctly adds the concept of the Moon "orbiting" the Earth, the idea of "different angles" of sunlight, plus a simple diagram suggesting the beginnings of a visual model of the phenomena.

Another example is provided by student Sam:

> Sam (P-TI): “The Moon goes through phases because it orbits around the earth, and so at different dates of the orbit more light hits the Moon.”

> Sam (P-RT): “The Moon goes through phases because it rotates around the Earth, and when it is at different locations you see only some of the Moon where it is lit.”

Notice that after traditional instruction, Sam retains the primitive concept that the actual amount of light hitting the moon changes, accounting for the changing phase that we see. By comparison, after the ranking tasks exercises, Sam recognizes that as the Moon “rotates around Earth” we see “only some of the Moon where it is lit”. This indicates that Sam now recognizes that the Moon is always half lit, but our view from Earth of that lit half changes. While still a shaky framework, an important element of the concept has been added by the ranking task treatment.

Student written narratives indicated that their Level of Understanding (cf. Section. 4.7) rose from 2.6 after traditional instruction to 3.6 after the ranking task treatment. Although this is evidence of useful conceptual progress, as concerned teachers we are still disappointed in the frequent lack of depth in student understanding, and the persistence of alternative conceptions despite the interventions. This resistance to change supports previous research concluding that a stable change in conceptual state requires repeated exposure to concepts that are new to students over time and a variety of contexts (Grayson, 2004).

Research Question #4

The fourth research question asked "To what extent do students perceive the ranking tasks exercises to be valuable in the introductory astronomy classroom?"

As discussed in Section 4.8, our study utilized a five-step Likert scale covering four dimensions of student perception (interest, enjoyment, "helped my learning", and "helped me prepare for tests") about the astronomy ranking tasks. Student responses presented in Figure 7 show that 83% believed that ranking tasks positively benefited their learning. We take this to be a substantial and encouraging finding concerning the usefulness of ranking tasks in the introductory astronomy classroom.

Despite the widely perceived benefit of ranking tasks by students, about 8% responded in a "somewhat" to "strongly" negative reaction across the four dimensions of student attitude about ranking tasks. Our past teaching experience suggests that this is about the proportion of university students who will complain about any participatory classroom activity. More concretely, this percentage is consistent with student attitudes reported in studies of other active-engagement strategies (e.g., 11% negative reported on classroom personal responder devices by Brissenden *et al*., 2004)

In this study, our best information regarding what students did not enjoy about the ranking task exercises comes from their written comments to the free-response question. The single clearest message of dissatisfaction (12% reporting this) was that some students found ranking tasks repetitive or boring. However, student narrative responses do not provide enough information to identify exactly what aspect of the ranking task might have caused this perception. A design feature of our astronomy ranking tasks (cf. Section 1.7) was the use of multiple presentation formats (figures, graphs, tables) within ranking tasks sets. Our ranking tasks averaged 3.4 format styles (representations) within each set of five exercises. In addition, the astronomy ranking tasks typically presented just four to six physical situations in each ranking task. This is a smaller number than was generally recommended for physics ranking tasks in the widely known work by O'Kuma, Maloney and Hieggelke (2000). We attribute this small negative perception to our belief that after students answer one or two questions on a particular astronomy topic, they feel that another question - no matter how visually or conceptually different - is similar and therefore repetitive.

5.4 Implications for Teaching

This investigation has important implications for science education research, and astronomy education in particular. These include the application of education research and cognitive learning theory to the development of a new kind of conceptual exercise (ranking tasks), a study of its practical implementation in the classroom, and a robust quantitative assessment of student learning outcomes. Implications of this study are discussed below.

Ranking tasks can be effective in helping students learn

The central implication of this study is the compelling experimental evidence from which we assert that a research based program of ranking task conceptual exercises can significantly improve student understanding of key introductory astronomy concepts beyond the knowledge gained from traditional instruction. We define "research based program" as curriculum material informed by cognitive science, education psychology, science education research, constructivism, and conceptual change theory.

The careful quantitative measures applied in the experimental design contribute substantially to the value of this study. The normalized gains and various effect sizes measured in this study on astronomy ranking tasks can now be compared in meta-analysis studies with outcomes produced by other teaching strategies or curriculum material.

Ranking tasks are easy to implement into the traditional classroom

Research has widely shown that traditional lecture-based classroom instruction yields limited results in student learning (Deming, 2002; Prather, Bailey & Slater, 2003; Reddish, Saul & Steinberg, 1998). Despite this evidence, lecture remains a key component in most college science classrooms. Learning theory and the results of this study indicate that by supplementing brief traditional lecture with conceptually challenging and intellectually engaging activities such as ranking tasks, students can dramatically improve their performance on standard assessment tests.

This study found that the prepared sets of topical (phase of the moon, Kepler's Laws, star magnitude, etc.) ranking tasks are easily incorporated into both small and large introductory astronomy classrooms. They require only minimal training of instructors and students in their use, and they do not require radical changes in classroom protocol in the traditional 50 to 75 minute class period. After a brief (15 to 20 minute) mini-lecture and instructor-led demonstrations, we found that students groups could be formed quickly. These collaborative groups could then successfully complete a series of three or four ranking task exercises in 15 to 20 minutes.

The study found that it is extremely important to students that they immediately receive feedback on correct answers to the ranking tasks (often to settle good-natured disagreement among themselves!). As a result, instructors should plan for a few minutes of class time for concluding discussion. Alternatively, a hard-copy answer sheet available in the classroom or on-line might be substituted, but we recognize that providing answers might also reduce collaborative effort if students think the "right answers" will shortly be handed to them. Engaged, collaborative effort is the key to lasting and robust understanding beyond lecture.

In addition to classroom collaborative work, more challenging ranking tasks are well-suited to include in homework assignments. Student comments after the study suggest that it is important that instructors include ranking tasks in later exams in order to maintain student enthusiasm and interest in these conceptual exercises.

Proper introduction of the ranking task format is essential to success

In both the early pilot studies and the final data collection phases of the study we informally observed student behavior when they were first presented with ranking tasks exercises. The format of the exercises is quite novel to almost all students, and we observed both positive and negative first reactions. For many students, the lack of "hints" typical with 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 for some students.

We conclude that it is critical that instructors first introduce ranking tasks with a number of simple examples that students will find familiar in their everyday life. The study began, for example, with a ranking task featuring images of people of different ages that asked students to rank order them from youngest to oldest. Students must be shown how to start and complete a ranking task, and have some success in properly presenting their answer. In particular, it is critical to help students become comfortable with identifying and formatting rankings where two or more physical situations are equivalent. In the previous example, this might include pictures of people of the same age.

After students practiced together with a few introductory examples of ranking tasks that featured familiar topics from everyday life, there rarely seemed to be further difficulties with the format.

Additional implications in the design of ranking tasks

Wording: As in any conceptual exercise, very careful attention to the wording of each ranking task is important. Through iterations of use with students it is possible to identify ambiguous, under-defined, or overly technical phrases that hinder students' ability to successfully complete the ranking task without help.

Particular care in wording is needed in scaffolded series of ranking tasks in which slight changes in wording are used to motivate students to think about various situations from a new perspective. In our pilot studies, several students wanted the ranking tasks revised to underline or highlight such instructional changes. However, there is arguably great value in requiring students to read each exercise carefully.

Variety within ranking task sets: With 12% of the participants in this study mentioning the repetitive nature of the study ranking tasks, we conclude that it is important to promote as much variety as possible in the design of the exercises. This might include (1) changing the format for presenting the physical situations (line drawing illustrations, graphs, tables, photographs, etc), (2) providing new applications from both everyday and astronomical applications, or (3) simply alternating the ranking order (e.g., not always high to low).

Number of situations to rank: Some additional discussion is in order concerning the optimum number of physical situations that a student should be asked to rank. An approach suggested by Maloney and Friedel (1996) is that six to eight variations are usually needed to distinguish between the possible varieties of student strategies in physics exercises. We found this to also be true for astronomy topics. However, in our pilot studies of astronomy ranking tasks, informal student feedback convinced us that students quickly became frustrated when more than six variations are presented to them. With too many alternatives, the exercise became one of detailed book-keeping that complicate thoughtful comparisons. Also, ranking tasks with a maximum of six alternatives best fit our available in-class time of 20 to 30 minutes. As a result, we conclude that a series of short ranking task exercises with four to six situations each was preferable to a more lengthy one that might attempt to expose all possible student conceptual strategies.

Repeat as needed for effect: A final implication of this study for both teaching and student learning is the necessity to work iteratively toward the design of effective curriculum material and successful classroom implementation. Students learned from the ranking tasks, and the investigators learned along with them how to design and utilize ranking tasks in the classroom. From the pilot studies and later formal data collection, we conclude that the design and implementation of new curriculum material such as ranking tasks can take two, three, or more iterations in order to achieve the optimum learning outcomes.

5.5 Suggestions for Further Study

This study of the effects of ranking task curriculum in the introductory astronomy class has focused on applying cognitive learning theory to the design of the ranking tasks, measuring changes in student understanding after the instructional treatments, and measuring student attitudes about their experience with ranking tasks. In the course of the study, further questions have arisen that peak our curiosity as science educators. Such questions concerning useful future work are presented below.

1. Do collaborative ranking tasks improve student scores on conceptual exercises more than an equivalent increase in "time on task" using traditional lecture-based instruction? That is, does twenty minutes of additional lecture produce the same results as 20 minutes of collaborative ranking task exercises following a short lecture?

2. This investigation - including the early pilot studies - has shown that ranking tasks can be developed around almost any astronomy topic. The focus of this study has been the application of ranking tasks to topics in which students must consider the interaction of several variables in predicting some effect. These include, for example, net gravitational forces, orbital period, seasonal temperature, star luminosity, and star distance and magnitude relationships. Many core concepts in introductory astronomy are, however, more narrative and memory-based in nature. For example, the evolution of stars, scale of objects in the Universe, and the nature of light. Useful future research might investigate and compare the effectiveness of ranking tasks in promoting student understanding when applied to these two different types of conceptual exercises, and to determine if there might be different design guidelines appropriate for ranking tasks applied to these two types of core concepts.

3. Are ranking tasks as a conceptual exercise and learning experience for students more effective if undertaken individually or as part of a collaborative group? A related question: Is a computer-based interactive program of ranking tasks presented individually to students more effective than collaborative paper-and-pencil exercises?

4. Are ranking tasks more effective than traditional lecture in overcoming common astronomy alternative conceptions? Do ranking tasks promote enough cognitive dissonance to cause dissatisfaction with prior alternative conceptions?

5. Can student alternative conceptions or common language difficulties (e.g., confusing rotation with revolution) be effectively elicited and identified by a diagnostic program of ranking tasks? Can a computer-based interactive program using ranking tasks effectively elicit, identify, and automatically address such conceptual difficulties with remedial exercises in order to help student understanding?

5.6 Concluding Comments

A formidable body of education research shows that lecture-based instruction has limited effectiveness, and that teaching strategies based on cognitive learning theory and active learning significantly improve student understanding (cf. Section 1.1). In spite of this evidence, surveys indicate that astronomy is still mostly taught using traditional lecture and teacher-centered demonstration. Although research clearly shows the advantage of active learning, science faculty often cite (Bailey, Jones & Slater, 2003) the difficulty in finding or developing active-learning curriculum materials for their classroom. As a consequence, the philosophy of this research was to develop and test a suite of ranking task conceptual exercises that would improve student understanding through active-engagement techniques, and which can be easily incorporated by faculty into their lecture-based teaching style.

This research confirms the importance of learner-centered activities in promoting student understanding, and demonstrates new curriculum material useful in the introductory astronomy classroom. From the pre-course and post-lecture test scores we found that after conventional instruction test scores rose to 61% correct, but we find this level of understanding less than satisfactory. By adding just a brief period of learner-centered instruction after the lecture using sets of astronomy ranking tasks which were designed around constructivist learning theory, however, we found that student test scores rose very significantly over a broad range of astronomy topics - to a more satisfactory 77 percent correct. An interesting result of this research was that using standard metrics in education research, we found that the normalized gain from the ranking tasks was equal to the entire previous gain from traditional lecture-based instruction.

Finally, our classroom experience with ranking tasks showed that (1) ranking task conceptual exercises are easily incorporated into the traditional classroom, and (2) that end-of-semester student surveys showed that the overwhelming majority of students think that ranking task exercises helped them learn and helped them prepare for tests.

By developing and carefully testing these pedagogically sound curriculum materials, we assert that this investigation takes an important step forward in addressing a critical need in science and astronomy education research. The results further support the emerging view that…

"It's not so much what the teacher does, it's what students do that affects their learning."

(Quote attributed to the CAPER Team (cf. Section 1.6) at U. of Arizona)

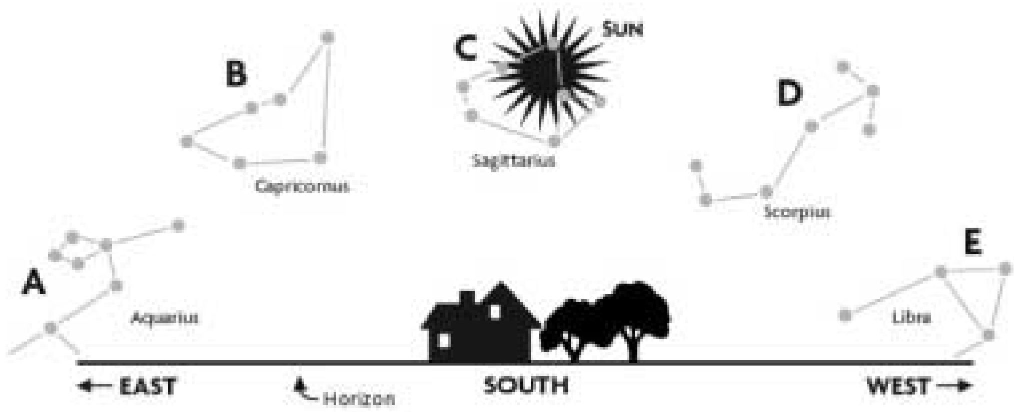
Appendix A

Astronomy Ranking Task Exercises

Astronomy Ranking Task: Motion of the Sky

Exercise #1

Description: If you could see both the Sun and the other stars during the day, this is what the sky would look like for an observer in the northern hemisphere while looking south at noon on January 1. The Sun would appear in the sky next to the more distant stars in the constellation Sagittarius, (labeled constellation C). Also shown are other constellations (named and labeled A, B, D, and E) that will be visible above the horizon at this time when facing south.



Ranking Instructions: Starting with how the sky would appear at sunrise (6am), rank the order that the Sun will appear next to each constellation (if at all) over the next several hours until sunset (6pm). For simplicity, refer to the constellations by letter (A, B, C, etc.) rather than the actual name.

Ranking Order:

Constellation next to the Sun at sunrise (6am) 1 ___ 2 ___ 3 ___ 4 ___ 5 ___ Constellation next to the Sun at sunset (6pm).

Or, the Sun will appear next to the same constellation from sunrise to sunset._____ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____

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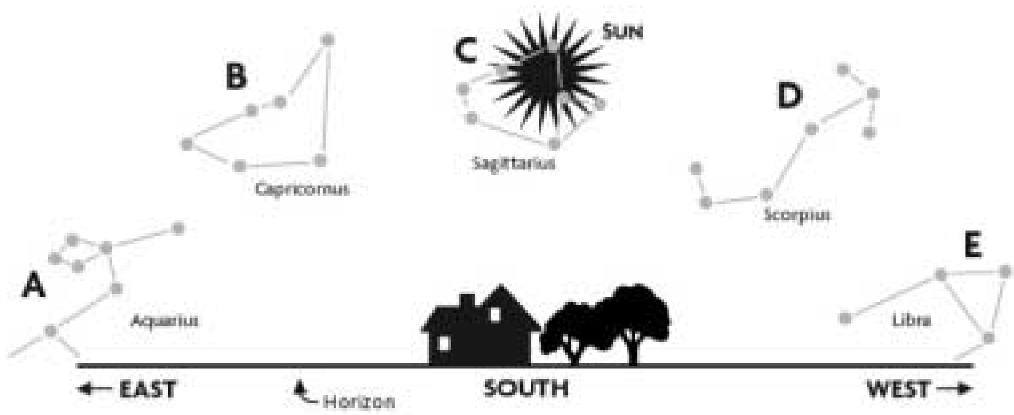
Astronomy Ranking Task:
Motion of the Sky

Exercise #2

Description: If you could see both the Sun and the other stars during the day, this is what the sky would look like for an observer in the northern hemisphere while looking south at noon on January 1. The Sun would appear in the sky next to the more distant stars in the constellation Sagittarius, (labeled constellation C). Also shown are other constellations (named and labeled A, B, D, and E) that will be visible above the horizon at this time when facing south.



Ranking Instructions: Rank the constellations (A - E) in the order that they will be located from highest in the sky to farthest below the horizon, 6 hours after the time shown.

Ranking Order:

Highest in sky 1 ___ 2 ____ 3 ____ 4 ____ 5 ____ Farthest below horizon.

Or, all will remain at the locations shown above 6 hours later. ________ (indicate with check mark)

Carefully explain your reasoning for ranking this way:

____

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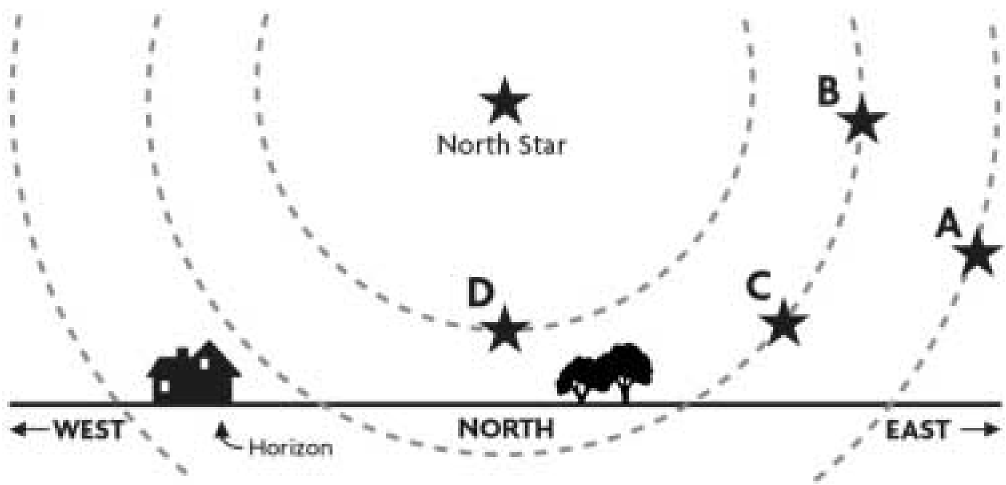
Astronomy Ranking Task:
Motion of the Sky

Exercise #3

Description: The figure below shows the evening sky as it would appear while looking north at 9PM tonight for an observer in the northern hemisphere. Notice Polaris, the North Star, appears fairly high in the sky – while other stars (labeled A - D) appear to slowly move counter-clockwise in great circles around the North Star.



Ranking Instructions: First, at the location of each star (A – D) draw a short arrow to indicate the <u>direction</u> that each star will appear to move for the instant shown. Next, rank the stars (A – D) in order of the number of hours (from greatest to least) that each star is above the horizon during each 24 hour day.

Ranking Order:

Greatest number of hours above horizon 1 ____ 2 _____ 3 _____ 4 _____ Least number of hours above horizon.

Or, all the stars are above the horizon the same number of hours per day. ________ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____

____

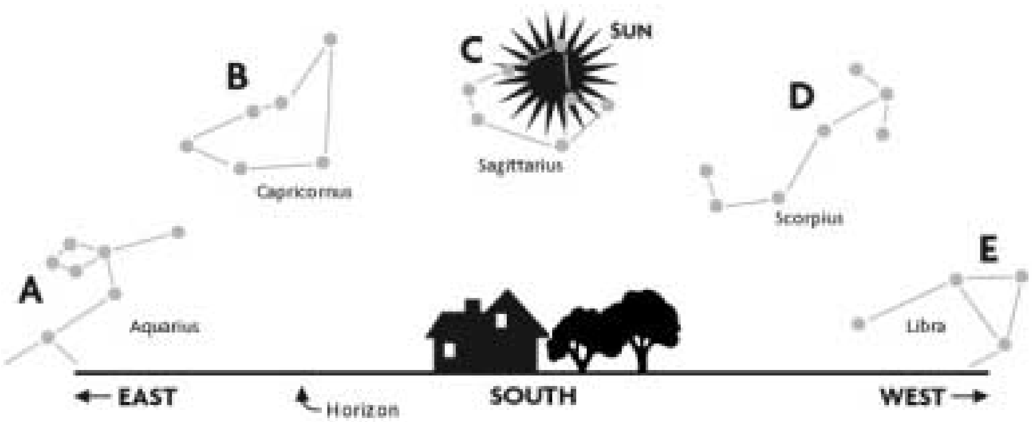
____

____

Astronomy Ranking Task:
Motion of the Sky

Exercise #4

Description: If you could see both the Sun and the other stars during the day, this is what the sky would look like for an observer in the northern hemisphere while looking south at noon on January 1. The Sun would appear in the sky next to the more distant stars in the constellation Sagittarius, (labeled constellation C). Also shown are other constellations (named and labeled A, B, D, and E) that will be visible above the horizon at this time when facing south.



Ranking Instructions: Rank the constellations (A - E) in the order that they would first appear to rise above the horizon on this day.

Ranking Order: First to rise 1 ___ 2 ____ 3 ____ 4 ____ 5 ____ Last to rise

Or, all the constellations would appear to rise above the horizon at the same time. ________ (indicate with check mark).

Or, all the constellations are always above the horizon. _____ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____

____

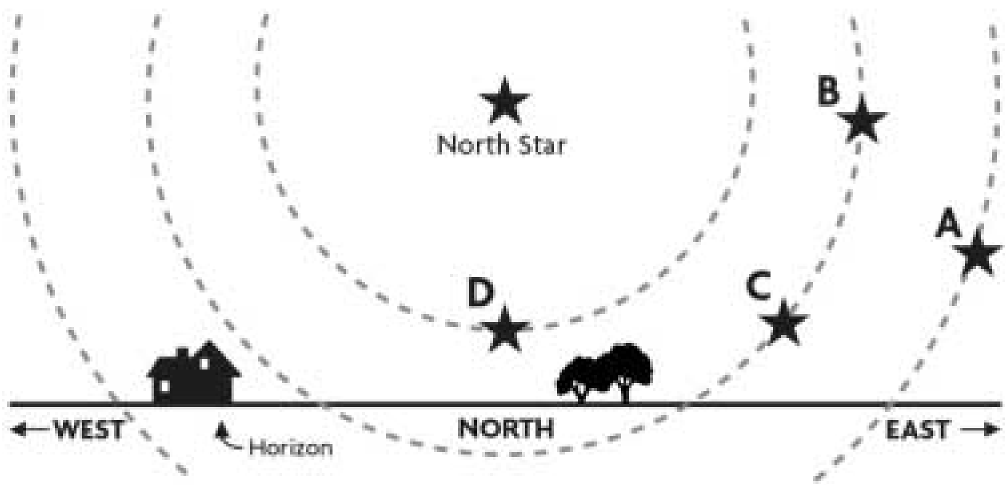
____

____

Astronomy Ranking Task:
Motion of the Sky

Exercise #5

Description: The figure below shows the evening sky as it would appear while looking north at 9PM tonight for an observer in the northern hemisphere. Notice that Polaris, the North Star, appears fairly high in the sky – while other stars (labeled A - D) appear to slowly move counter-clockwise in great circles around the North Star.



Ranking Instructions: First, at the location of each star (A – D) draw a short arrow to indicate the <u>direction</u> that each star will appear to move for the instant shown. Next, rank the stars (A - D) in the order that these stars first appear in the eastern part of the observer's sky for the day shown.

Ranking Order:

First star to appear in the eastern part of sky 1 ____ 2 _____ 3 _____ 4 _____ Last to appear in the eastern sky.

Or, all these stars would appear in the eastern part of the sky at the same time. ________ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

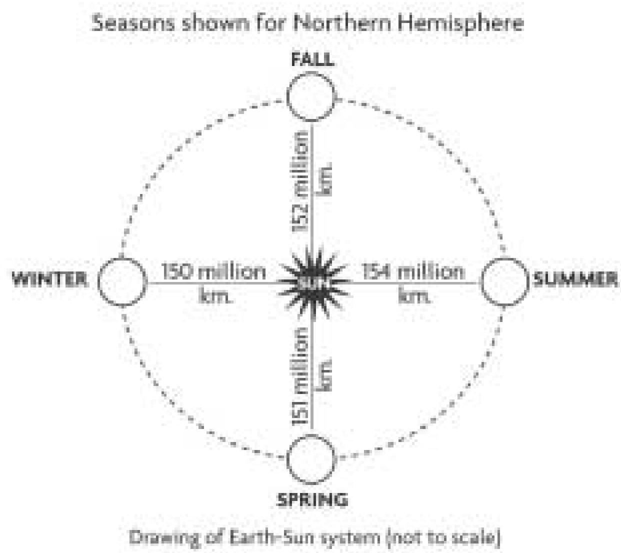
____
____
____
____

Astronomy Ranking Task:
The Seasons

Exercise #1

Description: The figure below shows the Earth in its nearly (but not quite) circular orbit around the Sun, and the Earth-Sun distance for each season.

Northern Hemisphere Season	Southern Hemisphere Season	Earth-Sun Distance (km)
Spring	Fall	151 million
Summer	Winter	154 million
Fall	Spring	152 million
Winter	Summer	150 million



A. Ranking Instructions: For a person in the Northern Hemisphere, rank the Earth-Sun distance (from greatest to least) by season. (Use season names.)

