Foundations of Cognitive Science

Lesson Plan to teach the concept of Gravity & Orbits

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Gravity and Orbits

Topic and Audience

- **Topic:** Gravity and Orbits
- **Audience:** Middle School (11- to 14-years-old); Astronomy, Earth Science, or Physics Classes.

Learning Objectives

1. Students will be able to IDENTIFY the variables that affect the strength of gravity (*Domain: Cognitive*; *Level: Knowledge*).
2. Students will be able to DESCRIBE and EXPLAIN motions of the Earth, the Earth's Moon, and the International Space Station (*Domain: Cognitive*; *Level: Comprehension*).
3. Students will be able to SUMMARIZE the importance of gravity as a force in our solar system (*Domain: Cognitive*; *Level: Comprehension*).
4. Students will be able to COMPARE the motions of the Earth, the Earth's Moon, and the International Space Station (*Domain: Cognitive*; *Level: Analysis*).
5. Students will be able to INFER how an object's motions will change if gravity is changed (*Domain: Cognitive*; *Level: Evaluation*).

Cognitive Challenges

1. Issues Around Prerequisite or Prior Knowledge

All students will be able to define forces as a push or pull and identify gravity as a type of force. Students will have familiarity with the components and organization of the solar system, such as that the Sun is at the center of our solar system and that each orbiting object has a period of revolution. Students will vary in their understanding of how gravity works--some may simply think that gravity is what prevents us from floating into space, while others may understand that gravity is an attraction between two masses. All students will be able to define mass as the amount of matter (stuff) in an object. Students will also vary in their abilities to use simulations: some students may have extensive experience with simulations, while other students will have an absence or lack of such experiences. All students will have some experience with giving, receiving, and implementing peer feedback. The individual differences in ability, however, will be evaluated via an assessment before the in-class lesson, as they are one of the most important factors to consider while designing all lessons (Lohman, 1986).

2. Issues Around Multiple Representations

Since the learning objectives require that the students only use the “model” portion of the simulation (and not the “to scale” portion of the simulation), there are no multiple representations in this lesson. Since multiple representations can lead to a deeper understanding of a domain, it may be beneficial to redesign the simulation with additional representations such as a graph that instantly plots an object’s gravitational force as this object’s mass changes. The merits and faults of such a modification is described in the **Theories** section of this lesson plan.

3. Issues Around Interactivity

As described by Domagk, Schwartz, and Plass (2010), many variables "can affect the way that an interactive feature is actually used and the cognitive processes in which a learner engages" (2010, p. 4). Due to such factors as a student's level of motivation or the design of the learning environment, a student may employ interactive features in this lesson plan's simulation to actually help them to learn, or to instead appear engaged but only to be so behaviorally. The importance of "adding effective questions that encourage the learners to make inferences from the content" (Clark & Mayer, 2016, p. 232) via differentiated worksheets is further discussed in the **Theories** section of this lesson plan.

4. Issues Around Inquiry Learning

During the simulation activity, students will be able to test their assumptions and hypotheses by changing the input values for the simulation (such as star mass or planet mass) and seeing its impact on the corresponding output values (such as the trajectory and/or period of revolution). In order to support the individual differences of students, there will be two versions of the worksheet that the students will complete while investigating with the simulation: the novice version which will contain purposeful questions to scaffold learning and the expert version which will allow students to develop and implement their own plans for learning. According to the **guided discovery principle**, novices "learn better when guidance is incorporated into discovery-based multimedia environments" (Mayer, 2014, p. 9), as is the case for the novice version of the worksheet for the simulation. If the expert students were also assigned the novice version, the **expert reversal principle** would apply and negatively affect the learning of these students who would then be forced to "integrate and cross-reference the simplified and redundant material with their available knowledge" (Mayer, 2005a, p. 584). To prevent this extraneous load, the less-structured, expert version of the worksheet for the simulation will thus be offered to the expert students.