Ranking Order: Greatest distance 1 _______ 2 _______ 3 _______ 4 _______ Least distance

Or, the Earth-Sun distance for each season is the same. ________ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____

____

____

____

Continued on next page.

B. Ranking Instructions: For a person in the Southern Hemisphere, rank the Earth-Sun distance (from greatest to least) by season. (Use season names.)

Ranking Order: Greatest distance 1 _______ 2 _______ 3 _______ 4 _______ Least distance

Or, the Earth-Sun distance for each season is the same. ________ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____

____

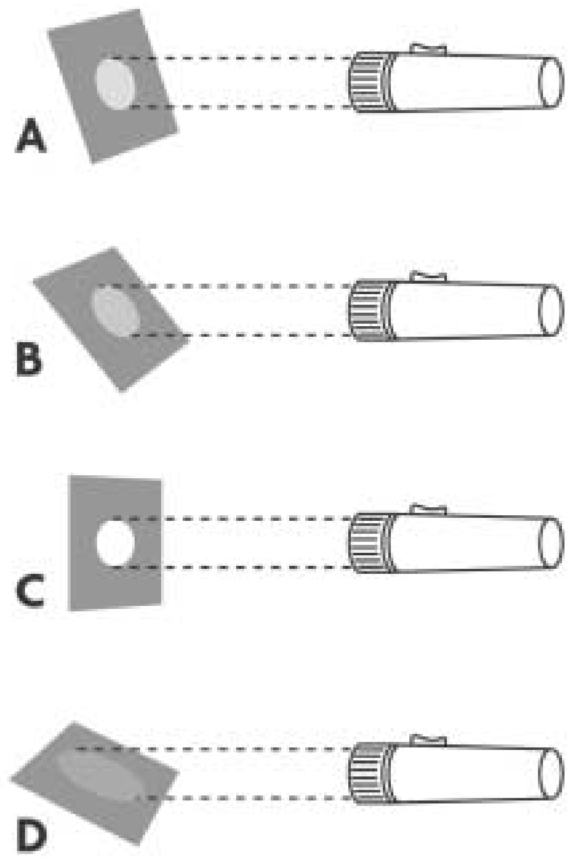
____

____

Astronomy Ranking Task:
The Seasons

Exercise #2

Description: In each figure below a flashlight is shown projecting identical beams of light onto pieces of paper (A – D) inclined at various angles.



A. Ranking Instructions: Rank the size of the illuminated area (from largest to smallest) on each piece of paper (A – D).

Ranking Order: Largest 1 _____ 2 _____ 3 _____ 4 _____ Smallest

Or, the illuminated areas are all the same size. ________ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____
____
____
____

B. Ranking Instructions: Rank the brightness (from brightest to dimmest) of each illuminated area on the pieces of paper (A – D).

Ranking Order: Brightest 1 _____ 2 _____ 3 _____ 4 _____ Dimmest

Or, the areas are all the same brightness. ________ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____
____
____
____

C. Ranking Instructions: Imagine that you placed a very sensitive thermometer against the illuminated area of each piece of paper and measured its temperature. Rank the temperature (from coolest to hottest) of each illuminated area (A – D).

Ranking Order: Coolest 1 _____ 2 _____ 3 _____ 4 _____ Hottest

Or, the temperatures of each illuminated area would all be the same. ________ (indicate with check mark).

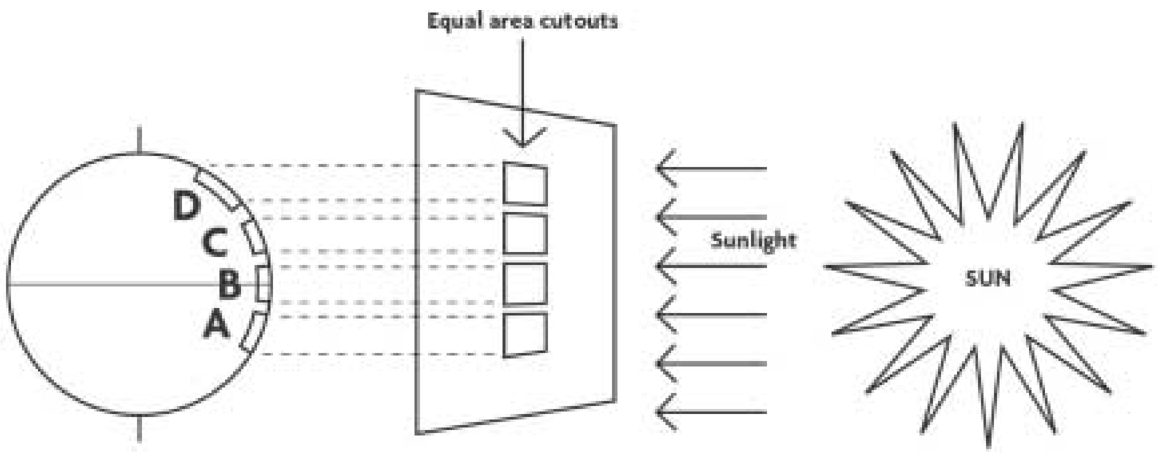
Carefully explain your reasoning for ranking this way:

____
____
____
____

Astronomy Ranking Task:
The Seasons

Exercise #3

Description: In the figure below parallel beams of sunlight are projected through equal sized cutouts of a screen and then strike a spherical globe at locations A - D. Note that A and C are at the same "latitude" on the globe.



Ranking Instructions: Rank the size (from largest to smallest) of the illuminated areas (A – D) on the globe.

Ranking Order: Largest 1 _____ 2 _____ 3 _____ 4 _____ Smallest

Or, each of the illuminated areas are equal. ________ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____
____
____
____

B. Ranking Instructions: Rank the brightness (from brightest to dimmest) of each illuminated area on the globe (A – D).

Ranking Order: Brightest 1 _____ 2 _____ 3 _____ 4 _____ Dimmest

Or, the areas are all the same brightness. ________ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____
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____

C. Ranking Instructions: Imagine that you placed very sensitive thermometers against each illuminated area on the globe and measured its temperature. Rank the temperature (from coolest to hottest) of each illuminated area (A – D).

Ranking Order: Coolest 1 _____ 2 _____ 3 _____ 4 _____ Hottest

Or, the temperatures of each illuminated area would all be the same. ________ (indicate with check mark).

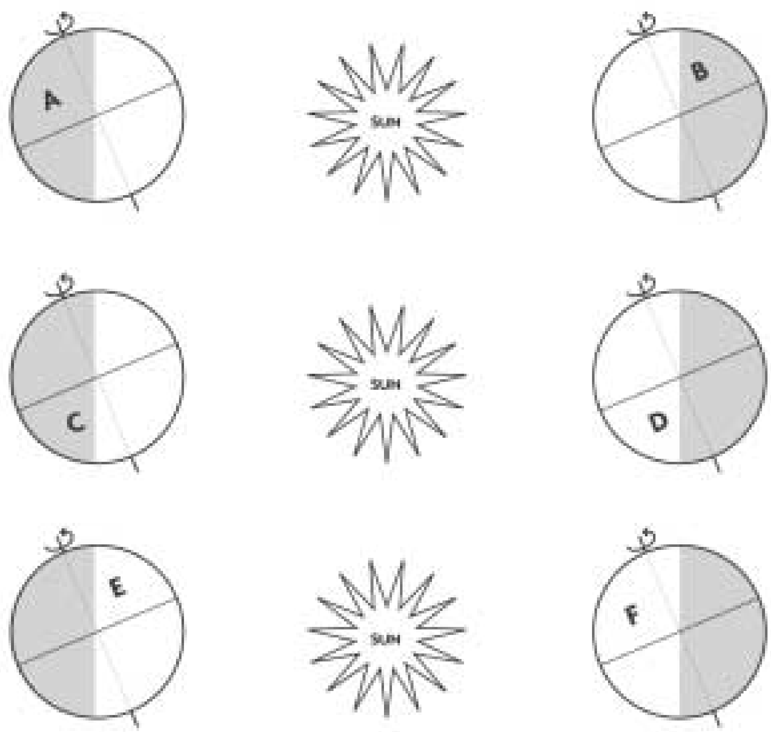
Carefully explain your reasoning for ranking this way:

____
____
____
____

Astronomy Ranking Task:
The Seasons

Exercise #4

Description: In the figure below six different locations (A - F) on Earth are shown during a particular time of the year. Note that each location is the same distance away from the equator.



A. Ranking Instructions: Rank the time it takes (from longest to shortest) for each location (A – F) to complete one full rotation.

Ranking Order: Longest time 1 _____ 2 _____ 3 _____ 4 _____ 5_____ 6_____ Shortest time

Or, the time it takes each location to make one full rotation is the same. ________ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

B. Ranking Instructions: Rank the time (from longest to shortest) that each location spends in daylight during each 24 hour period.

Ranking Order: Longest time 1 _____ 2 _____ 3 _____ 4 _____ 5_____ 6_____ Shortest time.

Or, the time each location spends in daylight is the same. ________ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____
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C. Ranking Instructions: Imagine that you placed identical glasses of water at each location (A - F). Rank the temperature (from coolest to hottest) of the water in each glass at the end of a full day.

Ranking Order: Coolest 1 _____ 2 _____ 3 _____ 4 _____ 5_____ 6_____ Hottest

Or, the temperature of each glass of water would be the same. ________ (indicate with check mark).

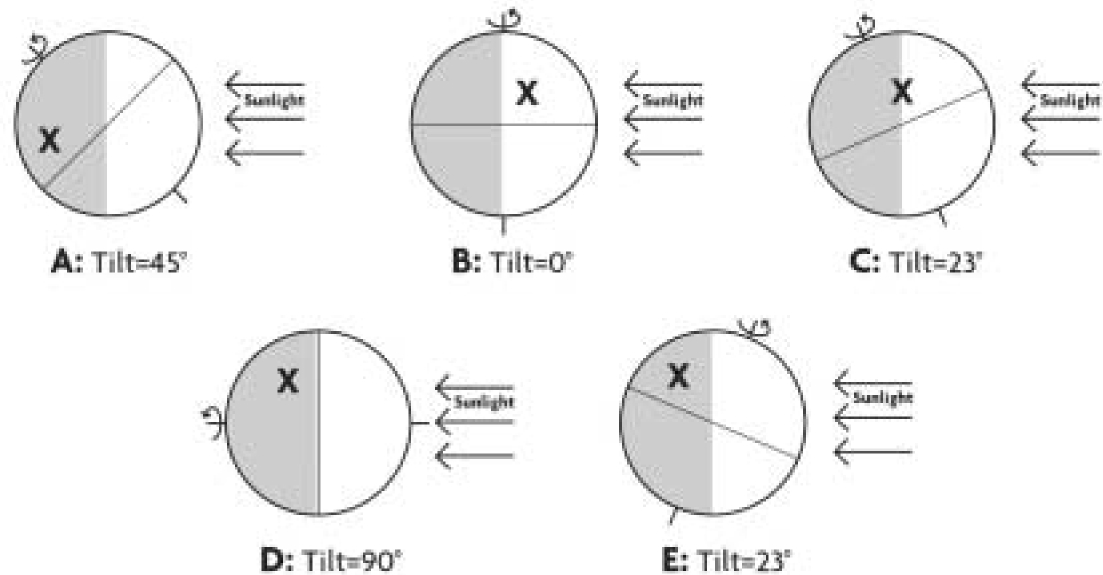
Carefully explain your reasoning for ranking this way:

____
____
____
____

Astronomy Ranking Task:
The Seasons

Exercise #5

Description: In the figures (A – E) below parallel beams of sunlight illuminate globes tilted at various angles. Like the Earth, the globes rotate so that each location (indicated by an X) on each globe is sometimes in sunlight and sometimes in darkness. Assume that the globes make one full rotation every 24 hours, and that the distance of each "X" above the equator is the same on each globe.



A. Ranking Instructions: Rank the time (from longest to shortest) that each location spends in daylight during the 24 hour rotation period.

Ranking Order: Longest time 1 _____ 2 _____ 3 _____ 4 _____ 5 _____ Shortest time

Or, the time spent in daylight for each location is the same. ________ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

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B. Ranking Instructions: Imagine that you placed identical glasses of water at each location indicated by an "X" for globes A - E. Rank the highest temperature (from coolest to hottest) a glass of water would reach during a 24 hour period at each location.

Ranking Order: Coolest 1 _____ 2 _____ 3 _____ 4 _____ 5_____ Hottest

Or, the temperature of each glass of water is the same. ________ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

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____
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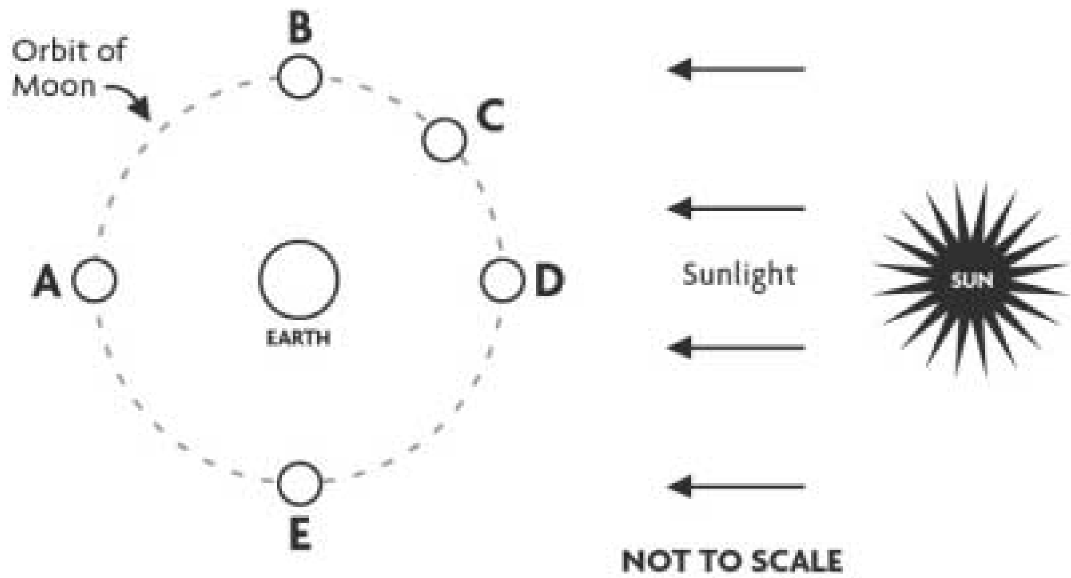
Astronomy Ranking Task:
Phases of the Moon

Exercise #1

Description: The figure below shows a "top view" of the Sun, Earth, and five different positions (A - E) of the Moon during one orbit of Earth. Note that the distances shown for the Sun to Earth and for Earth to the Moon are not drawn to scale.



Ranking Instructions: Rank (from greatest to least) the amount of the Moon's entire surface that is illuminated by sunlight for the five positions (A-E) shown.

Ranking Order: Greatest 1 ____ 2 ____ 3 ____ 4____ 5 ____ Least

Or, the amount of the entire surface of the Moon illuminated by sunlight is the same at all the positions. ____ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____

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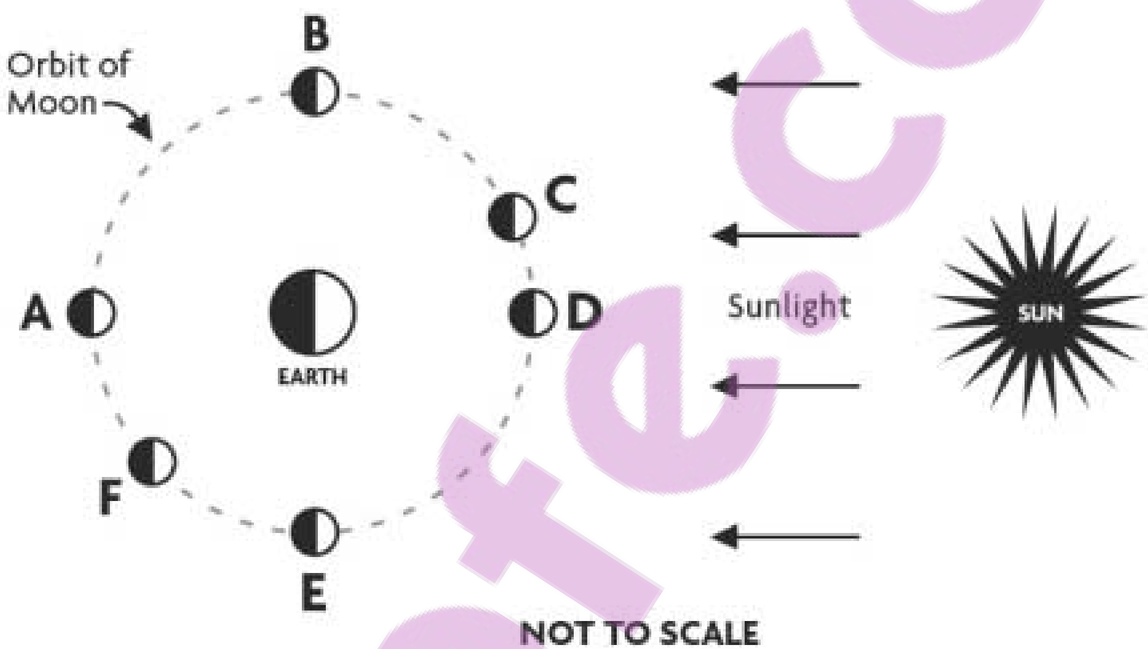
____

____

Astronomy Ranking Task:
Phases of the Moon

Exercise #2

Description: The figure below shows a "top view" of the Sun, Earth and six different positions (A - F) of the Moon during one orbit of Earth. Note that the distances shown for the Sun to Earth and for Earth to the Moon are not drawn to scale.



Ranking Instructions: Rank (from greatest to least) the amount of the Moon's illuminated surface that is visible from Earth at each of the six positions (A – F) shown.

Ranking Order: Greatest 1 ___ 2 ____ 3 ____ 4 ____ 5 ____ 6 ____ Least

Or, the amount of the Moon's illuminated surface visible from Earth is the same in all positions. _____ (indicate with check mark).

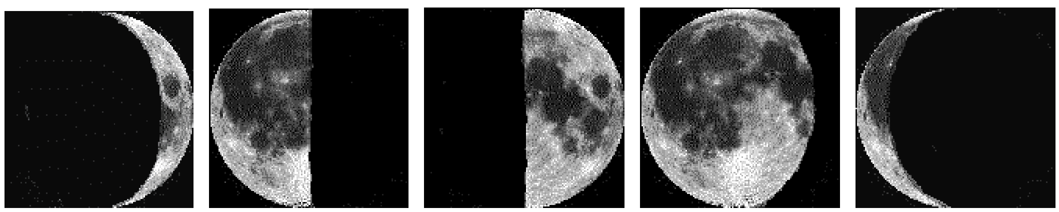
Carefully explain your reasoning for ranking this way:

____
____
____
____

Astronomy Ranking Task:
Phases of the Moon

Exercise #3

Description: Shown below are five different phases of the Moon (A – E) as seen by an observer in the Northern Hemisphere.



A **B** **C** **D** **E**

Ranking Instructions: Beginning with the waxing gibbous phase of the Moon, rank the moon phases shown below in the order that the observer would see them over the next four weeks.

Ranking Order:

First phase following waxing gibbous phase 1 ___ 2 ____ 3 ___ 4 ____ 5 ____ Last phase seen.

Or, all of these phases would be visible at the same time. _____ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____

____

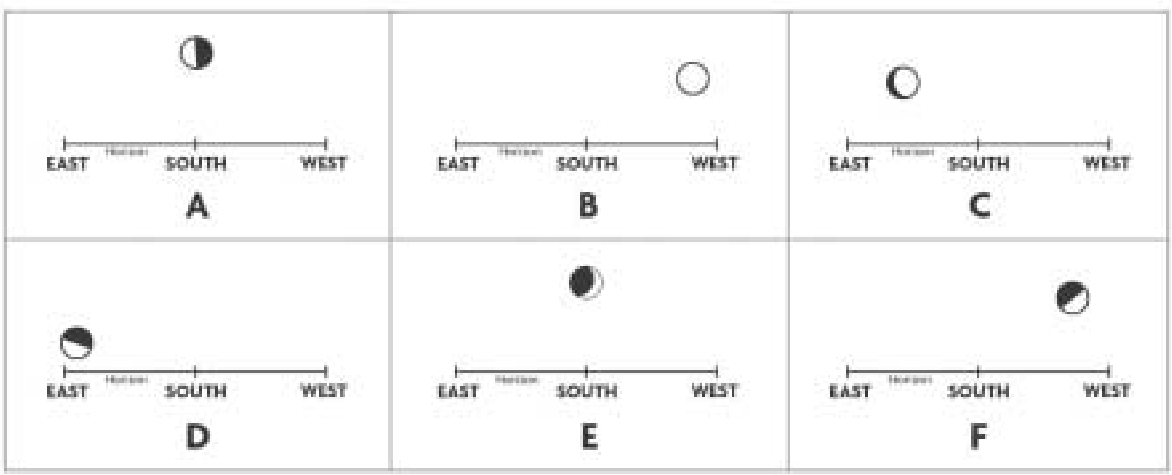
____

____

Astronomy Ranking Task:
Phases of the Moon

Exercise #4

Description: In each figure below (A – F) 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 areas on each moon figure show the unlit portions of the Moon visible from Earth at that time. Assume that sunset occurs at 6 pm and that sunrise occurs at 6 am.



Ranking Instructions: 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).

Ranking Order:

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).

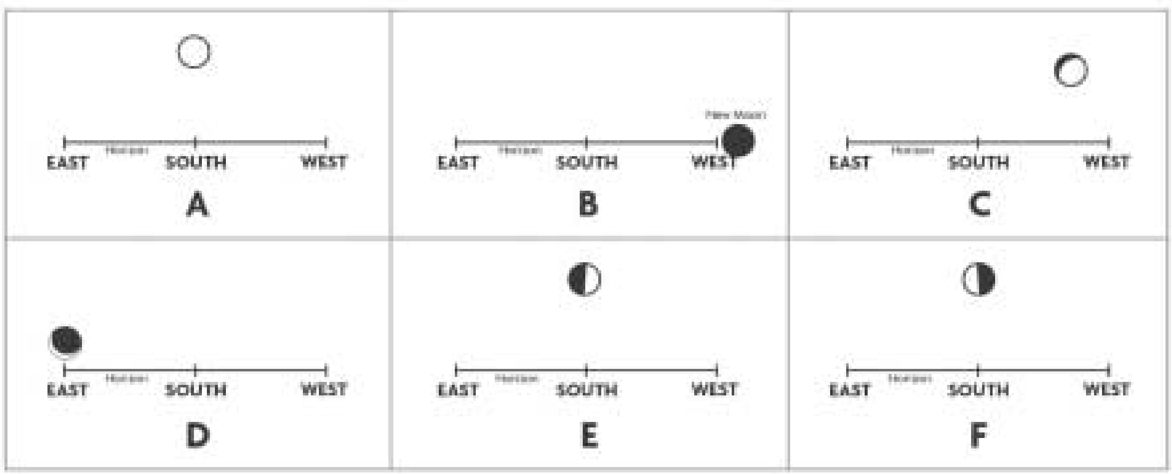
Carefully explain your reasoning for ranking this way:

____
____
____
____

Astronomy Ranking Task:
Phases of the Moon

Exercise #5

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.



Ranking Instructions: 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).

Ranking Order:

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).

Carefully explain your reasoning for ranking this way:

____

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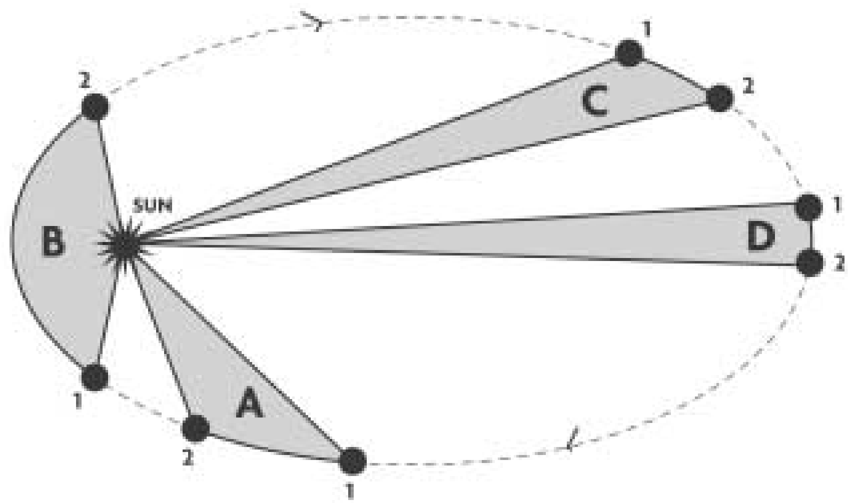
Astronomy Ranking Task:
Kepler's Laws – Orbital Motion

Exercise #1

Description: The figure below shows several positions of a comet traveling in an elliptical orbit around the Sun. Four different segments of its orbit (A – D), and the corresponding triangular shaped area swept out by the comet, have been shaded in gray. Assume that each of the shaded triangular segments have the same area.



A. Ranking Instruction: Rank the time it took (from greatest to least) for the comet to move along each of the segments (A – D) of the orbit.

Ranking Order: Greatest 1_______ 2_______ 3_______ 4_______ Least

Or, the time to travel each segment would be the same. ______ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____

____

____

____

Continued on next page.

B. Ranking Instructions: Rank the distance (from greatest to least) the comet traveled during each of the segments (A – D) of the orbit.

Ranking Order: Greatest 1_______ 2_______ 3_______ 4_______ Least

Or, the distance traveled during each segment would be the same. ______ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____
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____
____

C. Ranking Instructions: Rank the speed (from slowest to fastest) of the comet during each segment (A – D) of the orbit.

Ranking Order: Slowest 1_______ 2_______ 3_______ 4_______ Fastest

Or, the speed of the comet during each of the segments would be the same. ______ (indicate with check mark).

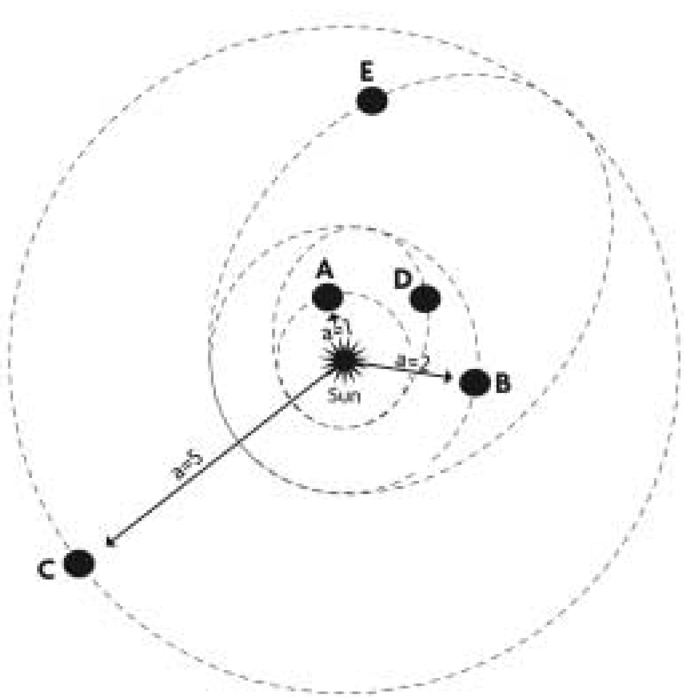
Carefully explain your reasoning for ranking this way:

____
____
____
____

Astronomy Ranking Task:
Kepler's Laws – Orbital Motion

Exercise #2

Description: The figure below shows a star and five orbiting planets (A – E). Note that planets A, B and C are in perfectly circular orbits. In contrast, planets D and E have more elliptical orbits. Note that the closest and farthest distances for the elliptical orbits of planets D and E happen to match the orbital distances of planets A, B, and C as shown in the figure.



Ranking Instructions: Rank the orbital period (from longest to shortest) of the planets.

Ranking Order: Longest 1 ___ 2 ____ 3 ____ 4 ____ 5 ____ Shortest

Or, the orbital periods of the planets would all be the same. ________ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____

____

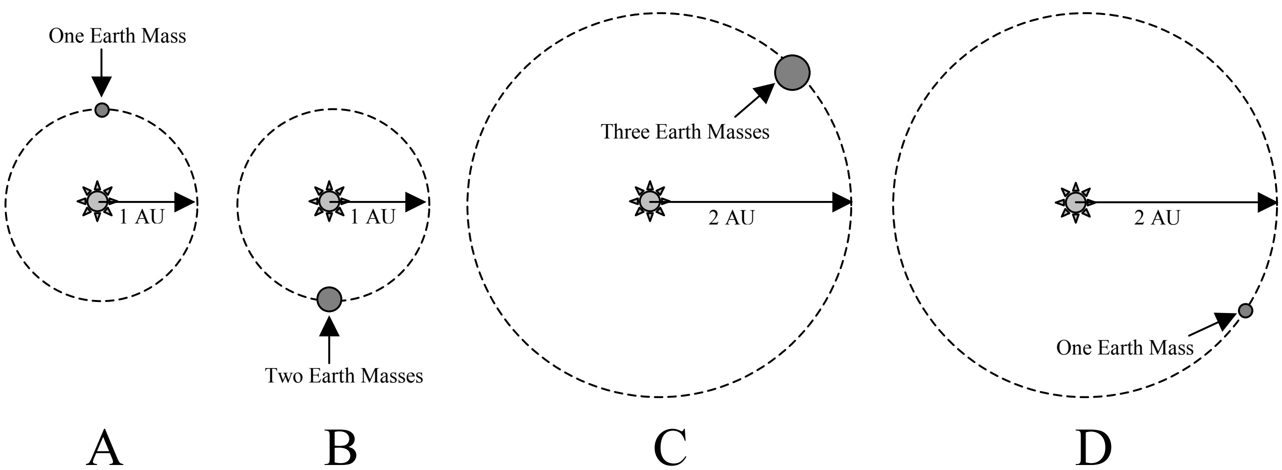
____

____

Astronomy Ranking Task:
Kepler's Laws – Orbital Motion

Exercise #3

Description: The figure below shows four identical one solar mass stars, and four planets (A – D) of different masses in circular orbits of various sizes. In each case the mass of the planet is given in Earth masses and the orbital distance is given in Astronomical Units (AU). Note that the sizes of the stars and planets, and the orbital distances have not been drawn to scale.



Ranking Instructions: Rank the orbital periods (from longest to shortest) of the planets (A – D).

Ranking Order: Longest 1 ___ 2 ____ 3 ____ 4 ____ Shortest

Or, the orbital periods of the planets would all be the same. ________ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____

____

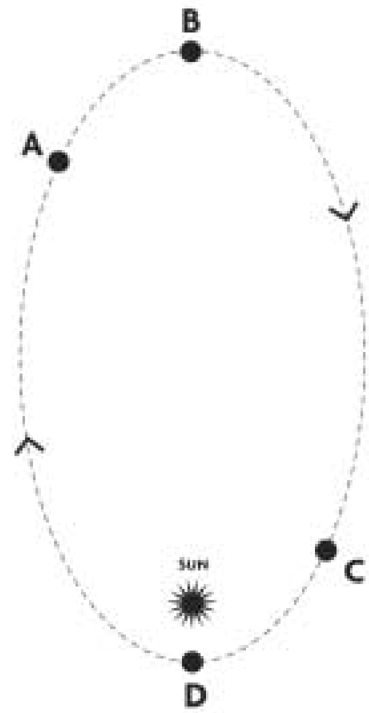
____

____

Astronomy Ranking Task:
Kepler's Laws – Orbital Motion

Exercise #4

Description: The figure below shows four locations (A – D) of an asteroid during its elliptical orbit around the Sun.



Ranking Instructions: Rank the speed (from fastest to slowest) that the asteroid would have at each of the four locations.

Ranking Order: Fastest 1 ____ 2 ____ 3 ____ 4 ____ Slowest

Or, the orbital speed at each location would be the same. ________ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

Astronomy Ranking Task:
Kepler's Laws – Orbital Motion

Exercise #5

Description: The table below provides a partial list of the orbital periods (in years), and orbital distances (in AU) for six planets orbiting a one solar-mass star. The mass of each planet is also provided (in Earth masses).

PLANET	ORBIT DISTANCE (Semi-major axis in AU)	PERIOD (Years)	MASS (Earth Masses)
A		20.0	500
B	0.8		375
C	3.0		100
D		2.0	50
E	5.0		3
F		3.5	0.5

Ranking Instructions: Use the provided information to rank the distance (from farthest to closest) of the planets (A – F) from the star. Note that it is not necessary to complete the table before making your rankings.

Ranking Order: Farthest 1 ____ 2 ____ 3 ____ 4 ____ 5 ____ 6 ____ Closest

Or, the orbital distances for the planets would all be the same. ________ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____

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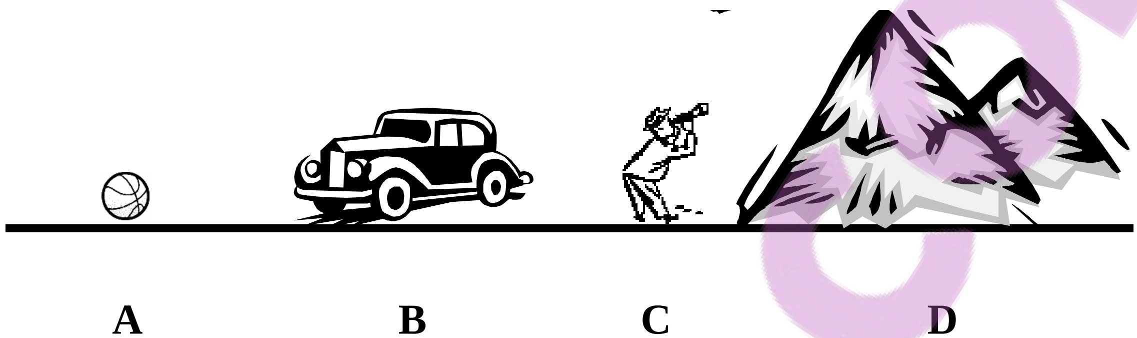
____

____

Astronomy Ranking Task: Gravity

Exercise #1

Description: The figure below shows several objects (A – D) of different masses located on the surface of the earth.



A. Ranking Instructions: Rank (from greatest to least) the strength of the gravitational force exerted by Earth on each of the objects (A – D).

Ranking Order: Greatest 1 ______ 2 _______ 3 _______ 4 ______ Least

Or, the gravitational force exerted on each object is the same. _________
(indicate with a check mark)

Carefully explain your reasoning for ranking this way:

B. Ranking Instructions: Rank (from greatest to least) the strength of the gravitational force exerted by each of the objects A – D on Earth.

Ranking Order: Greatest 1 ______ 2 _______ 3 _______ 4 ______ Least

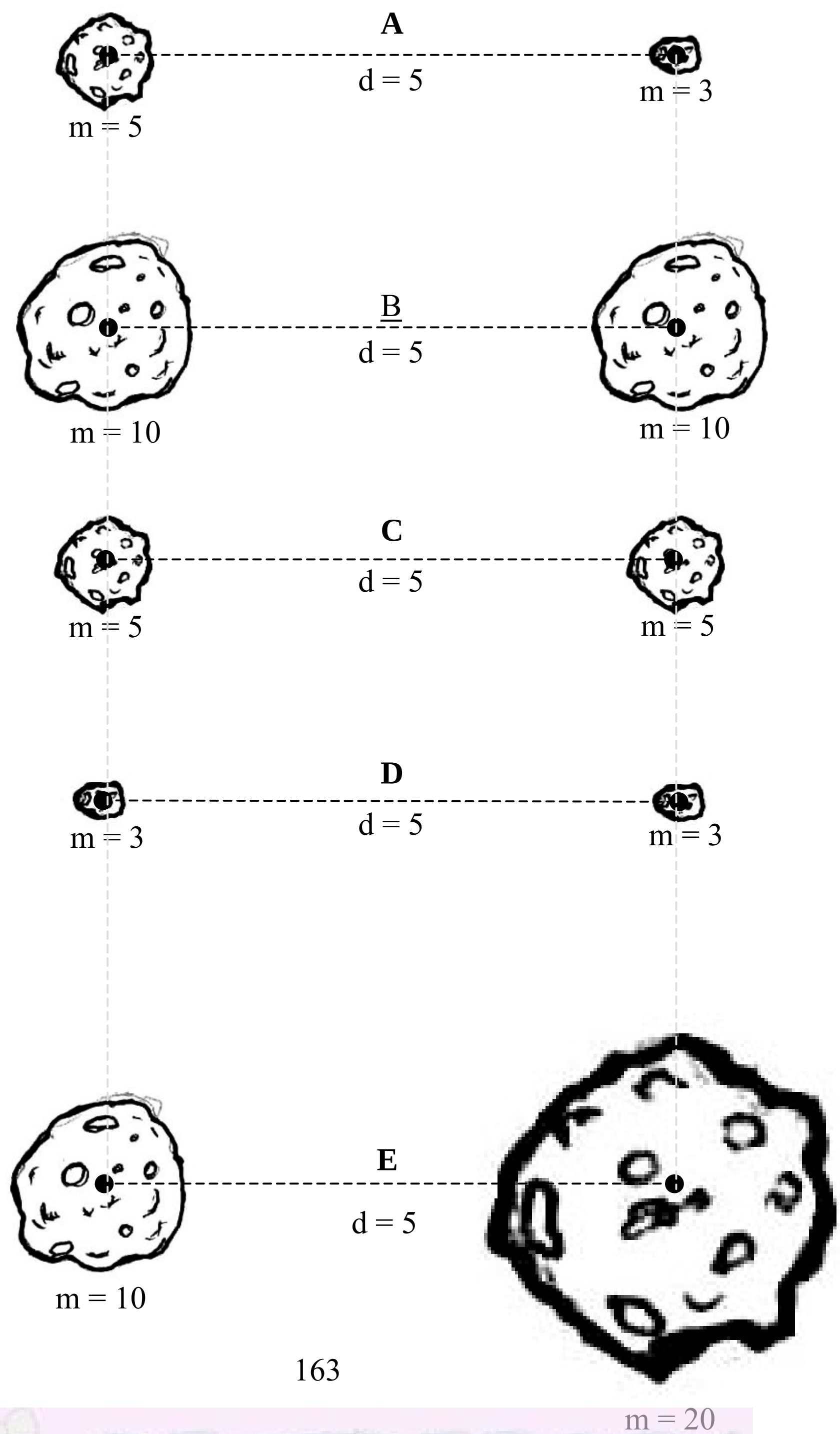
Or, the gravitational force exerted by each object is the same. _________
(indicate with a check mark)

Carefully explain your reasoning for ranking this way:

Astronomy Ranking Task: Gravity

Exercise #2

Description: The figures below (A – E) each show two rocky asteroids with masses (m), expressed in arbitrary units, separated by a distance (d), also expressed in arbitrary units.



A. **Ranking Instructions:** Rank (from greatest to least) the strength of the gravitational force exerted on the asteroid located on the left side of each pair.

Ranking Order: Greatest 1 ____ 2 _____ 3 _____ 4 ____ 5 ____ Least

Or, the strength of the gravitational force exerted in each case is the same.
______ (indicate with a check mark)

Carefully explain your reasoning for ranking this way:

____
____
____
____

B. **Ranking Instructions:** Rank (from greatest to least) the strength of the gravitational force exerted on the asteroid located on the right side of each pair.

Ranking Order: Greatest 1 ____ 2 _____ 3 _____ 4 ____ 5 ____ Least

Or, the strength of the gravitational force exerted in each case is the same.
______ (indicate with a check mark)

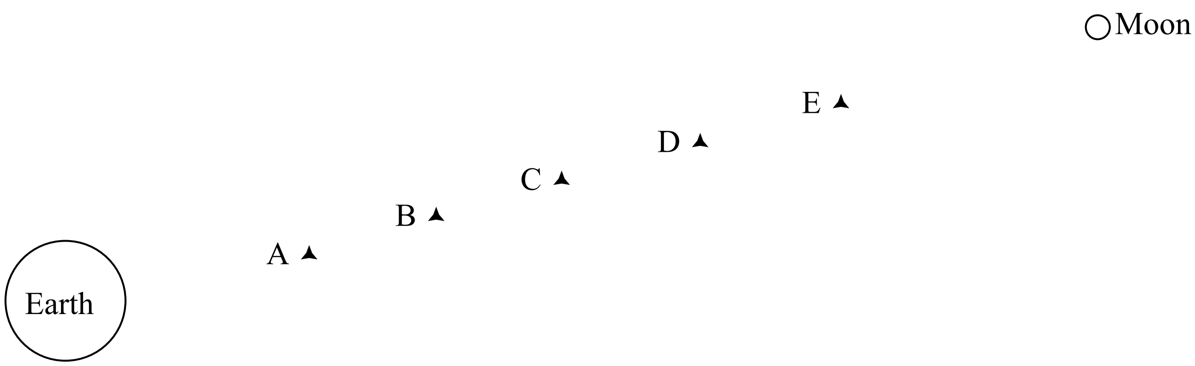
Carefully explain your reasoning for ranking this way:

____
____
____
____

Astronomy Ranking Task:
Gravity

Exercise #3

Description: In the picture below, the Earth-Moon system is shown (not to scale) along with five possible positions (A - E) for a spacecraft traveling from Earth to the Moon. Note that position C is exactly half-way between Earth and the Moon..



A. Ranking Instructions: Rank (from greatest to least) the strength of the gravitational force at positions A - E exerted by the Moon on the spacecraft.

Ranking Order: Greatest 1 ______ 2 _______ 3 _______ 4 ______ 5 ______ Least

Or, the gravitational force exerted at each position is the same. _________
(indicate with a check mark)

Carefully explain your reasoning for ranking this way:

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____
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Continued on next page.

B. Ranking Instructions: Rank (from greatest to least) the strength of the total gravitational forces at positions A - E exerted by both the Earth and the Moon on the spacecraft.

Ranking Order: Greatest 1 ______ 2 _______ 3 _______ 4 ______ 5 ______ Least

Or, the gravitational force exerted at each position is the same. _________ (indicate with a check mark)

Carefully explain your reasoning for ranking this way:

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____
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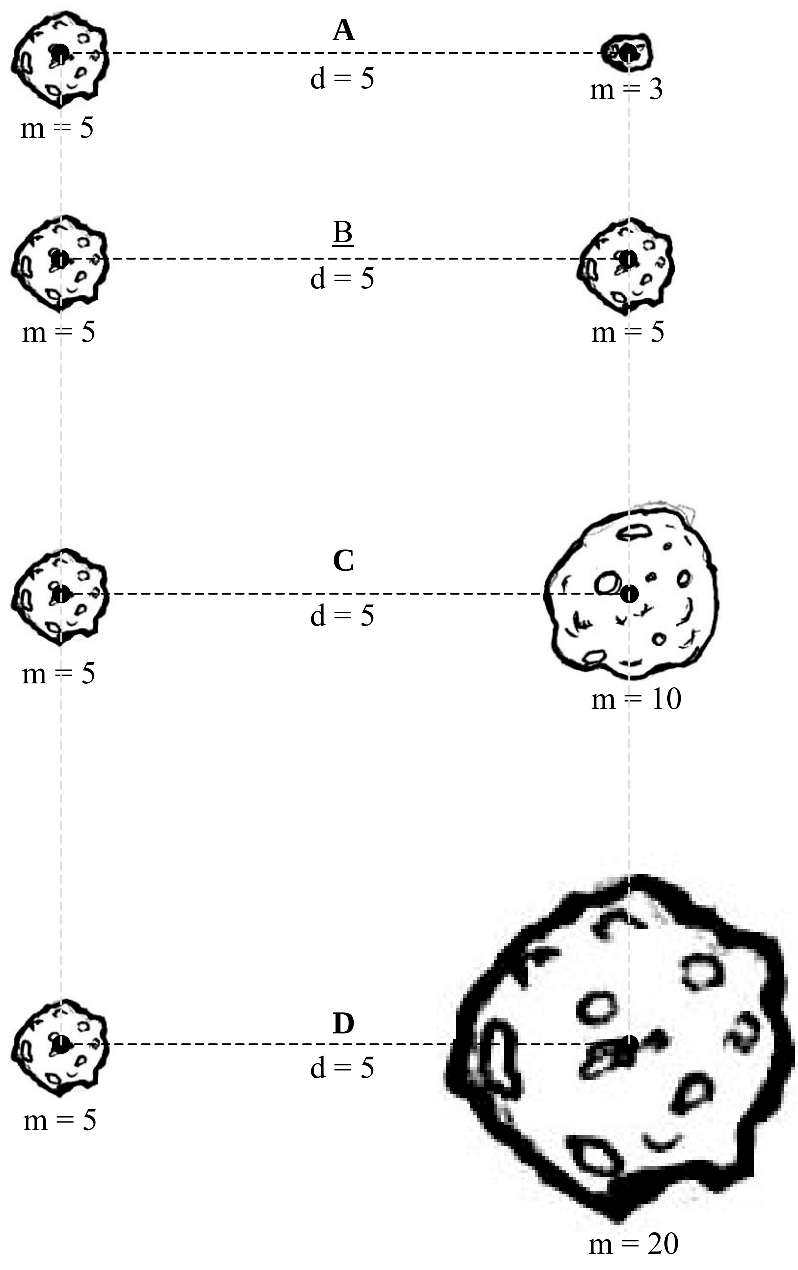
Astronomy Ranking Task:
Gravity

Exercise #4

Description: The figures below (A – D) each show two rocky asteroids with masses (m), expressed in arbitrary units, separated by a distance (d), also expressed in arbitrary units.



A. Ranking Instructions: Rank (from greatest to least) the strength of the gravitational force exerted on the asteroid located on the left side of each pair.

Ranking Order: Greatest 1 ____ 2 _____ 3 _____ 4 ____ Least

Or, the strength of the gravitational force exerted in each case is the same. _________ (indicate with a check mark)

Carefully explain your reasoning for ranking this way:

____
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B. Ranking Instructions: Using Newton's Second Law, rank the acceleration (from greatest to least) that the asteroids located on the left side of each pair would experience due to the gravitational force exerted on it.

Ranking Order: Greatest 1 ______ 2 _______ 3 _______ 4 ______ Least

Or, the accelerations for each asteroid is the same. _________ (indicate with a check mark)

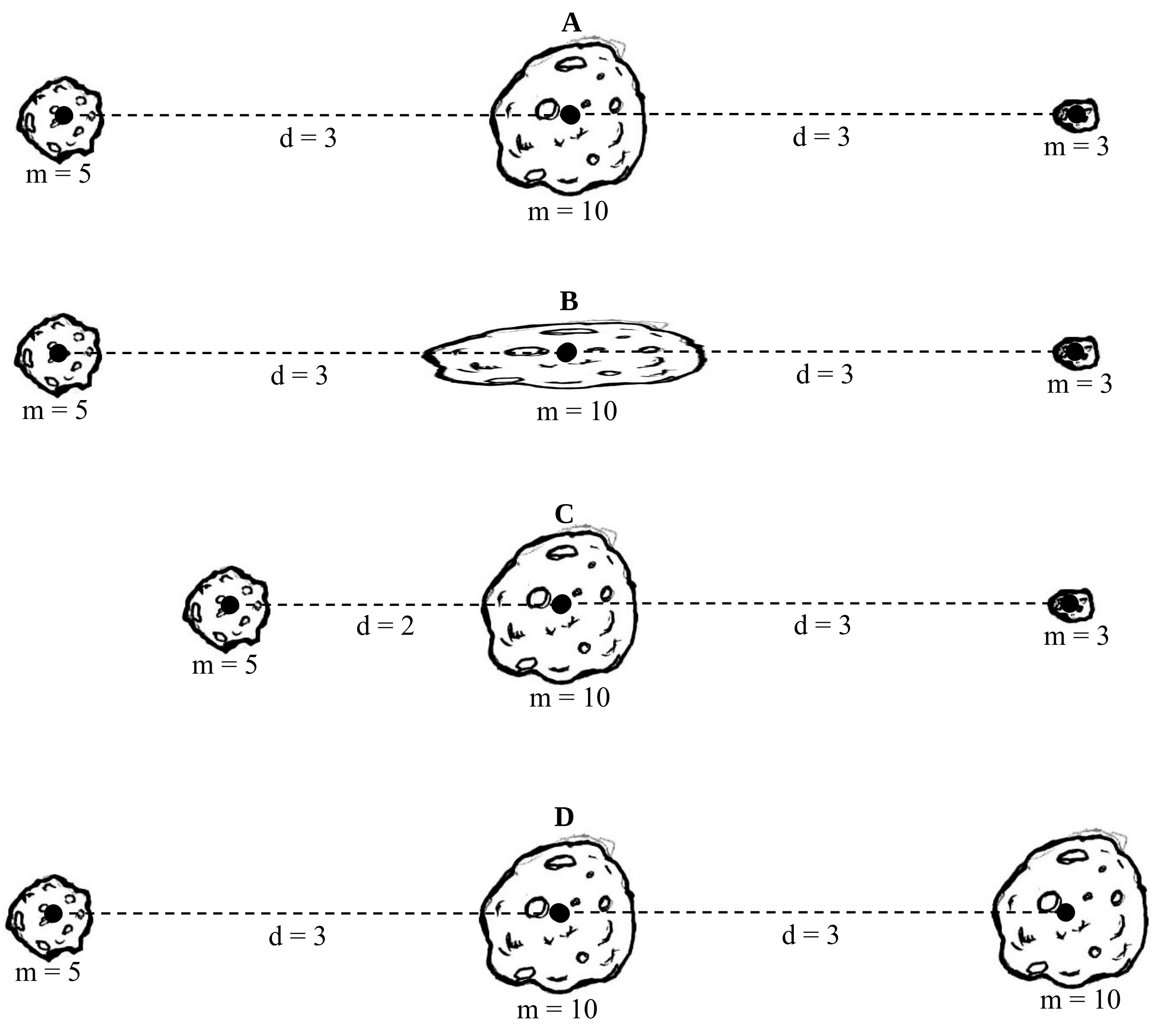
Carefully explain your reasoning for ranking this way:

____
____
____
____

Astronomy Ranking Task:
Gravity

Exercise #5

Description: The figures below (A – D) each show a large central asteroid along with two other asteroids located to the right and left of the central asteroid. The masses (m) of the asteroids are expressed in arbitrary units, and the distance (d) from the center asteroid is also expressed in arbitrary units.



Ranking Instructions: Rank (from greatest to least) the strength of the net (or total) gravitational force exerted on the center asteroid by its two neighboring asteroids.

Ranking Order: Greatest 1 _____ 2 _____ 3 _____ 4 _____ Least

Or, gravitational forces are all the same strength. _________ (indicate with a check mark)

Carefully explain your reasoning for ranking this way:

Astronomy Ranking Task:
Gravity

Exercise #6

Description: The table below shows the masses and distances (expressed in arbitrary units) between four different pairs of stars (Cases A – D).

Case	Mass of star #1	Distance between star #1 and star #2	Mass of star #2
A	4	2	2
B	2	2	8
C	8	4	4
D	1	3	5

Ranking Instructions: Rank (from greatest to least) the strength of the gravitational force exerted between the pairs of stars in cases A - D.

Ranking Order: Greatest 1 _______ 2 ________ 3 ________ 4 _______ Least

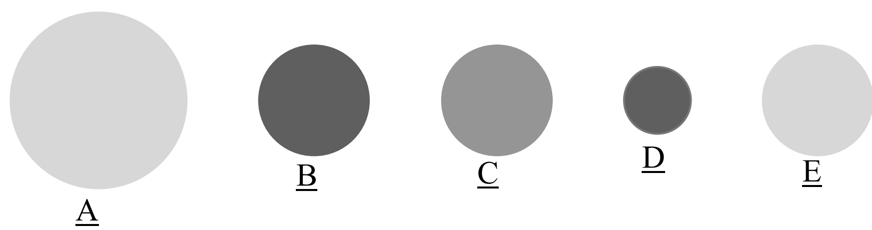
Or, gravitational force exerted between each pair of stars is the same. __________ (indicate with a check mark

Carefully explain your reasoning for ranking this way:

Astronomy Ranking Task: Luminosity of Stars

Exercise #1

Description: Imagine you are comparing the five electric hot plates (A – E) of different sizes and temperatures. The temperature of each hot plate is indicated by a shade of gray such that the lighter the shade of gray, the higher the temperature of the hot plate.



A. Ranking instructions: Rank the surface area (from largest to smallest) of the hotplates.

Ranking Order: Largest 1 ____ 2 ____ 3 ____ 4 _____ 5 _____Smallest

Or, all the hotplates have the same surface area. _____ (indicate with a check mark)

Carefully explain your reasoning for ranking this way:

____
____
____
____

B. Ranking instructions: Rank the temperature (from hottest to coldest) of the hotplates.

Ranking Order: Hottest 1 ____ 2 ____ 3 ____ 4 _____ 5 _____ Coldest

Or, all the hotplates have the same temperature _____ (indicate with a check mark)

Carefully explain your reasoning for ranking this way:

____
____
____
____

C. Ranking instructions: Rank the total energy output or luminosity (from greatest to least) of the hotplates.

Ranking Order: Greatest 1 ____ 2 ____ 3 ____ 4 _____ 5 _____ Least

Or, all the hotplates have the same energy output or luminosity. _____ (indicate with a check mark)

Carefully explain your reasoning for ranking this way:

____

____

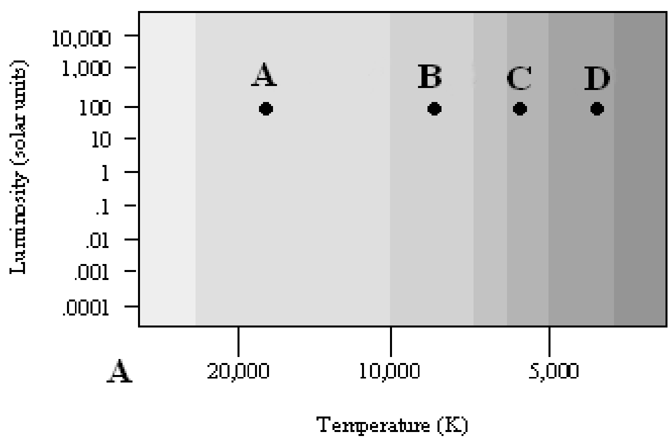
____

____

Astronomy Ranking Task: Luminosity of Stars

Exercise #2

Description: Consider the Hertzsprung-Russell (HR) diagram shown below which relates the luminosity (in solar units) to the temperature for four stars (A - D).



A

A. Ranking instructions: Rank the temperature of the stars (A – D) from hottest to coolest.

Ranking Order: Hottest 1 ____ 2 ____ 3 ____ 4 _____ Coldest

Or, all the stars have the same temperature. _____ (indicate with a check mark)

Carefully explain your reasoning for ranking this way:

____

____

____

____

B. Ranking instructions: Rank the luminosity of the stars (A – D) from greatest (brightest) to least (dimmest).

Ranking Order: Greatest 1 ____ 2 ____ 3 ____ 4 _____ Least

Or, all the stars have the same luminosity. _____ (indicate with a check mark)

Carefully explain your reasoning for ranking this way:

C. Ranking instructions: Rank the surface area of the stars (A – D) from largest to smallest.

Ranking Order: Largest 1 ____ 2 ____ 3 ____ 4 _____ Smallest

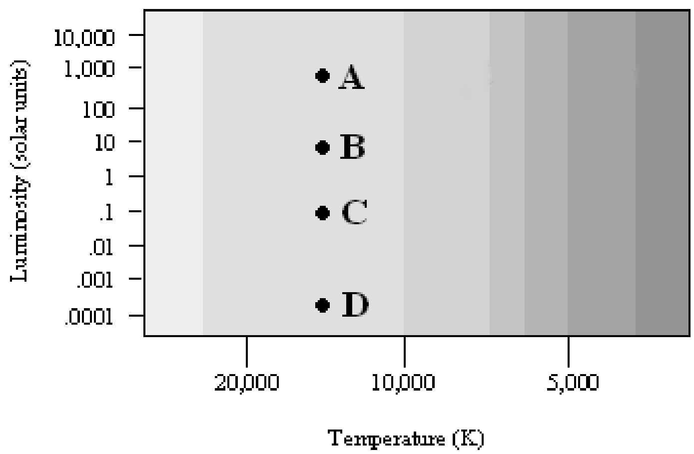
Or, all the stars have the same surface area. _____ (indicate with a check mark)

Carefully explain your reasoning for ranking this way:

Astronomy Ranking Task:
Luminosity of Stars

Exercise #3

Description: Consider the Hertzsprung-Russell (HR) diagram shown below which relates the luminosity (in solar units) to the temperature for four stars (A - D).



A. Ranking instructions: Rank the temperature of the stars (A – D) from hottest to coldest.

Ranking Order: Hottest 1 ____ 2 ____ 3 ____ 4 _____ Coldest

Or, all the stars have the same temperature. _____ (indicate with a check mark)

Carefully explain your reasoning for ranking this way:

____
____
____
____

B. Ranking instructions: Rank the luminosity of the stars (A – D) from greatest (brightest) to least (dimmest).

Ranking Order: Greatest 1 ____ 2 ____ 3 ____ 4 _____ Least

Or, all the stars have the same luminosity. _____ (indicate with a check mark)

Carefully explain your reasoning for ranking this way:

____
____
____
____

C. Ranking instructions: Rank the surface area of the stars (A – D) from smallest to largest.

Ranking Order: Smallest 1 ____ 2 ____ 3 ____ 4 _____ Largest

Or, all the stars have the same surface area. _____ (indicate with a check mark)

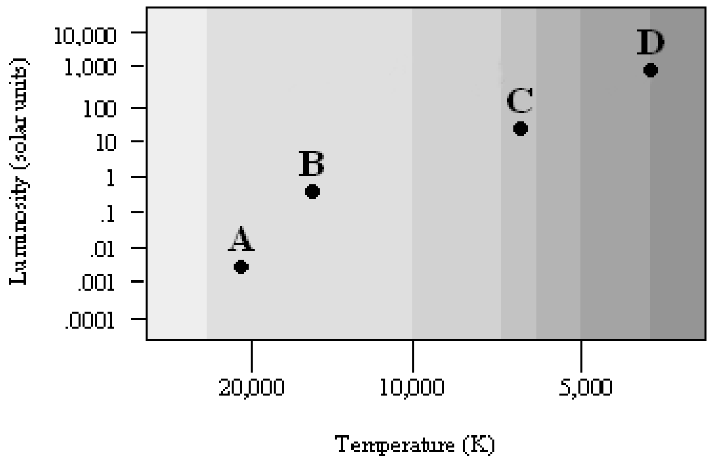
Carefully explain your reasoning for ranking this way:

____
____
____
____

Astronomy Ranking Task:
Luminosity of Stars

Exercise #4

Description: Consider the Hertzsprung-Russell (HR) diagram shown below which relates the luminosity (in solar units) to the temperature for four stars (A - D).



A. Ranking instructions: Rank the temperature of the stars (A – D) from hottest to coldest.

Ranking Order: Hottest 1 ____ 2 ____ 3 ____ 4 _____ Coldest

Or, all the stars have the same temperature. _____ (indicate with a check mark)

Carefully explain your reasoning for ranking this way:

____

____

____

____

B. Ranking instructions: Rank the luminosity of the stars (A – D) from greatest (brightest) to least (dimmest).

Ranking Order: Greatest 1 ____ 2 ____ 3 ____ 4 _____ Least

Or, all the stars have the same luminosity. _____ (indicate with a check mark)

Carefully explain your reasoning for ranking this way:

____
____
____
____

C. Ranking instructions: Rank the surface area of the stars (A – D) from largest to smallest.

Ranking Order: Largest 1 ____ 2 ____ 3 ____ 4 _____ Smallest

Or, all the stars have the same surface area. _____ (indicate with a check mark)

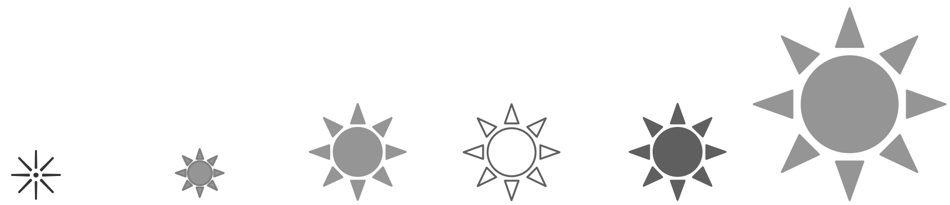
Carefully explain your reasoning for ranking this way:

____
____
____
____

Astronomy Ranking Task:
Luminosity of Stars

Exercise #5

Description: The temperature and surface area for six stars (A - F) are given in the table below. The temperature of each star is also indicated by a shade of gray such that the lighter the shade of gray, the higher the temperature of the star.



Star	A	B	C	D	E	F
Surface Area	1	1	2	2	2	4
Temperature	1000 K	2000 K	2000 K	3000 K	1000 K	2000 K

Ranking instructions: Rank the luminosity of the stars (A – F) from greatest (brightest) to least (dimmest).

Ranking Order: Greatest 1 ____ 2 ____ 3 ____ 4 _____ 5 _____ 6 _____ Least

Or, all the stars have the same luminosity. _____ (indicate with a check mark)

Carefully explain your reasoning for ranking this way:

____

____

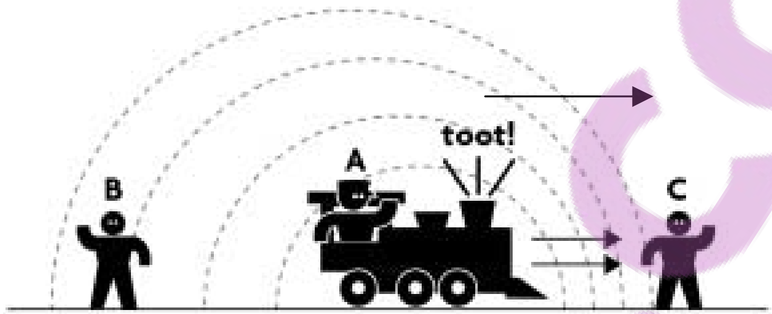
____

____

Astronomy Ranking Task:
Doppler Shift

Exercise #1

Description: The figure below shows a train traveling toward the right and sounding its horn.
Three persons are shown at locations A, B, and C. Assume that all three people can hear the train blowing its horn.



A. Ranking Instructions: Rank the pitch of the horn from highest pitch (or frequency) to lowest pitch (or frequency) as heard by each person (A – C)

Ranking Order: Highest 1_______ 2_______ 3_______ Lowest

Or, the pitch heard by each person would be the same. ______ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

B. Ranking Instructions: Rank the wavelength (from longest to shortest) of the sound of the horn as heard by each person (A – C).

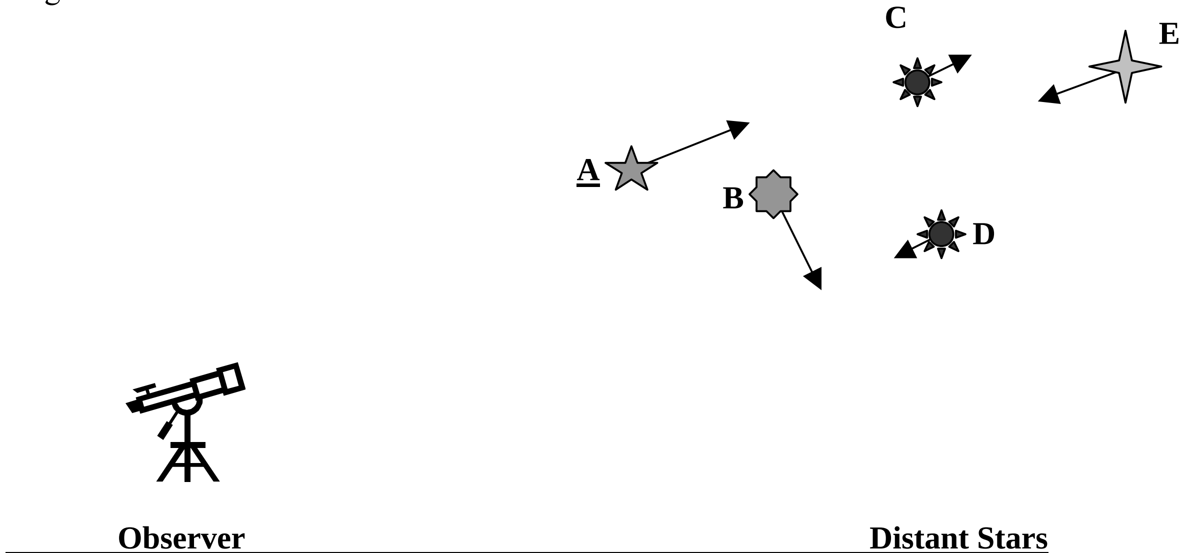
Ranking Order: Longest 1_______ 2_______ 3_______ Shortest Or, the wavelength heard is the same for each person.____ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

Astronomy Ranking Task:
Doppler Shift

Exercise #2

Description: The figure below shows the motion of five distant stars (A - E) relative to a stationary observer (telescope). The speed and direction of each star is indicated by the length and direction of the arrows shown.



Ranking Instructions: Rank the Doppler shift of the light observed from each star (A – E) from greatest "blueshift", through no shift, to greatest "redshift".

Ranking Order:
Greatest blueshift 1_____ 2_____ 3_____ 4 ____ 5 ____ Greatest redshift

Or, the Doppler shift for each star is the same. ______ (indicate with check mark).

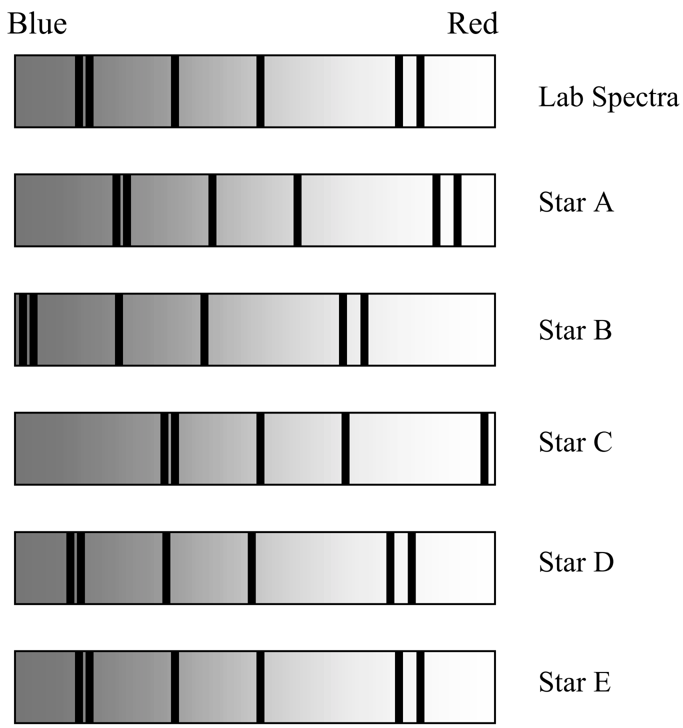
Carefully explain your reasoning for ranking this way:

____
____
____
____

Astronomy Ranking Task:
Doppler Shift

Exercise #3

Description: The first spectra shown below is of an element as it appears in a laboratory here on Earth. In addition, the spectra of five stars (A - E) as seen from Earth are shown. Assume that the left end of each spectrum corresponds to shorter wavelengths (blue light) and that the right end of each spectrum corresponds with longer wavelengths (red light).



A. Ranking instructions: Rank the size of the Doppler shift (from largest to smallest) for the light from each star (A – E).

Ranking Order: Largest 1 ____ 2 ____ 3 ____ 4 _____ 5 _____ Smallest

Or, Doppler shift of the light from the stars would all be the same. _____ (indicate with a check mark)

Carefully explain your reasoning for ranking this way:

____
____
____
____

B. Ranking instructions: Rank the speed of the stars (A – E) from moving fastest toward the Earth to moving fastest away from Earth.

Ranking Order:

Moving fastest toward 1 ____ 2 ____ 3 ____ 4 _____ 5 _____ Moving fastest away

Or all the stars have the same speed _______ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

Astronomy Ranking Task:
Doppler Shift

Exercise #4

Description: An important line in the absorption spectrum of stars occurs at a wavelength of 656nm for stars at rest. Imagine that you study five stars (A-E) from Earth and discover that this absorption line is observed at the wavelength shown in the table below for each of the five stars.

STAR	Observed Wavelength of Absorption line
A	**650 nm**
B	**663 nm**
C	**656 nm**
D	**657 nm**
E	**646 nm**

Ranking instructions: Based on the information in the table above, rank the speed of the stars (A – E) from fastest moving toward Earth to fastest moving away from Earth.

Ranking Order:

Fastest moving toward Earth 1 ____ 2 ____ 3 ____ 4 _____ 5 _____ Fastest moving away from Earth.

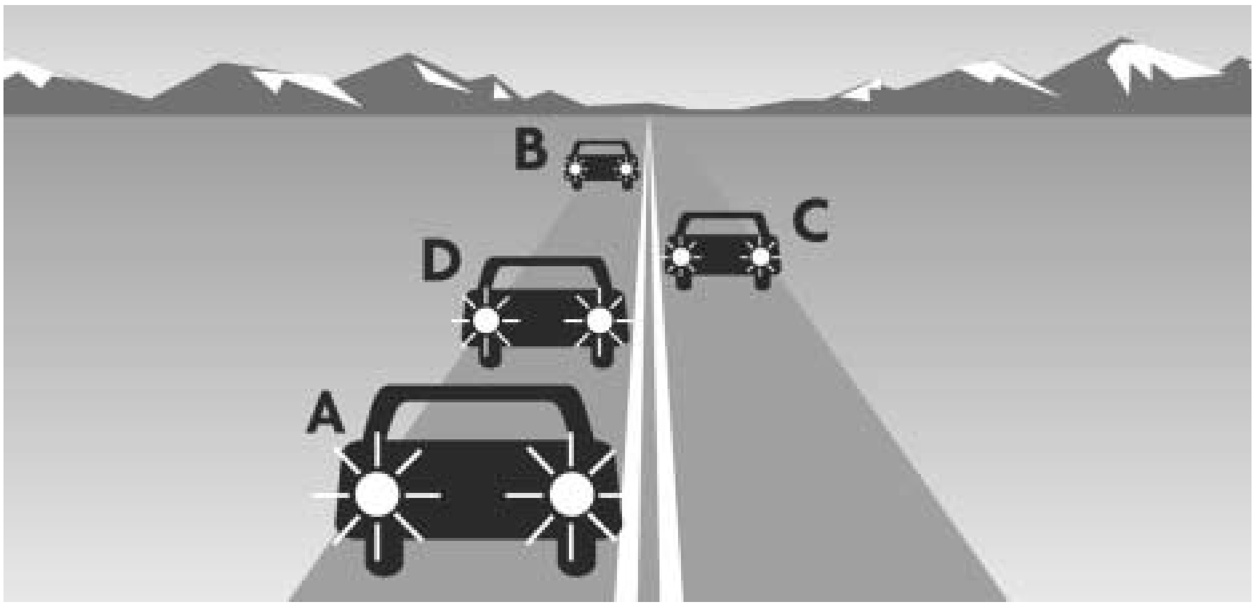
Or, he speeds of all the stars are the same. _______ (indicate with check mark).

Or,
Carefully explain your reasoning for ranking this way:
____
____
____
____

Astronomy Ranking Task:
Apparent and Absolute Magnitude

Exercise #1

Description: The figure below shows four identical cars (A - D) driving toward you at sunset with their headlights turned on. Each car is equipped with identical headlights.



A. Ranking Instructions: Rank the distance (from greatest to least) that each car is from you.

Ranking Order: Greatest 1 _______ 2 _______ 3 _______ 4 _______ Least

Or, the distance to each car is the same. ______ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____
____
____
____

Continued on next page.

B. Ranking Instructions: Rank the apparent brightness (from greatest to least) of each car's headlights.

Ranking Order: Greatest 1 _______ 2 _______ 3 _______ 4 _______ Least

Or, the apparent brightness of each car's headlights is the same. ______ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____
____
____
____

C. Ranking Instructions: Rank the actual (intrinsic) brightness (from greatest to least) of each car's headlights.

Ranking Order: Greatest 1 _______ 2 _______ 3 _______ 4 _______ Least

Or, the actual brightness of each car's headlights is the same. ______ (indicate with check mark).

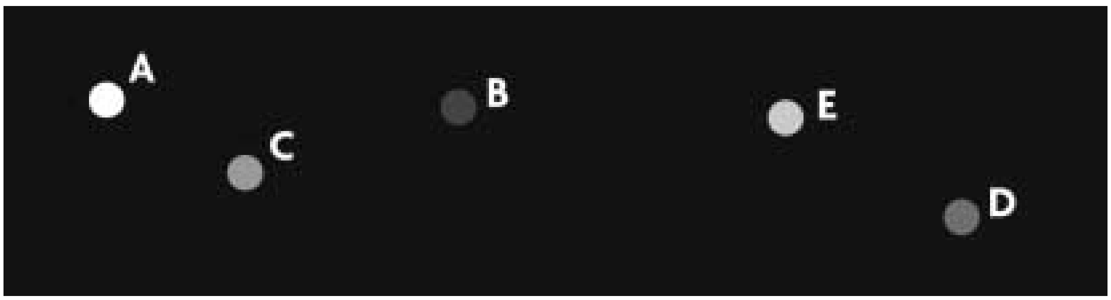
Carefully explain your reasoning for ranking this way:

____
____
____
____

Astronomy Ranking Task: Apparent and Absolute Magnitude

Exercise #2

Description: The figure below shows five stars (A - E) as they appear in the night sky from Earth. A darker shading is used to indicate the appearance of a dimmer star. Note that star B is shown the darkest, followed by D, C, E, and A.



A. Ranking Instructions: Rank the brightness (from greatest to least) of each star as it appears in the night sky.

Ranking Order: Greatest 1 _______ 2 _______ 3 _______ 4 _______ 5 _______ Least

Or, the brightness of each star would appear the same. ______ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____

____

____

____

B. Ranking Instructions: Rank the numerical value (from greatest to least) for each star's apparent magnitude.

Ranking Order: Greatest 1 _______ 2 _______ 3 _______ 4 _______ 5 _______ Least

Or, the apparent magnitude number would be the same for each star. ______ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____

C. Ranking Instructions: Rank the distance (from greatest to least) of each star from Earth.

Ranking Order: Greatest 1 _______ 2 _______ 3 _______ 4 _______ 5 _______ Least

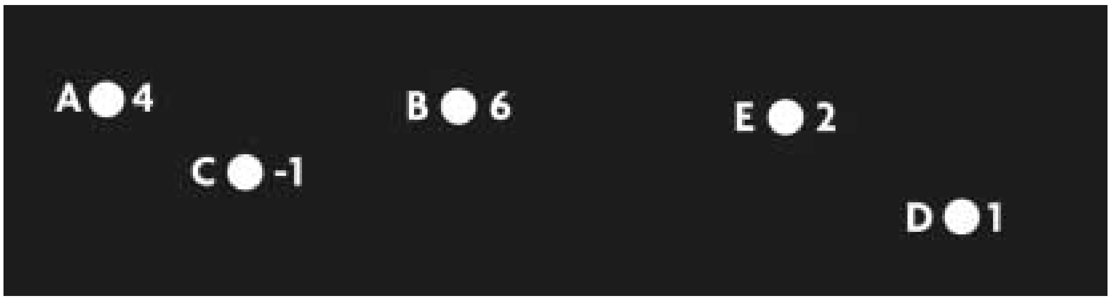
Or, the distance from Earth cannot be determined from this information. ______ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

Astronomy Ranking Task:
Apparent and Absolute Magnitude

Exercise #3

Description: The figure below shows five stars (A - E) as they appear in the night sky from Earth. The absolute magnitude number is also provided to the right of each star.



A. Ranking Instructions: Rank the brightness (from greatest to least) of each star (A – E) as it appears in the night sky.

Ranking Order: Greatest 1 _______ 2 _______ 3 _______ 4 _______ 5 _______ Least

Or, the brightness of each star appears the same. ______ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____
____
____
____

B. Ranking Instructions: Rank the total amount of energy (from greatest to least) given off by each star (A – E).

Ranking Order: Greatest 1 _____ 2 _____ 3 _____ 4 _____ 5 _____ Least

Or, the total amount of energy given off by each star would be the same. ______ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____
____
____
____

C. Ranking Instructions: Rank the actual brightness or luminosity (from greatest to least) of each star (A – E).

Ranking Order: Greatest 1 _____ 2 ______ 3 ______ 4 ______ 5 ______ Least

Or, the actual brightness/luminosity of each star is the same. ______ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____
____
____
____

D. Ranking Instructions: Rank the absolute magnitude number (from greatest to least) of each star (A – E).

Ranking Order: Greatest 1 ______ 2 ______ 3 ______ 4 ______ 5 ______ Least

Or, the absolute magnitude number of each star would be the same. ______ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____
____
____
____

E. Ranking Instructions: Rank the distance (from farthest to closest) of each star (A – E) from Earth.

Ranking Order: Farthest 1 ______ 2 ______ 3 ______ 4 ______ 5 ______ Closest

Or, the distance from Earth to each star is the same. ______ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____
____
____
____

Astronomy Ranking Task:
Apparent and Absolute Magnitude

Exercise #4

Description: The table below provides an incomplete list of the magnitude and distance (from Earth) for five stars (A - E).

Star Name	Apparent Magnitude	Absolute Magnitude	Distance from Earth (parsecs)
A	-1	3	
B	5	1	
C		0	10
D	1		10,000
E	3	3	

A. **Ranking Instructions:** Rank the brightness (from greatest to least) of each star (A – E) as it would appear in the night sky. Note that it is not necessary to complete the table before making your rankings.

Ranking Order: Greatest 1 _____ 2 _____ 3 _____ 4 _____ 5 _____ Least

Or, the brightness of each star would appear the same from Earth ___ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____
____
____
____

B. **Ranking Instructions:** Rank the apparent magnitude number (from greatest to least) of each star (A – E).

Ranking Order: Greatest 1 _____ 2 _____ 3 _____ 4 _____ 5 _____ Least

Or, the apparent magnitude number of each star is the same. ___ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____
____
____
____

C. **Ranking Instructions:** Rank the actual brightness or luminosity (from greatest to least) of each star (A – E).

Ranking Order: Greatest 1 _____ 2 _____ 3 _____ 4 _____ 5 _____ Least

Or, the actual brightness of each star is the same. ______ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____
____
____

D. **Ranking Instructions:** Rank the absolute magnitude number (from greatest to least) of each star (A – E).

Ranking Order: Greatest 1 _____ 2 _____ 3 _____ 4 _____ 5 _____ Least

Or, the absolute magnitude number of each star would be the same. ______ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____
____
____

E. **Ranking Instructions:** Rank the distance (from farthest to closest) to each star (A – E) from Earth.

Ranking Order: Farthest 1 _____ 2 _____ 3 _____ 4 _____ 5 _____ Closest

Or, the distance to each star from Earth would be the same. ______ (indicate with check mark).

Carefully explain your reasoning for ranking this way:

____
____
____

Appendix B

Pretest

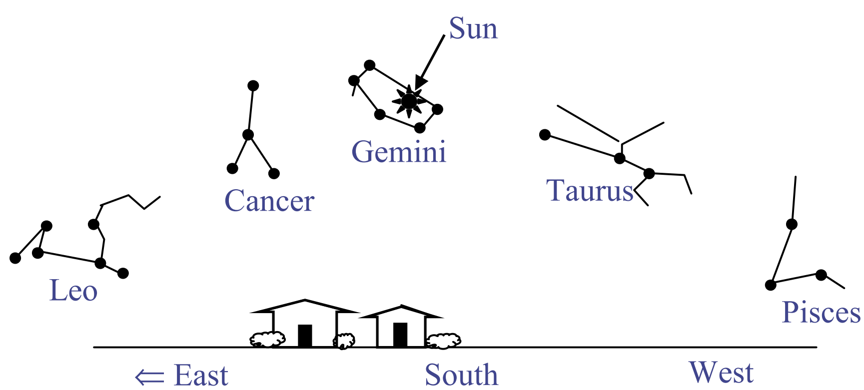
Pre-Course Assessment
of Astronomy Knowledge

Name: ___________________________________

NOTE: As discussed in the Participant Informed Consent Form, individual student names and scores are not retained in project records, and will not be released in any published results. We believe that participating in these exercises may help you in regular class tests. However, all tests relating specifically to our study are purely for educational research, and will not affect student course grades in any way. Just do your best!

1. If you could see stars during the day, this is what the sky would look like at noon on a given day. The Sun is near the stars of the constellation Gemini. Near which constellation would you expect the Sun to appear at sunrise?

a. Leo
b. Cancer
c. Gemini
d. Taurus
e. Pisces

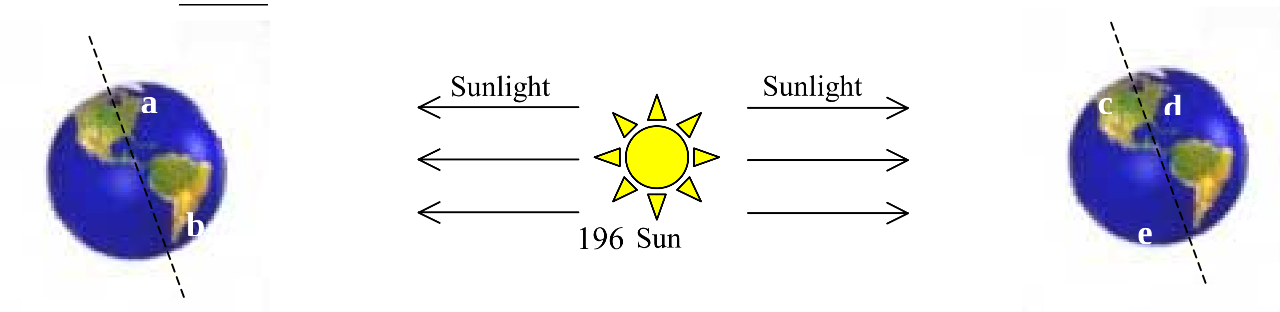


2. Which constellation will be highest in the sky 6 hours after the time shown in the drawing above?

a. Leo
b. Cancer
c. Gemini
d. Taurus
e. Pisces

3. Looking at the images below, which letter (a-e) best represents winter in the Northern Hemisphere?

Answer: ______



Note: this drawing is not to scale.

4. Which of the following best describes why the Moon goes through phases?

   a. Earth's shadow falls on different parts of the Moon at different times.
   b. The Moon is somewhat flattened and disk-like, and appears more or less round depending on the precise angle from which we see it.
   c. We see only part of the lit-up face of the Moon depending on its position relative to Earth and the Sun.
   d. The sunlight reflected from Earth lights up the Moon but is less effective when the Moon is lower in the sky than when it is higher in the sky.
   e. Earth's clouds cover potions of the Moon at various times resulting in the changing phases that we see.

5. The factor(s) that most affect the gravitational force between two objects are

   a. size and distance
   b. mass and size
   c. density and distance
   d. mass and distance
   e. density and size

6. Kepler's second law says "a line joining a planet and the Sun sweeps out equal areas in equal amounts of time." Which of the following statements means nearly the same thing?

   a. Planets move fastest when they are moving toward the Sun.
   b. Planets move equal distances throughout their orbit of the Sun.
   c. Planets move slowest when they are moving away from the Sun.
   d. Planets move farther in a given time when they are closer to the Sun.
   e. Planets move the same speed at all points during their orbit of the Sun.

7. You observe a very large and very luminous star in the constellation Orion. On the same night you observe another star in Orion (about the same distance away) that is known to be much smaller in size but has the same luminosity. Which star has the higher temperature?

   a. The smaller star
   b. The larger star
   c. They have the same temperature.
   d. There is insufficient information to determine this.

8. According to the Doppler effect:

   a. Light from an object that is far away from Earth is shifted to longer wavelengths (red light).

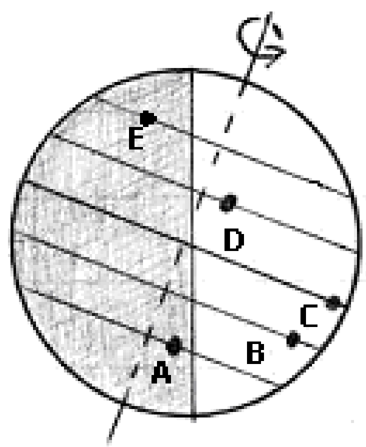
b. Light from an object that is close to Earth is shifted to longer wavelengths (red light).
c. Light from an object that is moving towards Earth is shifted to longer wavelengths (red light).
d. Light from an object that is moving away from Earth is shifted to longer wavelengths (red light).
e. Light from an object that is moving away from Earth is shifted to shorter wavelengths (blue light).

9. Star A appears brighter than Star B, but Star A actually gives off less light than Star B. The apparent magnitude for Star A is m = 0 and the absolute magnitude is M = 1. Which of the following are the best possible values for the apparent and absolute magnitudes of Star B?

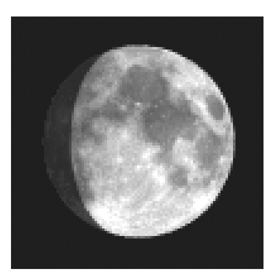
a. m = 1 and M = 1
b. m = -1 and M = 1
c. m = 1 and M = -1
d. m = -1 and M = -1

10. In the figure of Earth below, the location (A through E) that receives the largest number of daylight hours per day is…

a. Location A
b. Location B
c. Location C
d. Location D
e. Location E



11. What time is it when the moon phase shown at right first begins to rise above the horizon?

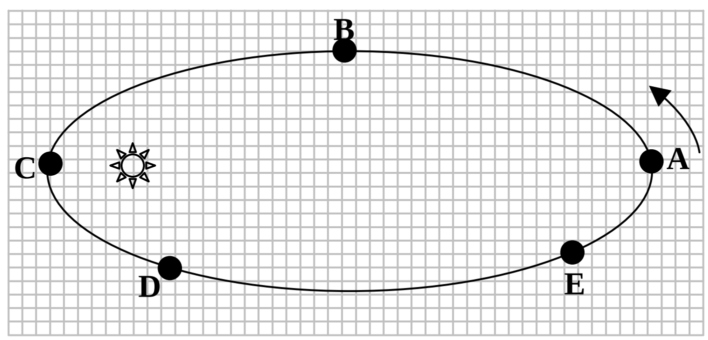


a. Mid-morning
b. Noon
c. Mid-afternoon
d. Midnight
e. Dawn

12. How far away from Earth can an object be and still feel the gravitational force of the Earth?

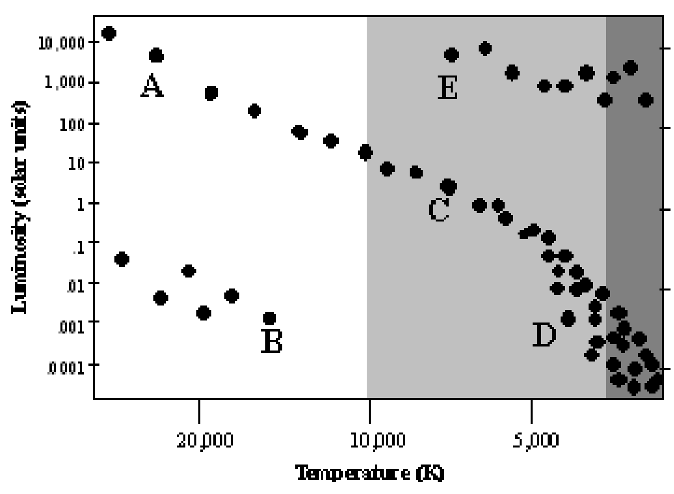
a. just above Earth's atmosphere
b) about half-way to the Moon
c) just beyond the Moon
d) the edge of the Solar system
e) infinity

13. The planet shown in the drawing at right obeys Kepler's Second Law. Each lettered position represents the location for the planet on a particular day. On which day (which lettered position) would the planet move the farthest during that day?



a. A
b. B
c. C
d. D
e. E

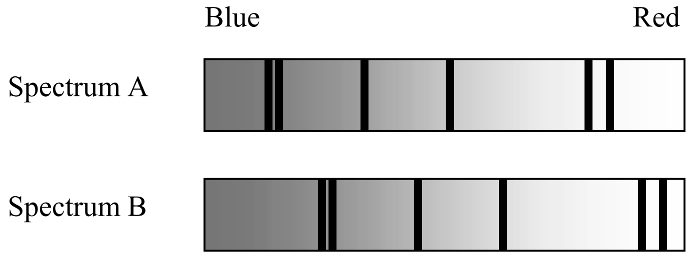
14. Consider the graph at right, which shows the brightness of a star versus its temperature. Notice that five stars labeled A through E are identified on the graph.



Which of the stars (A – E) is the largest (diameter)?

a. A
b. B
c. C
d. D
e. E

15. You observe two spectra (shown below) that are redshifted relative to that of a stationary source of light. Which of the following statements best describes how the sources of light that produced the two spectra were moving? *Assume that the left end of each spectrum corresponds to shorter wavelengths (blue light) and that the right end of each spectrum corresponds with longer wavelengths (red light).*

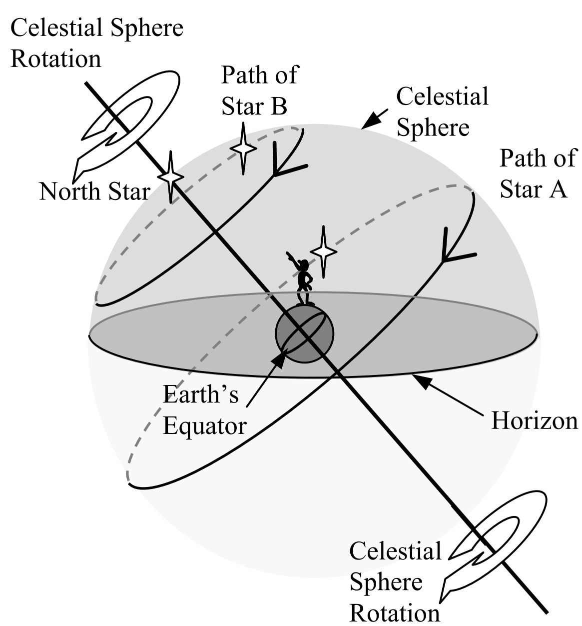


a. Source A is moving away from Earth faster than source B.
b. Source B is moving toward Earth faster than source A.
c. Source B is moving away from Earth faster than source A.
d. Both sources are moving with the same speed.
e. It is impossible to tell from looking at these spectra.

16. . The star Antares is located approximately 185 parsecs away from Earth. Its apparent magnitude is +1.1. Which of the following is most likely its absolute magnitude?

a. +183.9
b. +4.9
c. +1.8
d. +0.5
e. –5.4

17. Use the diagram at right to answer the question below. In this diagram the motions of Stars A and B are shown as they appear to move across the sky. Imagine that Stars A and B are bright enough to be visible even when the Sun is also in the sky. Also imagine that you are the



observer shown on Earth in the northern hemisphere.

Question: Which of the stars would you be able to observe the greatest number of hours per day?

a. Star A
b. Star B
c. Both stars are visible the same number of hours per day.

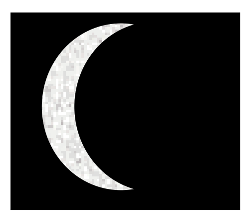
18. Which of the following best describes the cause for the seasons here on Earth?

a. The distance between Earth and the Sun changes during the year.
b. More sunlight reaches Earth during some times of the year than others.
c. Earth's rotational axis is tilted with respect to the plane of Earth's orbit around the Sun.
d. The Sun gives off different amounts of sunlight during different times of the year.
e. Some times of the year Earth orbits the Sun more slowly than other times of the year.

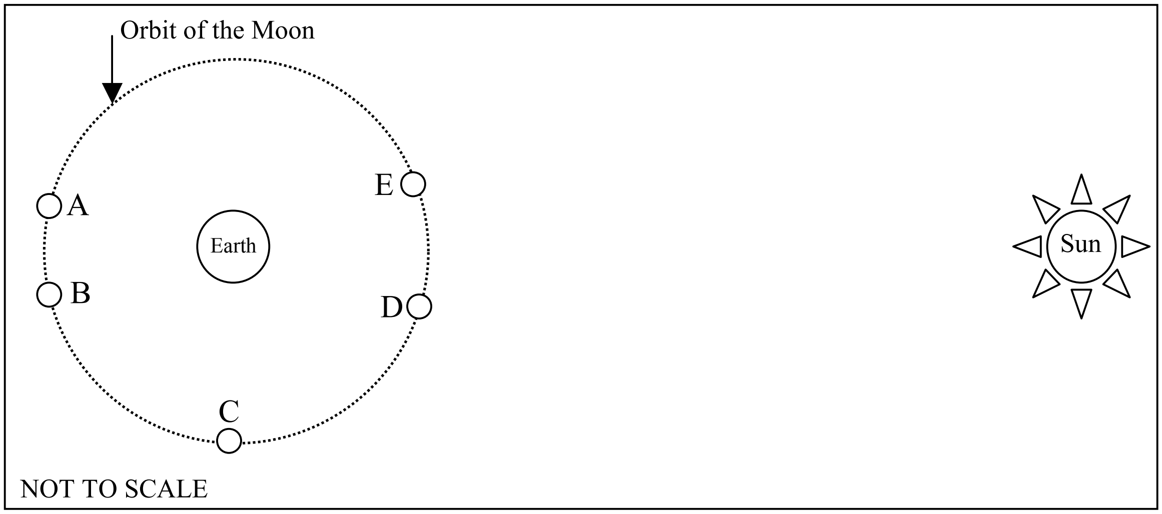
19. Which of the following best describes what would happen to the orbital period of a planet if the mass of the planet were doubled but it stayed at the same orbital distance?

a. It would orbit half as fast.
b. It would orbit less than half as fast.
c. It would orbit twice as fast.
d. It would orbit more than twice as fast.
e. It would orbit with the same speed.

20. The diagram below shows the Earth and Sun as well as five different possible positions (A – E) of the Moon. Which position of the Moon best corresponds with the phase of the Moon shown in the figure at right?



Answer: ________



21. The gravitational force between two bodies becomes zero

a. when another body lies in-between the two original bodies
b. when the distance between them becomes extremely large
c. at a location halfway between the two bodies
d. when they are balanced in a stable orbit around one another
e. when the two objects are not moving.

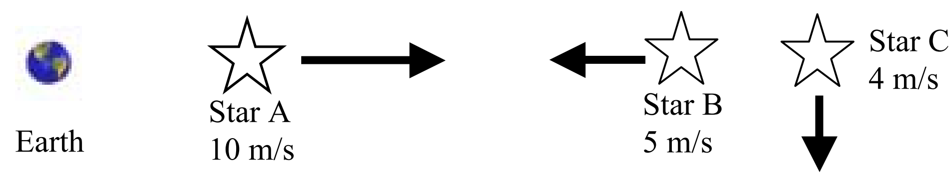
22. Jelly Star and Doodle Star are both the same size, but Jelly Star is much more luminous than Doodle. As a result, the temperature of Jelly must be

a. cooler than Doodle
b. hotter than Doodle
c. the same temp as Doodle
d. there is insufficient information to answer this question.

23. In order to double the gravitational force between two objects, you could

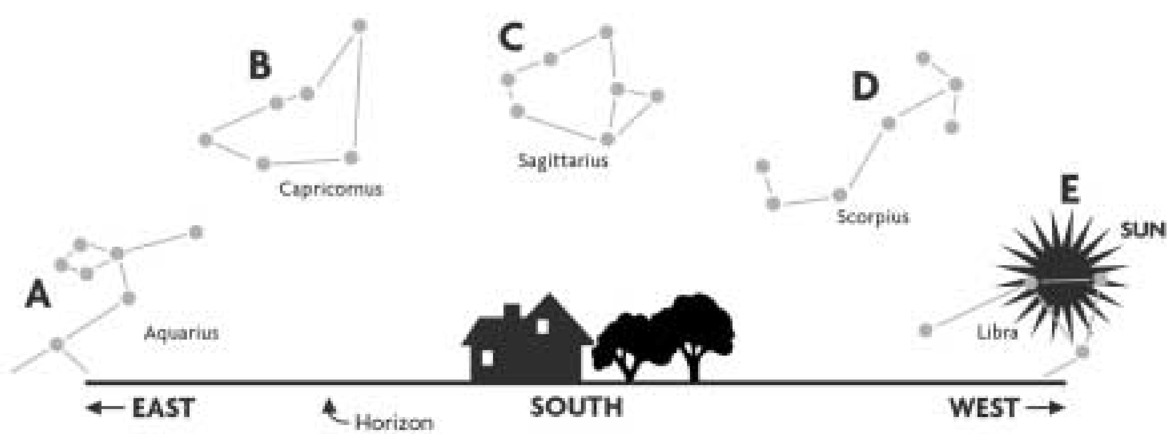
a. move them twice as close together
b. double the mass of only one of the objects
c. double the size of either object.
d. double the total mass of the two objects
e. move them twice as far apart

24. The picture below shows the motion of three stars (A – C) relative to the stationary Earth (not drawn to scale). Which of the following best describes how the light from the three stars would appear?



a. Star A - redshifted, Star B - redshifted, and Star C - redshifted
b. Star A - redshifted, Star B - blueshifted, and Star C - redshifted
c. Star A - No Doppler shift, Star B - redshifted, and Star C – No Doppler shift
d. Star A - blueshifted, Star B - blueshifted, and Star C - No Doppler shift
e. Star A - redshifted, Star B - blueshifted, and Star C - No Doppler shift

25. If you could see stars during the day, this is what the sky would look like at sunset on a given day. The Sun is near the stars of the constellation Libra (labeled constellation E). Also shown are other constellations (named and labeled A, B, C, and D) that will be visible above the horizon at this time when facing south.



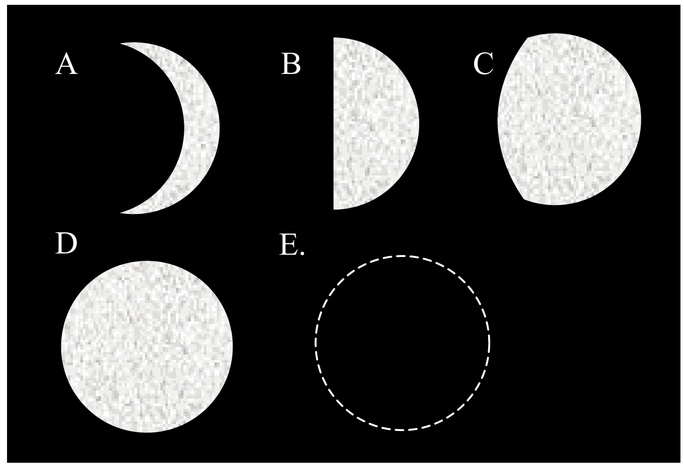
Question: Which of the following rankings would best describe the order that these constellations (A – E) would appear in the sky earlier today?

a. First to rise: C, B, D, E, A was last to rise.
b. First to rise: E, D, C, B, A was last to rise.
c. First to rise: A, B, C, D, E was last to rise.

d. First to rise: A, E, D, B, C was last to rise.
e. all constellations are above the horizon at the same time.

26. Imagine that you look to the eastern horizon as the Moon first rises and discover that it is in the new moon phase. Later when the moon reaches its highest position in the sky, which of the moon phases shown at right will the Moon look like?

Answer : _______



27. Imagine a new planet in our solar system is located at an average distance of 3 AU from the Sun. Which of the following best approximates the orbital period of this planet?

a. 3 years
b. 5 years
c. 9 years
d. 18 years
e. 27 years

28. Vega has an apparent magnitude of +0.0 and an absolute magnitude of +0.6. If it were moved twice as close from Earth as it is now, which following would occur?

a. Absolute magnitude number would increase.
b. Apparent magnitude number would increase.
c. Apparent magnitude number would decrease.
d. Apparent magnitude number would stay the same.
e. Absolute magnitude number would decrease.

Appendix C

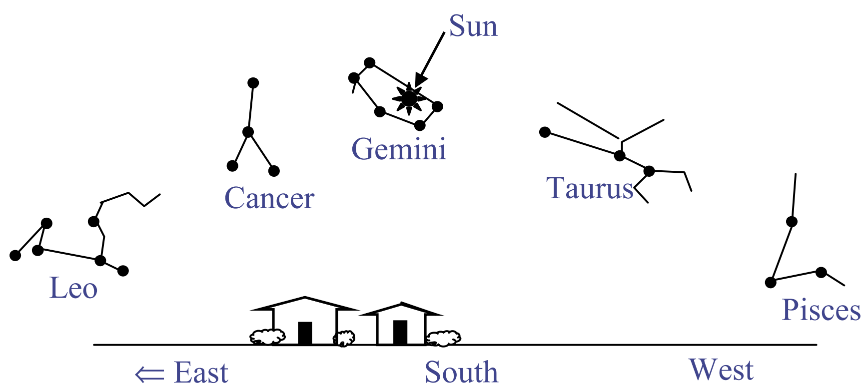
Post-Traditional Instruction Tests & Qualitative Questionnaire

Name: ___________________
ID: ______________________ Gender: Male _____ Female ____

Post-Lecture Assessment Test:
Motion of the Sky

1. If you could see stars during the day, this is what the sky would look like at noon on a given day. The Sun is near the stars of the constellation Gemini. Near which constellation would you expect the Sun to appear at sunrise?

a. Leo
f. Cancer
g. Gemini
h. Taurus
i. Pisces

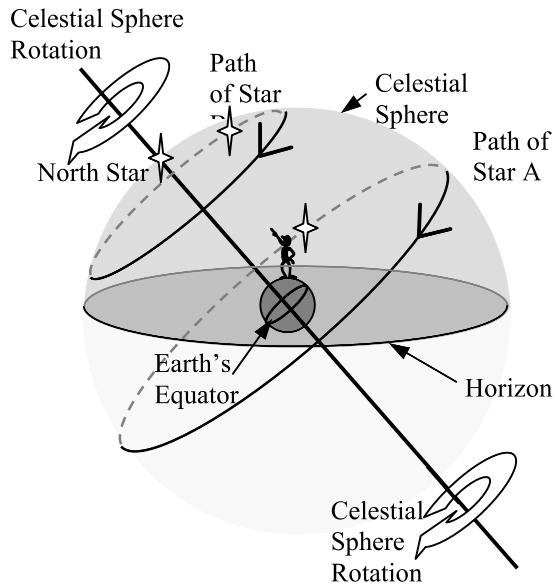


2. Which constellation will be highest in the sky 6 hours <u>after</u> the time shown in the drawing above?

e. Leo
f. Cancer
g. Gemini
h. Taurus
i. Pisces

<u>Turn Over – more questions on back of page</u>

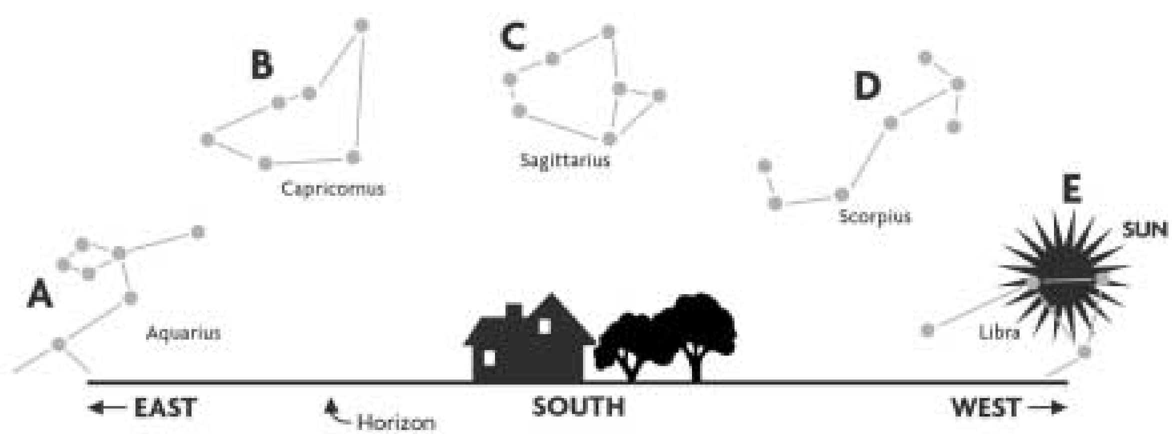
3. Use the diagram at right to answer the question below. In this diagram the motions of Stars A and B are shown as they appear to move across the sky. Imagine that Stars A and B are bright enough to be visible even when the Sun is also in the sky. Also imagine that you are the observer shown on Earth in the northern hemisphere.



Question: Which of the stars would you be able to observe the greatest number of hours per day?

d. Star A
e. Star B
f. Both stars are visible the same number of hours per day.

4. If you could see stars during the day, this is what the sky would look like at sunset on a given day. The Sun is near the stars of the constellation Libra (labeled constellation E). Also shown are other constellations (named and labeled A, B, C, and D) that will be visible above the horizon at this time when facing south.



Question: Which of the following rankings would best describe the order that these constellations (A – E) would appear in the sky earlier today?

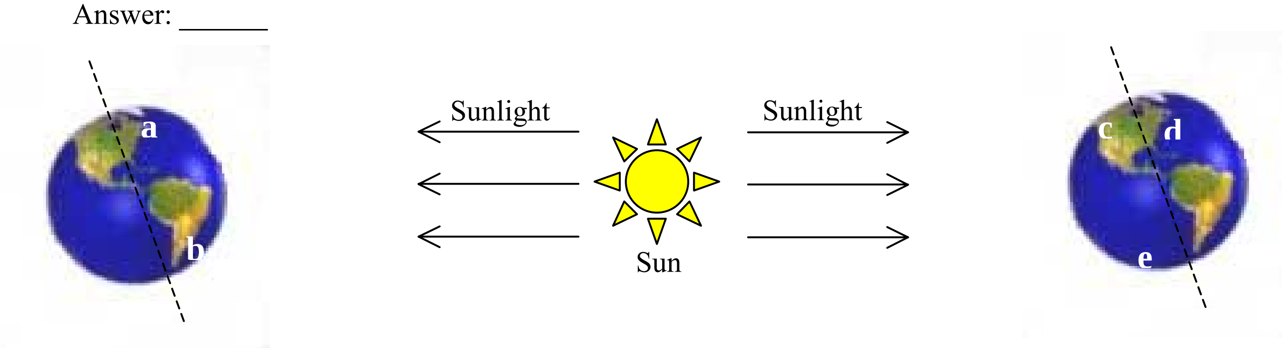
a. First to rise: C, B, D, E, A was last to rise.
b. First to rise: E, D, C, B, A was last to rise.
c. First to rise: A, B, C, D, E was last to rise.
d. First to rise: A, E, D, B, C was last to rise.
e. all constellations are above the horizon at the same time.

Name: ___________________
ID: ______________________ Gender: Male ______ Female ______

Post-Lecture Assessment Test:
Seasons

2. Looking at the images below, which letter (a-e) best represents winter in the Northern Hemisphere?

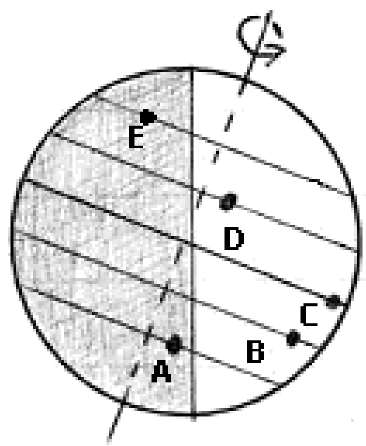
   Answer: ______



Note: this drawing is not to scale.

2. In the figure of Earth below, the location (A through E) that receives the largest number of daylight hours per day is…

   a. Location A
   b. Location B
   c. Location C
   d. Location D
   e. Location E



3. Which of the following best describes the cause for the seasons here on Earth?
   a. The distance between Earth and the Sun changes during the year.
   b. More sunlight reaches Earth during some times of the year than others.
   c. Earth's rotational axis is tilted with respect to the plane of Earth's orbit around the Sun.
   d. The Sun gives off different amounts of sunlight during different times of the year.
   e. Some times of the year Earth orbits the Sun more slowly than other times of the year.

Name: __________________
ID: ______________________ Gender: Male ____ Female _____

Post-Lecture Assessment Test:
Lunar Phases

3. Which of the following best describes why the Moon goes through phases?

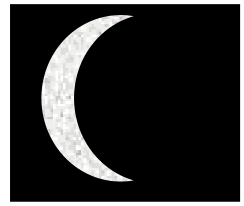
    e. Earth's shadow falls on different parts of the Moon at different times.
    f. The Moon is somewhat flattened and disk-like, and appears more or less round depending on the precise angle from which we see it.
    g. We see only part of the lit-up face of the Moon depending on its position relative to Earth and the Sun.
    h. The sunlight reflected from Earth lights up the Moon but is less effective when the Moon is lower in the sky than when it is higher in the sky.
    e. Earth’s clouds cover potions of the Moon at various times resulting in the changing phases that we see.

2. What time is it when the moon phase shown at right first begins to rise above the horizon?

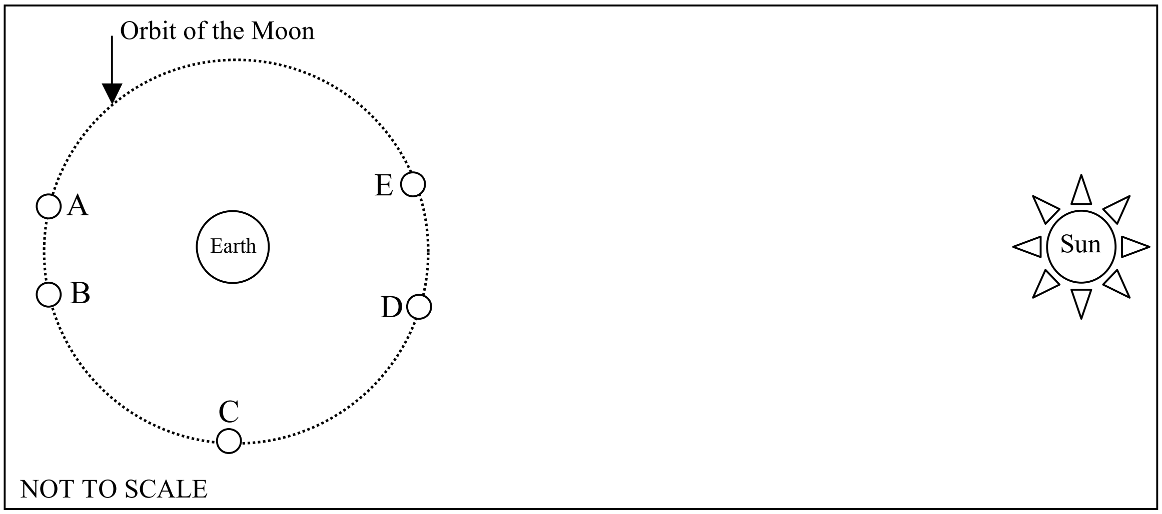
a. Mid-morning
b. Noon
c. Mid-afternoon
d. Midnight
e. Dawn

Turn over – more questions on back of page

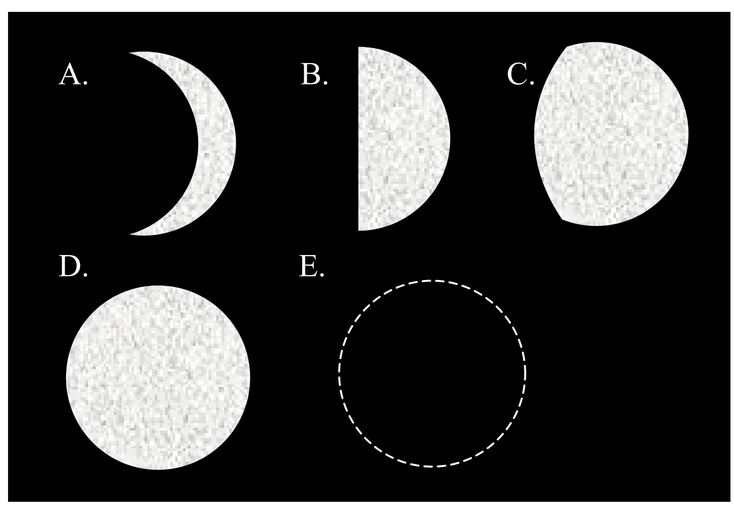
3. The diagram below shows the Earth and Sun as well as five different possible positions (A – E) of the Moon. Which position of the Moon best corresponds with the phase of the Moon shown in the figure at right?



Answer: ________



4. You look to the eastern horizon as the Moon first rises and discover that it is in the new moon phase. Later when the moon reaches its highest position in the sky, which of the moon phases shown at right will the Moon look like?



Answer : _______

Name: __________________
ID: _____________________ Gender: Male ______ Female ______

Post Lecture Qualitative Questionnaire:
Lunar Phases

1. Provide a detailed description of why you think the Moon goes through phases?

2. Would the phase of the Moon shown at right ever be above the horizon sometime during the daytime (between 6am and 6pm)? Explain why or why not.

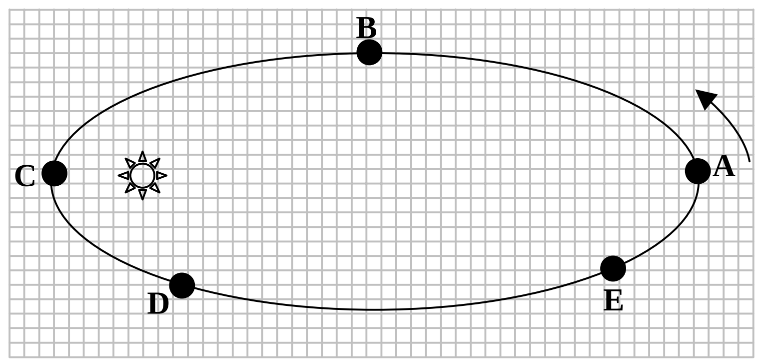
Name: __________________
ID: _____________________ Gender: Male ______ Female ______

Post-Lecture Assessment Test:
Kepler's Laws

2. Kepler's second law says "a line joining a planet and the Sun sweeps out equal areas in equal amounts of time." Which of the following statements means nearly the same thing?

   a. Planets move fastest when they are moving toward the Sun.
   b. Planets move equal distances throughout their orbit of the Sun.
   c. Planets move slowest when they are moving away from the Sun.
   d. Planets move farther in a given time when they are closer to the Sun.
   e. Planets move the same speed at all points during their orbit of the Sun.

2. The planet shown in the drawing at right obeys Kepler's Second Law. Each lettered position represents the location for the planet on a particular day. On which day (which lettered position) would the planet move the farthest during that day?



   a. A
   b. B
   c. C
   d. D
   e. E

4. Which of the following best describes what would happen to the orbital period of a planet if the mass of the planet were doubled but it stayed at the same orbital distance?

   a. It would orbit half as fast.
   b. It would orbit less than half as fast.
   c. It would orbit twice as fast.
   d. It would orbit more than twice as fast.
   e. It would orbit with the same speed.

4: Imagine a new planet in our solar system is located at an average distance of 3 AU from the Sun. Which of the following best approximates the orbital period of this planet?

a. 3 years
b. 5 years
c. 9 years
d. 18 years
e. 27 years

Name: __________________
ID: ______________________   Gender: Male ______ Female ______

Post-Lecture Assessment Test:
Gravity

Name: ________________________________

1. The factor(s) that most affect the gravitational force between two objects are

   a. size and distance
   b. mass and size
   c. density and distance
   d. mass and distance
   e. density and size

2. How far away from Earth can an object be and still feel the gravitational force of the Earth?

   a. just above Earth's atmosphere
   b) about half-way to the Moon
   c) just beyond the Moon
   d) the edge of the Solar system
   e) infinity

3. The gravitational force between two bodies becomes zero

   a. when another body lies in-between the two original bodies
   b. when the distance between them becomes extremely large
   c. at a location halfway between the two bodies
   d. when they are balanced in a stable orbit around one another
   e. when the two objects are not moving.

4. In order to double the gravitational force between two objects, you could

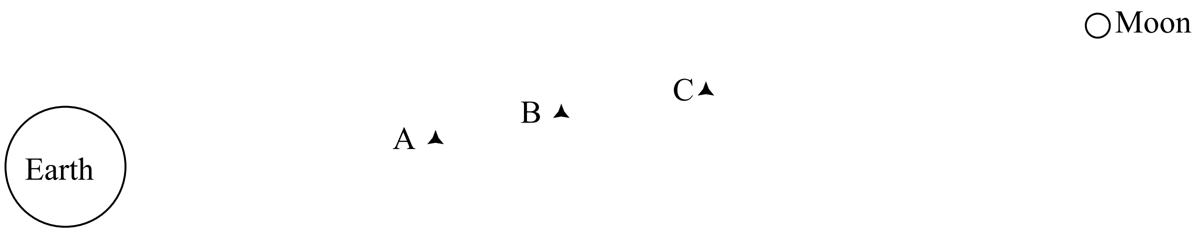
   a. move them twice as close together
   b. double the mass of only one of the objects
   c. double the size of either object.
   d. double the total mass of the two objects

e. move them twice as far apart

Name: ___________________
ID: ______________________ Gender: Male ______ Female ______

Post-Lecture Qualitative Questionnaire:
Gravity

1. In the picture below the Earth-Moon system is shown (not to scale) along with three possible positions (A - C) for a spacecraft traveling from Earth to the Moon. Note that position B is exactly halfway between Earth and the Moon.



At which of the lettered positions (A - C), if any, could the net (or total) gravitational force of the spacecraft by both Earth and the Moon be zero? Explain your reasoning.

2. How could you make the gravitational force between two objects become zero? Explain your reasoning.

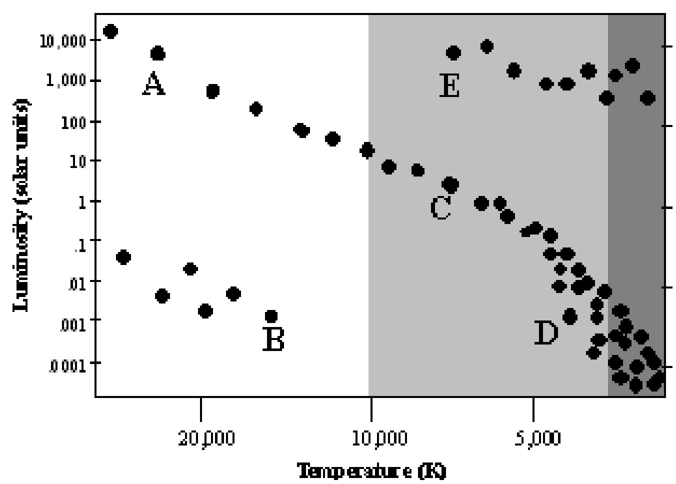
Name: __________________
ID: _____________________ Gender: Male ______ Female ______

Post-Lecture Assessment Test:
Luminosity of Stars

1. You observe a very large and very luminous star in the constellation Orion. On the same night you observe another star in Orion (about the same distance away) that is known to be much smaller in size but has the same luminosity. Which star has the higher temperature?

a. The smaller star
b. The larger star
c. They have the same temperature.
d. There is insufficient information to determine this.

2. Consider the graph at right, which shows the brightness of a star versus its temperature. Notice that five stars labeled A through E are identified on the graph.



Which of the stars (A – E) is the largest (diameter)?

a. A
b. B
c. C
d. D
e. E

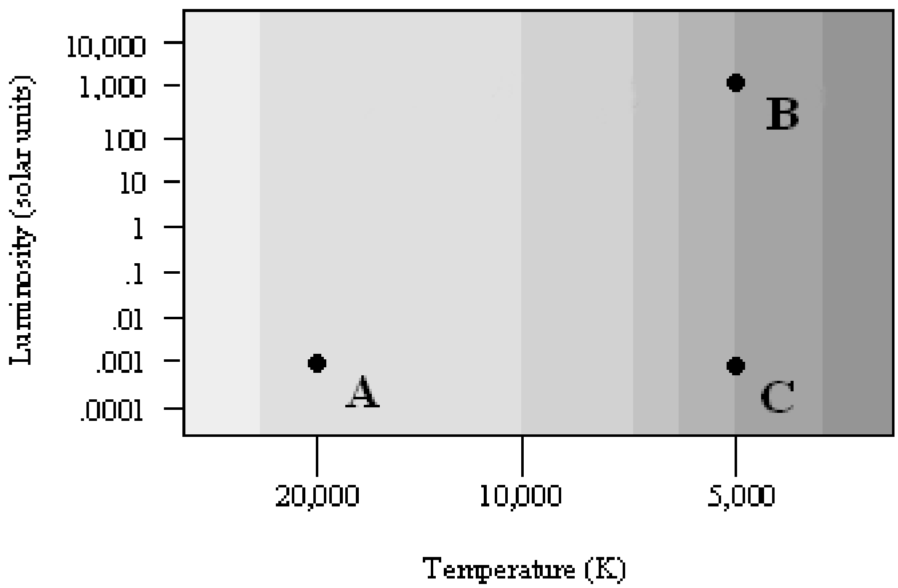
3. Jelly Star and Doodle Star are both the same size, but Jelly Star is much more luminous than Doodle. As a result, the temperature of Jelly must be

a. cooler than Doodle
e. hotter than Doodle
f. the same temp as Doodle
g. there is insufficient information to answer this question.

Name: ___________________
ID: ______________________ Gender: Male ______ Female ______

Post-Lecture Qualitative Questionnaire:
Luminosity of Stars

1. Consider the H-R diagram shown below, and the three stars (A – C) indicated on the diagram.



Question: Which of these stars is the smallest? Explain your reasoning.

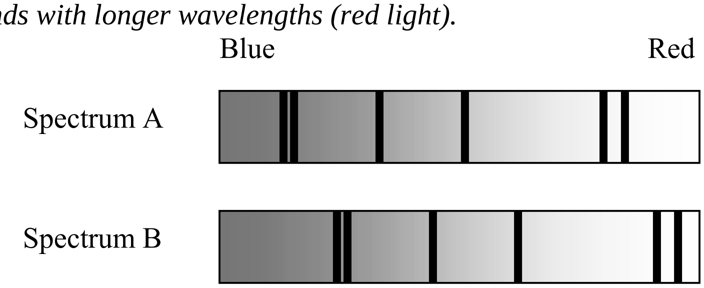
Name: __________________
ID: _____________________ Gender: Male ______ Female ______

Post-Lecture Assessment Test:
Doppler Shift

1. According to the Doppler effect:

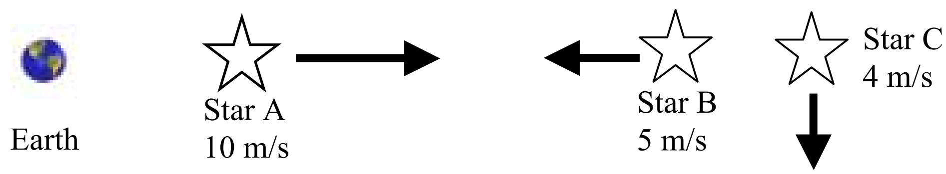
f. Light from an object that is far away from Earth is shifted to longer wavelengths (red light).
g. Light from an object that is close to Earth is shifted to longer wavelengths (red light).
h. Light from an object that is moving towards Earth is shifted to longer wavelengths (red light).
i. Light from an object that is moving away from Earth is shifted to longer wavelengths (red light).
j. Light from an object that is moving away from Earth is shifted to shorter wavelengths (blue light).

2. You observe two spectra (shown below) that are red-shifted relative to that of a stationary source of light. Which of the following statements best describes how the sources of light that produced the two spectra were moving? *Assume that the left end of each spectrum corresponds to shorter wavelengths (blue light) and that the right end of each spectrum corresponds with longer wavelengths (red light).*



a. Source A is moving away from Earth faster than source B.
b. Source B is moving toward Earth faster than source A.
c. Source B is moving away from Earth faster than source A.
f. Both sources are moving with the same speed.
g. It is impossible to tell from looking at these spectra.

3. The picture below shows the motion of three stars (A – C) relative to the stationary Earth (not drawn to scale). Which of the following best describes how the light from the three stars would appear?



f. Star A - redshifted, Star B - redshifted, and Star C - redshifted
g. Star A - redshifted, Star B - blueshifted, and Star C - redshifted
h. Star A - No Doppler shift, Star B - redshifted, and Star C – No Doppler shift
i. Star A - blueshifted, Star B - blueshifted, and Star C - No Doppler shift
j. Star A - redshifted, Star B - blueshifted, and Star C - No Doppler shift

Name: ________________
ID: ____________________ Gender: Male ______ Female ______

Post-Lecture Assessment Test:
Magnitude-Distance

1. Star A appears brighter than Star B, but Star A actually gives off less light than Star B. The apparent magnitude for Star A is m = 0 and the absolute magnitude is M = 1. Which of the following are the best possible values for the apparent and absolute magnitudes of Star B?

   b. m = 1 and M = 1
   c. m = -1 and M = 1
   d. m = 1 and M = -1
   e. m = -1 and M = -1

2. The star Antares is located approximately 185 parsecs away from Earth. Its apparent magnitude is +1.1. Which of the following is most likely its absolute magnitude?

   a. +183.9
   b. +4.9
   c. +1.8
   d. +0.5
   e. –5.4

3. Vega has an apparent magnitude of +0.0 and an absolute magnitude of +0.6. If it were moved twice as close from Earth as it is now, which following would occur?

   a. Absolute magnitude number would increase.
   b. Apparent magnitude number would increase.
   c. Apparent magnitude number would decrease.
   d. Apparent magnitude number would stay the same.
   e. Absolute magnitude number would decrease.

Appendix D

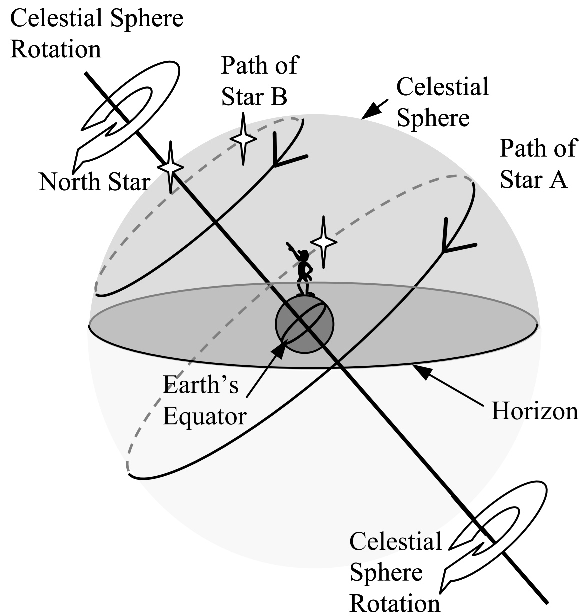
Post-Ranking Task Tests & Qualitative Questionnaire

Name: ________________

ID: ____________________ Gender: Male ______ Female ______

Post-RT Assessment Test:
Motion of the Sky

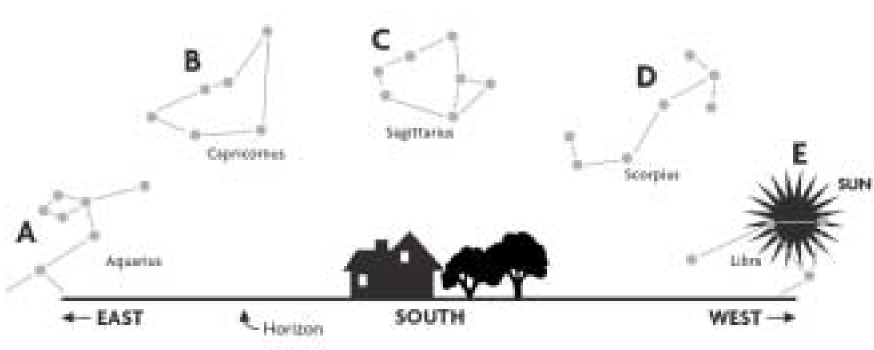
1. Use the diagram at right to answer the question below. In this diagram the motions of Stars A and B are shown as they appear to move across the sky. Imagine that Stars A and B are bright enough to be visible even when the Sun is also in the sky. Also imagine that you are the observer shown on Earth in the northern hemisphere.



Question: Which of the stars would you be able to observe the least number of hours per day?

g. Star A
h. Star B
i. Both stars are visible the same number of hours per day.

2. If you could see stars during the day, this is what the sky would look like at sunset on a given day. The Sun is near the stars of the constellation Libra (labeled constellation E). Also shown are other constellations (named and labeled A, B, C, and D) that will be visible above the horizon at this time when facing south.

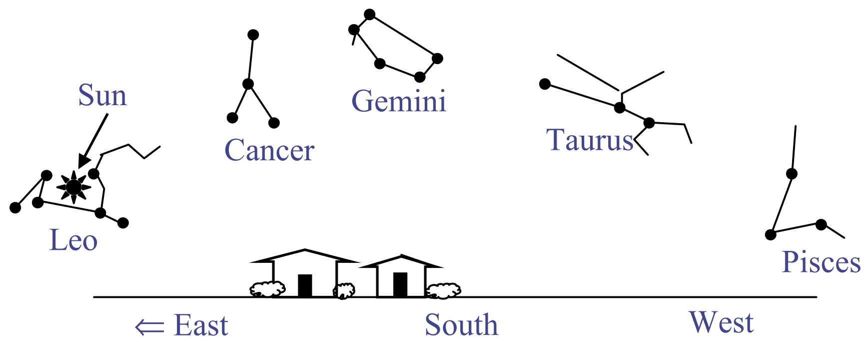


Question: Which of the following rankings would best describe the order that these constellations (A – E) would appear in the sky earlier today?

a. First to rise: A, E, D, B, C was last to rise.
b. First to rise: C, B, D, E, A was last to rise.
c. First to rise: A, B, C, D, E was last to rise.
d. First to rise: E, D, C, B, A was last to rise.
e. All constellations are above the horizon at the same time.

3. If you could see stars during the day, this is what the sky would look like early in the morning on a given day. The Sun is near the stars of the constellation Leo. Near which constellation would you expect the Sun to appear at sunset?

a. Leo
j. Cancer
k. Gemini
l. Taurus
m. Pisces



4. Which constellation will be highest in the sky 3 hours <u>before</u> the time shown in the drawing above?

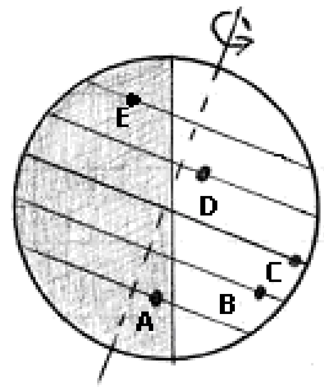
j. Leo
k. Cancer
l. Gemini
m. Taurus
n. Pisces

Name: __________________
ID: _____________________ Gender: Male ______ Female ______

Post-RT Assessment Test:
Seasons

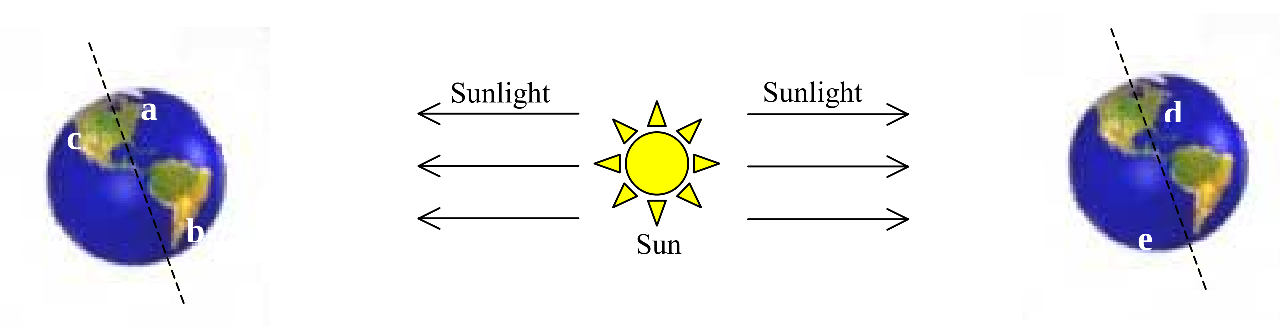
1. In the figure of the earth below, the location (A through D) that receives the smallest number of daylight hours per day is…

a. Location A
b. Location B
c. Location C
d. Location D
e. Location E



2. Which of the following best describes the cause for the seasons here on Earth?
   a. The Sun gives off different amounts of sunlight during different times of the year.
   b. Some times of the year Earth orbits the Sun more slowly than other times of the year.
   c. The distance between Earth and the Sun changes during the year.
   d. More sunlight reaches Earth during some times of the year than others.
   e. Earth's rotational axis is tilted with respect to the plane of Earth's orbit around the Sun.

3. Looking at the images below, which letter (a-e) best represents summer in the Northern Hemisphere?
Answer: __________



Note: this drawing is not to scale.

Name: __________________
ID: ______________________ Gender: Male ______ Female ______

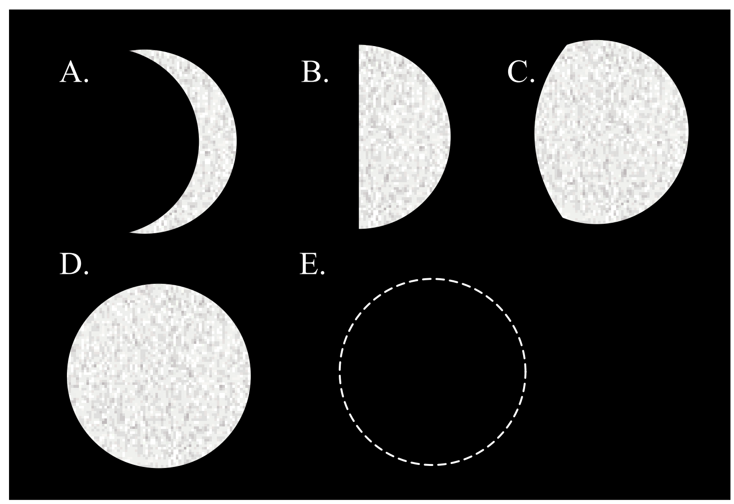
Post-RT Assessment Test:
Lunar Phases

4. Which of the following best describes why the Moon goes through phases?

   a. Earth’s clouds cover potions of the Moon at various times resulting in the changing phases that we see.
   b. The sunlight reflected from Earth lights up the Moon but is less effective when the Moon is lower in the sky than when it is higher in the sky.
   c. Earth's shadow falls on different parts of the Moon at different times.
   d. We see only part of the lit-up face of the Moon depending on its position relative to Earth and the Sun.
   e. The Moon is somewhat flattened and disk-like, and appears more or less round depending on the precise angle from which we see it.

2. You look to the eastern horizon as the Moon first rises and discover that it is in the new moon phase. Later when the moon reaches its highest position in the sky, which of the moon phases shown at right will the Moon look like?

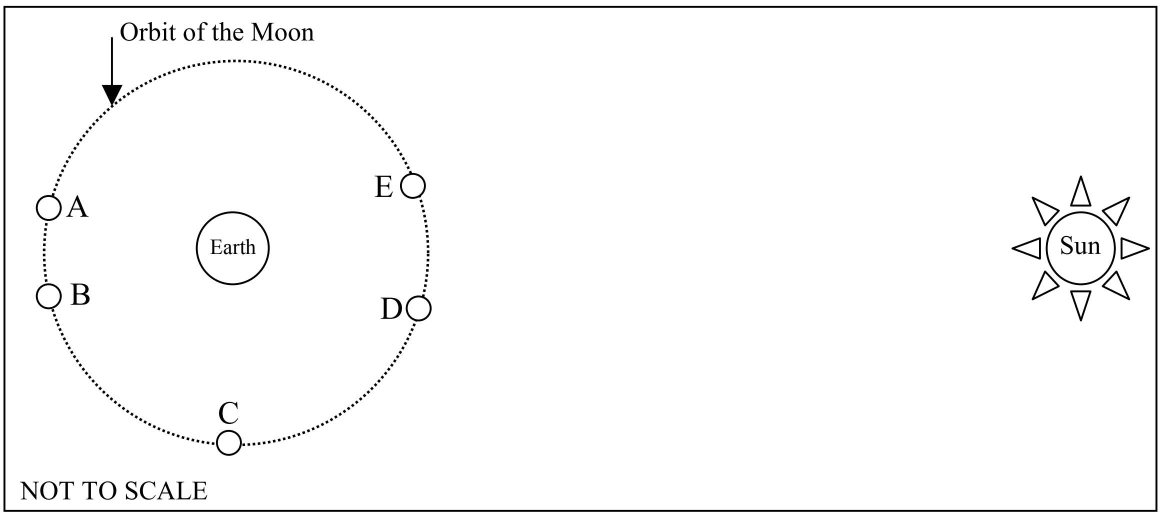
   Answer_______



Turn Over – more questions on back of page

3. The diagram to below shows the Earth and Sun as well as five different possible positions (A – E) of the Moon. Which position of the Moon best corresponds with the phase of the Moon shown in the figure at right?

Answer _______



4. What time is it when the moon phase shown at right first begins to rise above the horizon?

a. Early morning
b. Noon
c. Mid-afternoon
d. Midnight
e. Three hrs before dawn

Name: ___________________
ID: _______________________ Gender: Male ______ Female ______

Post Ranking Task Qualitative Questionnaire:
Lunar Phases

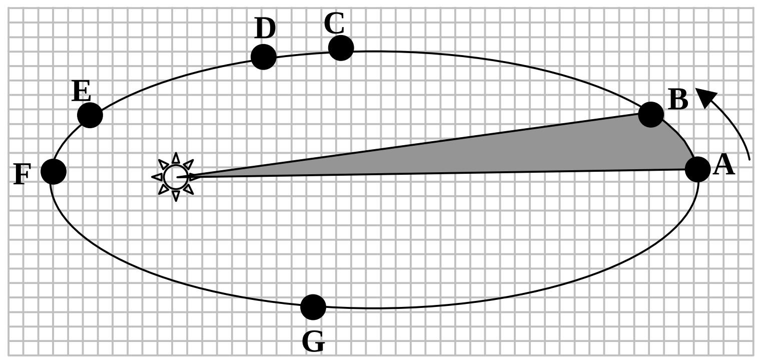
1. Provide a detailed description of why you think the Moon goes through phases?

2. Would the phase of the Moon shown at right ever be above the horizon sometime during the daytime (between 6am and 6pm)? Explain why or why not.

Name: ___________________
ID: _______________________ Gender: Male ______ Female ______

Post-RT Assessment Test:
Kepler's Laws

1. In the drawing at right, the motion of a planet traveling around a star is shown. We have shaded in a triangular area that was swept out during the motion of the planet while moving from position A to B. Which two other planet positions would sweep out another triangular area for the motion of the planet that would obey Kepler's Second Law?



   a. C to D
   b. E to F
   c. F to G
   d. G to A
   e. none of the above

2. Imagine a new planet in our solar system is located at an average distance of 2 AU from the Sun. Which of the following best approximates the orbital period of this planet?

   a. 1 years
   b. 2 years
   c. 3 years
   d. 4 years
   e. 8 years

3. If a small weather satellite and the large International Space Station are orbiting Earth at the same altitude above Earth's surface, which of the following is true?

   a. The large space station has a longer orbital period.
   b. The small weather satellite has a longer orbital period.
   c. Each has the same orbital period.

4. Kepler's second law says "a line joining a planet and the Sun sweeps out equal areas in equal amounts of time." Which of the following statements means nearly the same thing?

a. Planets move equal distances throughout their orbit of the Sun.
b. Planets move fastest when they are moving toward the Sun.
c. Planets move farther in a given time when they are closer to the Sun.
d. Planets move slowest when they are moving away from the Sun.
e. Planets move the same speed at all points during their orbit of the Sun.

Name: __________________
ID: ______________________ Gender: Male ______ Female ______

Post-RT Assessment Test:
Gravity

1. How far away from Earth can an object be and still feel the gravitational force of the Earth?

   a. just above Earth's atmosphere
   b) about half-way to the Moon
   c) just beyond the Moon
   d) the edge of the Solar system
   e) infinity

2. The factor(s) that most affect the gravitational force between two objects are

   a. size and distance
   b. mass and size
   c. density and distance
   d. mass and distance
   e. density and size

3. The gravitational force between two bodies becomes zero

   a. when another body lies in-between the two original bodies
   b. when the distance between them becomes extremely large
   c. at a location halfway between the two bodies
   d. when they are balanced in a stable orbit around one another
   e. when the two objects are not moving.

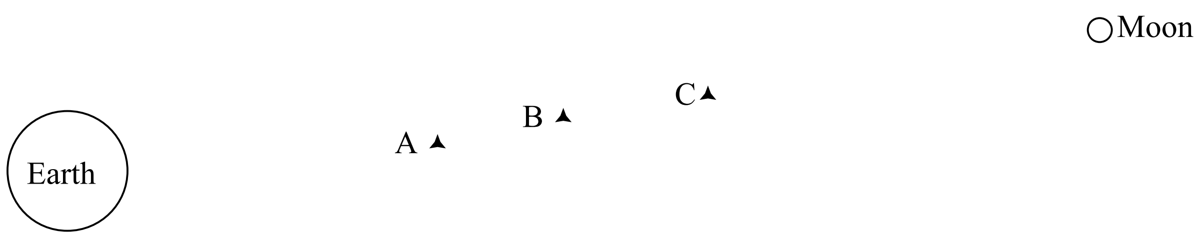
4. In order to triple the gravitational force between two objects, you could

   a. move them three times as close together
   b. triple the mass of only one of the objects
   c. triple the size of either object.
   d. triple the total mass of the two objects
   e. move them three times as far apart

Name: __________________
ID: _____________________ Gender: Male ______ Female ______

Post-Ranking Task Qualitative Questionnaire: Gravity

1. In the picture below the Earth-Moon system is shown (not to scale) along with three possible positions (A - C) for a spacecraft traveling from Earth to the Moon. Note that position B is exactly halfway between Earth and the Moon.



At which of the lettered positions (A - C), if any, could the net (or total) gravitational force of the spacecraft by both Earth and the Moon be zero? Explain your reasoning.

2. How could you make the gravitational force between two objects become zero? Explain your reasoning.

Name: ___________________
ID: ______________________ Gender: Male ______ Female ______

Post-RT Assessment Test:
Luminosity of Stars

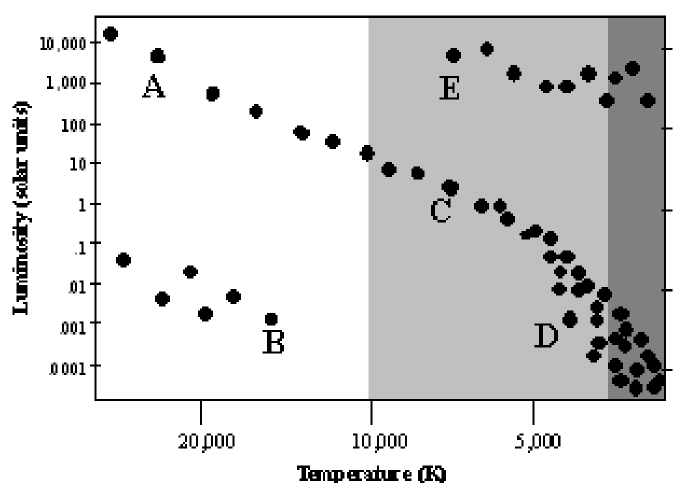
1. The star Betelgeuse and Rigel have the same luminosity but the temperature of Betelgeuse is cooler than Rigel. Which star has the greater surface area?

a. Betelgeuse
b. Rigel
c. They are the same size.
d. There is insufficient information to answer this question.

2. Jelly Star and Doodle Star are both the same size, but Jelly Star is much more luminous than Doodle. As a result, the temperature of Jelly must be

a. cooler than Doodle
h. the same temp as Doodle
c. hotter than Doodle cooler than Doodle
d. there is insufficient information to answer this question.

3. Consider the graph at right, which shows the brightness of a star versus its temperature. Notice that five stars labeled A through E are identified on the graph.



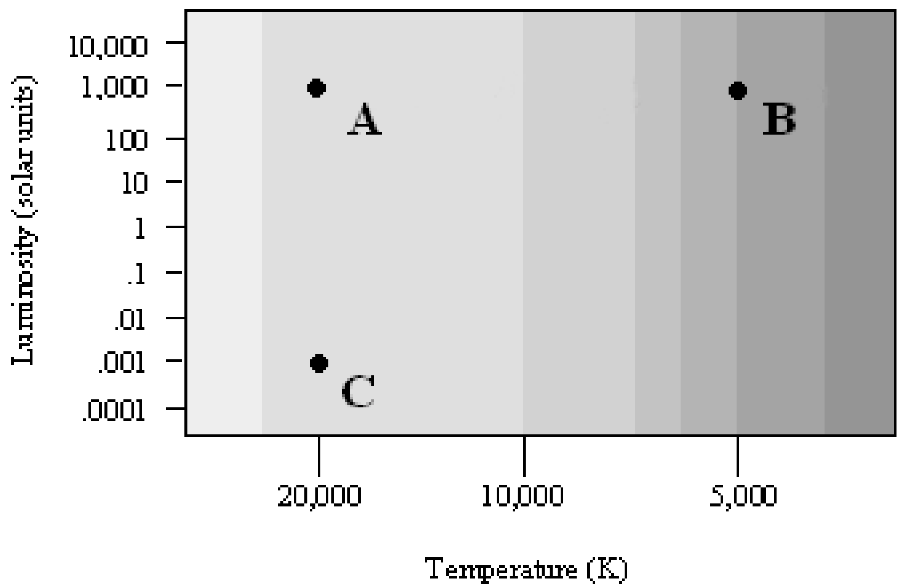
Which of the stars (A – E) is the smallest (diameter)?

a. A
b. B
c. C
d. D
e. E

Name: __________________
ID: _____________________ Gender: Male ______ Female ______

Qualitative Questionnaire:
Luminosity of Stars

1. Consider the H-R diagram shown below, and the three stars (A – C) indicated on the diagram.



Question: Which of these stars is the largest? Explain your reasoning.

Name: __________________
ID: _____________________ Gender: Male ______ Female ______

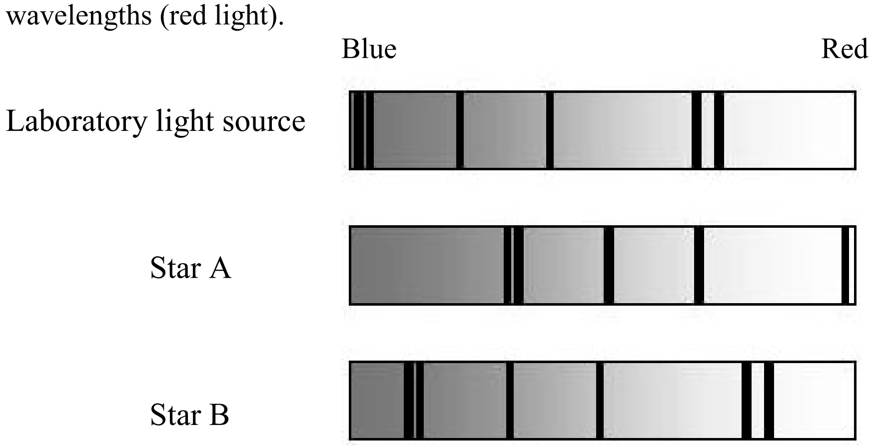
Post-RT Assessment Test:
Doppler Shift

1. Hydrogen has an absorption line that occurs at approximately 410 nm. When we look at the spectrum of the five stars (A-E) we find that this hydrogen absorption line has shifted to the wavelengths shown in the table below.

Which of these stars would be moving the fastest?
a. A
b. B
c. C
d. D
e. E

1. STAR	2. Wavelength of Absorption line
A	415 nm
B	416 nm
C	409 nm
D	400 nm
E	419 nm

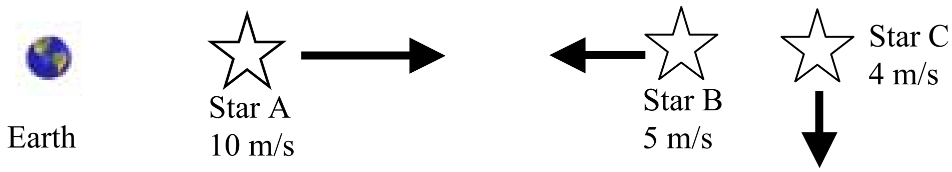
2. You observe the spectra of two stars (Star A and B) that are Doppler shifted relative to that of a stationary lab source of light. Which of the following statements best describes how the stars A and B were moving? Assume that the left end of each spectrum corresponds to shorter wavelengths (blue light) and that the right end of each spectrum corresponds with longer wavelengths (red light).



a. Star A is farther away from us than Star B.
b. Star A and Star B are both moving toward us, and Star B is moving the fastest.
c. Star A and Star B are both moving toward us, and Star A is moving the fastest.
d. Star A and Star B are both moving away from us, and Star A is moving the fastest.
e. Star A and Star B are both moving away from us, and Star B is moving the fastest.

Continued on next page.

3. The picture below shows the motion of three stars (A – C) relative to the stationary Earth (not drawn to scale). Which of the following best describes how the light from the three stars would appear?



k. Star A - redshifted, Star B - blueshifted, and Star C - redshifted
l. Star A - redshifted, Star B - redshifted, and Star C - redshifted
m. Star A - redshifted, Star B - blueshifted, and Star C – No Doppler shift
n. Star A - blueshifted, Star B - redshifted, and Star C - No Doppler shift
o. Star A - No Doppler shift, Star B - redshifted, and Star C – No Doppler shift

Name: ___________________
ID: _______________________ Gender: Male ______ Female ______

Post-RT Assessment Test:
Magnitude-Distance

1. Sirius has an absolute magnitude of -1.5 and an apparent magnitude of +1.4. If Sirius were moved twice as far from Earth as it is now, which of the following would occur?

a. Apparent magnitude number would stay the same
b. Absolute magnitude number would increase
c. Absolute magnitude number would decrease
d. Apparent magnitude number would increase
e. Apparent magnitude number would decrease

2. Rigel has an apparent magnitude of +0.18 and an absolute magnitude of -6.69. The distance to Rigel is

a. less than 10 parsecs.
b. about 10 parsecs.
c. more than 10 parsecs.
d. the distance cannot be determined from this information.

3. Star A appears brighter than Star B, but Star A actually gives off less light than Star B. The apparent magnitude for Star A is m = 0 and the absolute magnitude is M = 1. Which of the following are the best possible values for the apparent and absolute magnitudes of Star B?

f. m = 1 and M = 1
g. m = -1 and M = 1
h. m = 1 and M = -1
i. m = -1 and M = -1

Appendix E

Student Attitude Survey

Student Survey: Astronomy Ranking Task Study

General Information

1. Gender: A. Male
   B. Female

<u>Concerning the Ranking Task Activities</u>

To what extent do you agree or disagree with these statements?

2. The astronomy ranking task exercises contributed positively to my general interest in the course topics.

A	B	C	D	E
Strongly disagree				Strongly agree

3. The ranking task exercises were an enjoyable component of the classroom learning experience.

A	B	C	D	E
Strongly disagree				Strongly agree

4. The ranking tasks helped my learning of course material.

A	B	C	D	E
Strongly disagree				Strongly agree

5. The ranking task exercises helped me prepare for tests.

A	B	C	D	E
Strongly disagree				Strongly agree

<u>Important – Your Specific Comments!</u>

Please describe your overall experience with the ranking task exercises, including how the exercises affected your understanding of course concepts (if they did).

Appendix F

SIRB Approval Forms

ROCKHURST UNIVERSITY
Kansas City, Missouri
PROPOSED RESEARCH PROGRAM OR PROJECT

1. **Title of Proposed Program or Project:** An Investigation of Ranking Tasks as an Innovative Teaching Tool

Attach to this form a summary report, which should include purpose of study, background information, involvement of human subjects, methodology, evaluative instrument, protocol, potential risks and control of those risks. The document should clearly indicate which procedures are considered standard service procedures and those which are proposed for research purposes only.

A copy of any evaluative instrument(s), step by step procedures including pre-experimental directions or preparation, and a copy of the informed consent agreement should be attached. (For informed consent checklist, see next page.)

2. **Principal Investigator/Supervisor (Name and Degree(s)) [] Faculty [] Student [X] Other**

Edward E. Prather, PhD (Conceptual Astronomy & Physics Education Research Team)
Steward Observatory, Rm 203
University of Arizona – Tucson, AZ

3. **Co-Investigator(s) (Name and Degree(s) if Appropriate)**

David W. Hudgins, M.S. (PhD Candidate)	**[X] Faculty**	**[] Student**	**[] Other**
(Rockhurst University, Math/Physics/CS Dept.)	**[] Faculty**	**[] Student**	**[] Other**
________________	**[] Faculty**	**[] Student**	**[] Other**

4. **Consultants**
N/A

5. **Department and Academic Institution (Primary Affiliation)**

This investigation is part of Mr. Hudgins' doctoral research (University of South Africa - School of Math, Science, & Technology Education) in collaboration with the Dr. Prather at the University of Arizona, Dept. of Astronomy.

6. **Type of Request (check one)**
[] Original (necessary when there is any identifiable risks or when external agency requests full review.)
[X] Accelerated (may be used when proposal carries minimal risk)
[] Revision (Project number) **[] Supplement (Project number)**

7. **Dates of Proposed Project: From:** August 2004 **Through:** May 2005
8. **Signature of Primary Investigator**

9. **Signature(s) of Co-Investigator(s)**

LEAVE THE FOLLOWING BLANK FOR HUMAN SUBJECTS COMMITTEE USE

DATE RECEIVED	PROJECT NO.	PRIMARY REVIEWER	SECONDARY REVIEWER

HSC ACTION AND DATE	RETURN TO INVESTIGATOR (DATE)

HSC Form 1-86 (revised 5-98)

Rockhurst University:

Proposed Human Subjects Research Study

PROJECT TITLE: An Investigation of Ranking Tasks as an Innovative Teaching Tool

Contact: David W. Hudgins, M/P/CS Dept.

Background & Rational

Many instructors of the introductory astronomy course for non-science majors are frustrated by their students' inability to reason, and problem solve, quantitatively about astronomical concepts. Many instructors are also frustrated by the lack of quality quantitative teaching tools and curriculum available to them. Traditional quantitative curriculum involves little more than algorithmic problem solving displaying a student's algebra skills while requiring very little astronomy content knowledge. We have been developing Ranking Tasks to facilitate students' quantitative reasoning, and problem solving skills, in astronomy. Ranking tasks are a novel type of conceptual exercise in which students are presented four to eight different variations of a basic physical situation—usually shown as diagrams or pictures—which asks students to make a comparative judgment to identify the order or "ranking" of the various situations based on some physical outcome. Each situation is presented with different values for the variables involved, often including variables that are not important to the task.

Purpose & Objectives

The purpose and objectives of this study are to determine the efficacy of Ranking Tasks as an instructional tool to facilitate student learning of concepts in astronomy.

Methods to be Employed

Ranking tasks will be used to augment traditional instruction during class discussion about once every two weeks. After traditional instruction on one of the studied astronomy topics (and prior to the ranking task exercises) students will take a short multiple-choice question Pretest to assess their level of understanding. The Pretest will be collected along with student names or ID numbers so that students will receive participation credit for the day. Note that students who do not wish to participate in the study will still receive participation points for the day. After the Pretest is collected and participation points recorded for the students, the names/ID numbers are clipped off each individual Pretest before it is graded and recorded for the study.

In no way will students' grades be affected by choosing not to participate in the study, nor will their grades be affected by how well they perform on any testing. Students will be verbally informed about their right not to participate, and they will be verbally informed that in no way will their choice not to participate affect their grade. They will also be verbally informed that in no way will their grade be affected by their performance on any testing associated with this study. They will be advised that participating in the study may help them with additional understanding that may be helpful to them in normal class tests and final exams.

After the Pretest, will be given a series of paper-and-pencil Ranking Task exercises (see Appendix A for sample Ranking Tasks) to be completed as an in-class exercise. Students will work collaboratively and grade their own work at the end of the exercise and may keep the exercise for their own study. No recording of Ranking Tasks scores are taken as part of this study.

After the Ranking Task exercise is completed and discussed in class, the Posttest is given. This includes a short multiple-choice question Assessment Test (see Appendix B) and/or a Qualitative test. The Qualitative test poses a sample astronomy question to the student, and asks open-ended questions seeking to reveal the strategy that the student used in working the problem. Both the Assessment Test and Qualitative Test include the student's name or ID number in order to provide motivation. However, those names/ID numbers are immediately clipped off the test forms prior to grading and recording of student responses for this study.

Significance of Study

We believe that the results of this study will be of significance to instructors and students by helping us provide them with scientifically tested, effective teaching and learning materials.

1. STUDY POPULATION

a. Number of persons to be recruited for participation in the study:

    Approximately 275 students will be recruited for participation in this study. Approximately 25 students will be from Rockhurst University, and 250 students from the University of Arizona.

b. Description of the population to be recruited and rationale for their participation.

The target population at Rockhurst University will be students enrolled in PH1600 Introduction to Modern Astronomy, a physics course for non-science majors taught by Mr. Hudgins during Fall 2004 and Spring 2005, and who are 18 years of age or older.

c. What are the inclusion and exclusion criteria for study participation?

Any students, 18 years of age or older, who are enrolled in Mr. Hudgins' introductory astronomy course can be included.

2. RECRUITMENT AND CONSENT PROCEDURES.

a. Describe how you will contact individuals who may become participants in the study (e.g., web site, email, flyers, phone calls, advertisements).

Students will be advised on the first day of class of the opportunity to participate in the study, all privacy measures will be explained, and they will be asked to sign or "opt-out" using the Study Informed Consent Form.

b. Describe how the project will be explained to individuals when you recruit them for participation.

Students will be told at the beginning of each semester that throughout the semester, at intervals of approximately two weeks, they will be using new curriculum called Ranking Tasks that their instructor, Mr. Hudgins, has been helping to develop. They will be informed that they do not have to participate in the ranking tasks or subsequent assessment testing if they choose not to, and that in no way will their grade be negatively affective if they choose not to participate. In addition to being told at the beginning of the semester, they will also be informed of these same points just prior to any post-lecture Pretests.

c. Describe how informed consent will be obtained. (If the participants are minors, explain how assent will be secured.)

Students will be provided with a verbal and written disclaimer. The verbal disclaimer will be given to them at the beginning of the semester and on each day a Ranking Task will be handed out. There will be no minors participating in this study.

d. How will you make it clear to the recruits that their participation is voluntary and that they may withdraw at any time?

Students will be informed of the study at the beginning of the semester and on each day a Ranking Task will be handed out. During this time they will be verbally told that their participation is voluntary, that their choice to participate or not will in no way affect their grade, and that their performance on Ranking Tasks will in no way affect their grade.

3. METHODOLOGY AND DATA COLLECTION PROCEDURES

a. Is your project evaluating an active intervention or treatment procedure (to determine whether an intervention/treatment is effective for the people undergoing it)?

b.

- Yes_X_ No____. If yes, in lay terms provide a summary of the intervention and/or treatment methods and procedures to be employed

  We have been developing curriculum, called Ranking Tasks, for use in class that are designed to facilitate students in developing their proportional reasoning skills with respect to astronomy concepts. In general, students are presented with several similar scenarios, such as two masses separated by some distance, which they then have to rank from "greatest to least," "biggest to smallest," etc. For instance, in the example of two masses separated by some distance, to rank from greatest to least the gravitation force between the two masses. For each concept, there are several sets of Ranking Tasks which increase in difficulty (please see Appendix A for examples of Ranking Tasks).

c. What type of data collection and recording will be employed? Check all that apply and provide an explanation.

- ❑ **_X_ Questionnaires/Surveys**
- ❑ ___ Observations
- ❑ ___ Videotaping
- ❑ ___ Photography
- ❑ ___ Interviews/Focus Groups
- ❑ ___ Records Review (medical, educational, etc.)
- ❑ ___ Audiotaping
- ❑ _X_ Other (define): pen and pencil Ranking Task curriculum

c. In lay terms, provide a summary of the methods and procedures for data collection that will be employed.

Prior to the Ranking Task exercise, a Pretest (Assessment Test - Appendix B) will be administered. After the Ranking Task exercises, a Posttest ((Appendix C and D) will be administered. Ranking Tasks are self-graded by the students and no scores are recorded in this study. As describe earlier, the Assessment tests are collected with student names or ID numbers, but after participation credit is recorded for each student, the student names are clipped of the Assessment Test and Qualitative Test. No performance data is recorded that includes individual student names or identification.
At the end of the semester, an anonymous Likert-scale Attitude Survey Appendix D) will be administered to the students. The purpose is to investigate student impressions of the effectiveness of Ranking Tasks. No names are included or

recorded concerning the on the Attitude Survey, and complete student privacy is assured..

4. CONFIDENTIALITY OF PERSONAL IDENTIFYING INFORMATION

a. How will confidentiality of collected information be maintained?

Though we will be collecting student ID numbers at the top of the Assessment Tests and , Qualitative Tests as student participation points are recorded - and before any scoring or recording of data, all names and student ID numbers will be cut off the top of the paper and destroyed.

b. What are the plans for retention and/or destruction of linkages between study data and personal identifying information? (Specify when and how personal identifying information will be destroyed.)

No personal identifying information will be recorded or maintained a part of this study.

5. BENEFITS, COSTS, COMPENSATION & RISKS

a. Benefits: What are the potential benefits directly to the participants, if any?

The potential benefits directly to the participants of this study are a better understanding of astronomical concepts and increased quantitative reasoning skills.

Benefits: What are the potential broader benefits of the study?

The potential broader benefits of the study are to increase the number and types of teaching tools and curriculum available to instructors of astronomy and which will facilitate their students' reasoning skills.

b. Costs: What are the costs to the participants (monetary, time, etc)?

There are no costs to students—monetary, time, etc.—since all work will be completed during the normal course of their class time.

c. Compensation: Will monetary or other compensations be offered to the subjects? (If so, identify the amount of compensation and method of payment.)

There is no compensation that will be offered to students.

d. Risks: What risks to the participants could be encountered through participation in this project (physical, psychological, sociological, etc)?

There are no risks to participants completing Ranking Tasks.

Risks: Describe the approaches you will take to minimize these risks and/or to minimize their impact.

There are no risks to participants in completing Ranking Tasks or in the assessment test.

6. CONTACT PERSON:

All questions or reporting of adverse effects should be made to David W. Hudgins, Co-Investigator. (913-681-0992)

Project Title: _An Investigation of Ranking Tasks as an Innovative Teaching Tool

IDENTIFICATION OF PI(S)

Principal Investigator(s):	Degree(s):	Status/rank:	Department:	College:
Dr. Edward Prather	PhD	Asst. Research Scientist	Astronomy	Arts & Sci
________________	______		________	________

Faculty Advisor (if PI is a student):

________________	______	________	________	________

PI CONTACT INFORMATION

Contact phone:	621-6530	Fax:	621-1532
Email:	eprather@as.arizona.edu	Mailing address (PO Box):	Steward Observatory, Rm. 203 933 N. Cherry Ave. Tucson, AZ 85721

ADVISOR CONTACT INFORMATION

Contact phone: ______________ Fax: ______________

Email: ______________ Mailing address:

SUPPORT

Is this research project supported by intra- or extramural funding? ____ Yes _X_ No

If "yes", sponsoring agency/ies: ______________

Amount of funding: ______________

NOTE: Per Federal requirements, the full grant application must be submitted if the research described in your PRF is in conjunction with a grant proposal to the National Institutes of Health or one of its affiliated institutes.

Verification of Human Subjects Training

All individuals conducting research involving human subjects (with or without financial support of any sponsoring organization or agency) must complete Human Subjects training. Those individuals include principal investigators, co-investigators and all other individuals involved in the conduct of research. Students and their advisors must meet the same standard as faculty and staff.

Please list all individuals involved in the above-cited research study

Name	Research Role (PI, Co-PI, Collaborator, Sub-I, Data Manager, Research Assistant, etc.)	Will this person be involved in the consenting process? *	Training Title Indicate type of training: **Med-I**, **Med-II**, and/or **SBS** (see definitions below)**	Completion Date(s) for each Human Subjects training listed (mm/dd/yy)
Edward Prather	PI	$\boxed{\text{YES}}$ NO	Med-I	15 Dec 01
Gina Brissenden	Co-PI	$\boxed{\text{YES}}$ NO	SBS	9 Feb 04
Erin Doktor	Co-PI	$\boxed{\text{YES}}$ NO	SBS	9 Feb 04
David Hudgins	Co-PI	YES NO		
		YES NO		
		YES NO		
		YES NO		
		YES NO		
		YES NO		

*Consent forms are to be signed and dated by the subject (or their legal representative) and by the Principal Investigator or Co-Principal Investigator (no other study personnel may sign as Investigator without prior approval of the IRB). Other study personnel involved in the consenting process may sign as Presenter, but not as Investigator.

****Med-I**: *Social/Behavioral Science and Biomedical Researchers*
Text: Protecting Study Volunteers In Research (**First** Edition)
Authors: Cynthia McGuire Dunn/Gary. L. Chadwick

Med-II: Same as above (**Second** Edition)
Note: Either Med-I **OR** Med-II (both not required)

SBS: *Social/Behavioral Science Researchers only*
Text: Planning Ethically Responsible Research
Author: Joan E. Sieber

Revised: 10/03

ASSURANCES

If appropriate, after review by the Departmental Review Committee, please forward their opinions and comments along with the signatures on the Project Review Form to the Human Subjects Committee, University of Arizona, 1350 N. Vine Avenue, PO BOX 245137, Tucson, Arizona 85724-5137. Only one copy is required and will be retained for the Human Subjects Committee files and eventually microfilmed for a permanent record. Please provide responses to all of the following items.

1. PRINCIPAL INVESTIGATOR

By signing below, I, the Principal Investigator, assure to the IRB that all other investigators (co- investigators, collaborating
investigators, involved statisticians, consultants, or advisors) are fully aware of, and concur with, the project submission and that all Human Subjects training verification information provided in this form is accurate. I agree that no procedural changes relating to the human subjects will take place without prior review by the IRB.

Edward Prather___________________
______________________________________ Astronomy________________
Principal Investigator (typed) Signature/Date
Department

2. DEPARTMENTAL REVIEW COMMITTEE

We/I have examined the proposal cited above, and find that the (check all that apply)
■ yes ق no information contained herein is complete;
■ yes ق no scientific aspects of the project include appropriate provision for protecting the rights and welfare of the human subjects;
■ yes ق no required forms have been completed in accordance with the Federalwide Assurance filed by the University of Arizona with the U.S. Department of Health and Human Services.

■ yes ق no the procedures for obtaining informed consent comply with the spirit and intent of DHHS regulations.

Based on review of the proposal, the Departmental Review Committee has determined that this project (check only one):
__X__ should be exempt from IRB review. (Attach memo of explanation.)
_____ places human subjects at minimal risk.
_____ places human subjects at more than minimal risk.

____
________________________________ ______________
Chairman of Departmental Review Committee (typed) Signature
Date

Email (typed): ____

3. SUPERVISING OFFICIAL

I certify that:
■ yes ف no facilities are available to the investigator for assuring the safety and well-being of human subjects who participate;
■ yes ف no the investigator(s) is/are fully competent to accomplish the goals and techniques stated in the attached proposal;
ف yes ■ no signed consent forms will be filed in ______________ (administrative room/building) and retained for a period of six years.

I assume responsibility for insuring the competence, integrity, and ethical conduct of the investigator(s).

Peter Strittmatter________________________________

____
Head of Department, Dean of the College or comparable authority Signature
(PLEASE PRINT OR TYPE)

Astronomy Department Head___________________

____
Title Date
(PLEASE PRINT OR TYPE)

PROJECT ABSTRACT

In the space below, provide an abstract of the project in 400 words or less. Include information about (a) the background and rationale for the study; (b) the purpose and objectives; (c) methods to be employed and (d) significance of the study.

Background & Rational
Many instructors of the introductory astronomy course for non-science majors are frustrated by their students' inability to reason, and problem solve, quantitatively about astronomical concepts. Many instructors are also frustrated by the lack of quality quantitative teaching tools and curriculum available to them. Traditional quantitative curriculum involves little more than algorithmic problem solving displaying a student's algebra skills while requiring very little astronomy content knowledge. We have been developing Ranking Tasks to facilitate students' quantitative reasoning, and problem solving skills, in astronomy. Ranking tasks are a novel type of conceptual exercise in which students are presented four to eight different variations of a basic physical situation—usually shown as diagrams or pictures—which asks students to make a comparative judgment to identify the order or "ranking" of the various situations based on some physical outcome. Each situation is presented with different values for the variables involved, often including variables that are not important to the task.

Purpose & Objectives
The purpose and objectives of this study are to determine the efficacy of Ranking Tasks as an instructional tool to facilitate student learning of concepts in astronomy.

Methods to be Employed
Approximately once per week students will be given a paper-and-pencil Ranking Task (see Appendix D for sample Ranking Tasks) to be completed in class. Student ID numbers will be collected with the Ranking Task so that students can receive participation points for the day. Note that students who do not wish to participate in the Ranking Task will still receive participation points for the day. In no way will students' grades be affected by choosing not to participate in the Ranking Task, nor will their grades be affected by how well they perform on the Ranking Tasks. Once students' participation points have been recorded, their student ID numbers will be cut off the top of the paper and destroyed. Students will be verbally informed about their right not to participate, and they will be verbally informed that in no way will their choice not to participate affect their grade. They will also be verbally informed that in no way will their grade be affected by their performance on the Ranking Task.

Significance of Study
We believe that the results of this study will be of significance to instructors and students by helping us to provide them with high-quality, effective teaching and learning materials.

1. POPULATION

a. Number of persons to be recruited for participation in the study:

Approximately 300-600 students will be recruited for participation in this study.

d. Description of the population to be recruited and rationale for their participation (indicate age range, gender, ethnicity, vulnerable or captive population status). Note any special efforts to encourage the recruitment of women and/or representatives from racial or ethnic minority groups.

The target population will be students enrolled in the introductory astronomy course for non-science majors taught by Dr. Edward Prather at the U of A during Fall 2004, Spring 2005, Fall 2005, and Spring 2006 and who 18 years of age or older.

e. What are the inclusion and exclusion criteria for study participation?

Any students, 18 years of age or older, who are enrolled in Dr. Edward Prather's introductory astronomy course for non-science majors can be included.

2. RECRUITMENT AND CONSENT PROCEDURES. For each response in this section, note whether the activity will be done orally, in writing, or both. List here points to be covered in an oral or written presentation here. Place consent documents in Appendix A. Include copies of any visual material (advertisements, flyers, web announcements, etc.) in Appendix B for approval.

e. Describe how you will contact individuals who may become participants in the study (e.g., web site, email, flyers, phone calls, advertisements).

Ranking Tasks will be handed out to students during class time.

f. Describe how the project will be explained to individuals when you recruit them for participation (include the text of advertisements, phone solicitations, etc). Include any pre-screening questions or surveys that may be used.

Students will be told at the beginning of each semester that throughout the semester, at intervals of approximately one week, they will be using new curriculum called Ranking Tasks that their instructor, Dr. Edward Prather, has been helping to develop. They will be informed that they do not have to participate in the ranking tasks if they choose not to, and that in no way will their grade be negatively affective if they choose not to participate. In addition to being told at the beginning of the semester, they will also be informed of these same points just prior to the Ranking Tasks being handed out in class. In addition, each Ranking Task passed out to students will have this same information printed on the back (see Appendix A1).

g. Describe how informed consent will be obtained. (If the participants are minors, explain how assent will be secured.)

   Students will be provided with a verbal and written disclaimer. The verbal disclaimer will be given to them at the beginning of the semester and on each day a Ranking Task will be handed out. In addition, there will be a written disclaimer on the back of each Ranking Task (see Appendix A1 for examples of Ranking Tasks with disclaimer). There will be no minors participating in this study.

h. How will you make it clear to the recruits that their participation is voluntary and that they may withdraw at any time?

   Students will be informed of the study at the beginning of the semester and on each day a Ranking Task will be handed out. During this time they will be verbally told that their participation is voluntary, that their choice to participate or not will in no way affect their grade, and that their performance on Ranking Tasks will in no way affect their grade. This same information will also be provided in writing in the disclaimer on the back of each Ranking Task (see Appendix A1 for example of disclaimer).

3. METHODOLOGY AND DATA COLLECTION PROCEDURES

d. Is your project evaluating an active intervention or treatment procedure (to determine whether an intervention/treatment is effective for the people undergoing it)?
   - Yes_X_ No____. If yes, in lay terms provide a summary of the intervention and/or treatment methods and procedures to be employed

     We have been developing curriculum, called Ranking Tasks, for use in class that is designed to facilitate students in developing their proportional reasoning skills with respect to astronomy concepts. In general, students are presented with several similar scenarios, such as two masses separated by some distance, which they then have to rank from "greatest to least," "biggest to smallest," etc. For instance, in the example of two masses separated by some distance, to rank from greatest to least the gravitation force between the two masses. For each concept, there are several sets of Ranking Tasks which increase in difficulty (please see Appendix D for examples of Ranking Tasks).

e. What type of data collection and recording will be employed? Check all that apply and provide an explanation. (If Administrative Records are to be used, include a letter of authorization from the appropriate agencies in Appendix C. Include samples of all data collection instruments in Appendix D.)

❑ ___ Questionnaires/Surveys	❑ ___ Interviews/Focus Groups
❑ ___ Observations	❑ ___ Records Review (medical, educational, etc.)
❑ ___ Videotaping	❑ ___ Audiotaping
❑ ___ Photography	❑ _X_ Other (define): pen and pencil Ranking Task curriculum

d. In lay terms, provide a summary of the methods and procedures for data collection that will be employed.

Approximately once per week students will be given a paper-and-pencil Ranking Task (see Appendix D for sample Ranking Tasks) to be completed in class. Student ID numbers will be collected with the Ranking Task so that students can receive participation points for the day. Note that students who do not wish to participate in the Ranking Task will still receive participation points for the day. In no way will students' grades be affected by choosing not to participate in the Ranking Task, nor will their grades be affected by how well they perform on the Ranking Tasks. Once students' participation points have been recorded, their student ID numbers will be cut off the top of the paper and destroyed. Students will be verbally informed about their right not to participate, and they will be verbally informed that in no way will their choice not to participate affect their grade. They will also be verbally informed that in no way will their grade be affected by their performance on the Ranking Task. Students will be verbally informed both at the beginning of the semester and just prior to receiving each Ranking Task.

e. Where will the project be conducted? (If study is to be conducted at an off-campus agency or organizational location, include a letter of authorization in Appendix C).

This project will take place in the Nats 102 courses taught by PI Edward Prather during the Fall 2004, Spring 2005, and Fall 2005 semesters at the U of A.

4. CONFIDENTIALITY OF PERSONAL IDENTIFYING INFORMATION

c. How will confidentiality of collected information be maintained?

Though we will be collecting student ID numbers at the top of each Ranking Task, as soon as student participation points are recorded—and before any of the Ranking Tasks are looked at for "correctness"—their student ID numbers will be cut off the top of the paper and destroyed. The Ranking Tasks themselves (without student ID numbers will be kept in the office of Edward Prather.

d. What are the plans for retention and/or destruction of linkages between study data and personal identifying information? (Specify when and how personal identifying information will be destroyed.)

Though we will be collecting student ID numbers at the top of each Ranking Task, as soon as student participation points are recorded—and before any of the Ranking Tasks are looked at for "correctness"—their student ID numbers will be cut off the top of the paper and destroyed.

e. Will a Certificate of Confidentiality (through DHHS or another Federal agency) be utilized?

No

5. BENEFITS, COSTS, COMPENSATION & RISKS

e. Benefits: i. What are the potential benefits directly to the participants, if any?

The potential benefits directly to the participants of this study are a better understanding of astronomical concepts and increased quantitative reasoning skills.

Benefits: ii. What are the potential broader benefits of the study?

The potential broader benefits of the study are to increase the number and types of teaching tools and curriculum available to instructors of astronomy which will facilitate their students' quantitative reasoning skills.

f. Costs: i. What are the costs to the participants (monetary, time, etc)?

There are no costs to students—monetary, time, etc.—since all work will be completed during the normal course of their class time.

g. Compensation: Will monetary or other compensations be offered to the subjects? (If so, identify the amount of compensation and method of payment.)

There is no compensation that will be offered to students for completing Ranking Tasks.

h. Risks: i. What risks to the participants could be encountered through participation in this project (physical, psychological, sociological, etc)?

There are no risks to participants completing Ranking Tasks.

Risks: ii. Describe the approaches you will take to minimize these risks and/or to minimize their impact.

There are no risks to participants completing Ranking Tasks.

6. APPENDICES

Attach the following appendices to the PRF, in the order specified, labeled as indicated, and with a table of contents identifying all appendix materials. Use titles that are consistent with those used in the text of the PRF.

- A.1 Subject Informed Consent Form/Parental Informed Consent Form
- **A.2 Minor Assent Form**
- B. Recruitment Materials
- C. Site Authorization Letter (for study conduct and/or access to administrative records)
- D. Data Collection Instruments
- E. Grant Applications
- F. Explanation of human subjects training for non-UA personnel <Note from Diana Archangeli on September 29, 2003: please discuss alternatives to the Rochester test with Rebecca Dahl before submitting something in this section: rdahl@u.arizona.edu.>
- G. HIPAA documentation.

Appendix A1
Subject Informed Consent Form

Description/Disclaimer to appear on the back of ranking tasks and to be read aloud to students prior to handing out the Ranking Tasks:

We are inviting your voluntary participation in completing an astronomy Ranking Task. Astronomy Ranking Tasks are new curriculum we are developing to help students better understand concepts in astronomy. Completing the astronomy Ranking Task will in no way impact your grade, nor will your performance on the Ranking Task. In addition, your instructor will never know what your personal answers were.

There are neither perceived risks nor benefits for your participation. If you do not wish to participate, simply put your student ID number on the top of the paper so that you will receive participation points for attending class today, then leave the rest of the paper blank. If you have questions, we would be happy to answer them now or at the end of class.

Again, your participation will in no way impact your grade in this course.

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VITA

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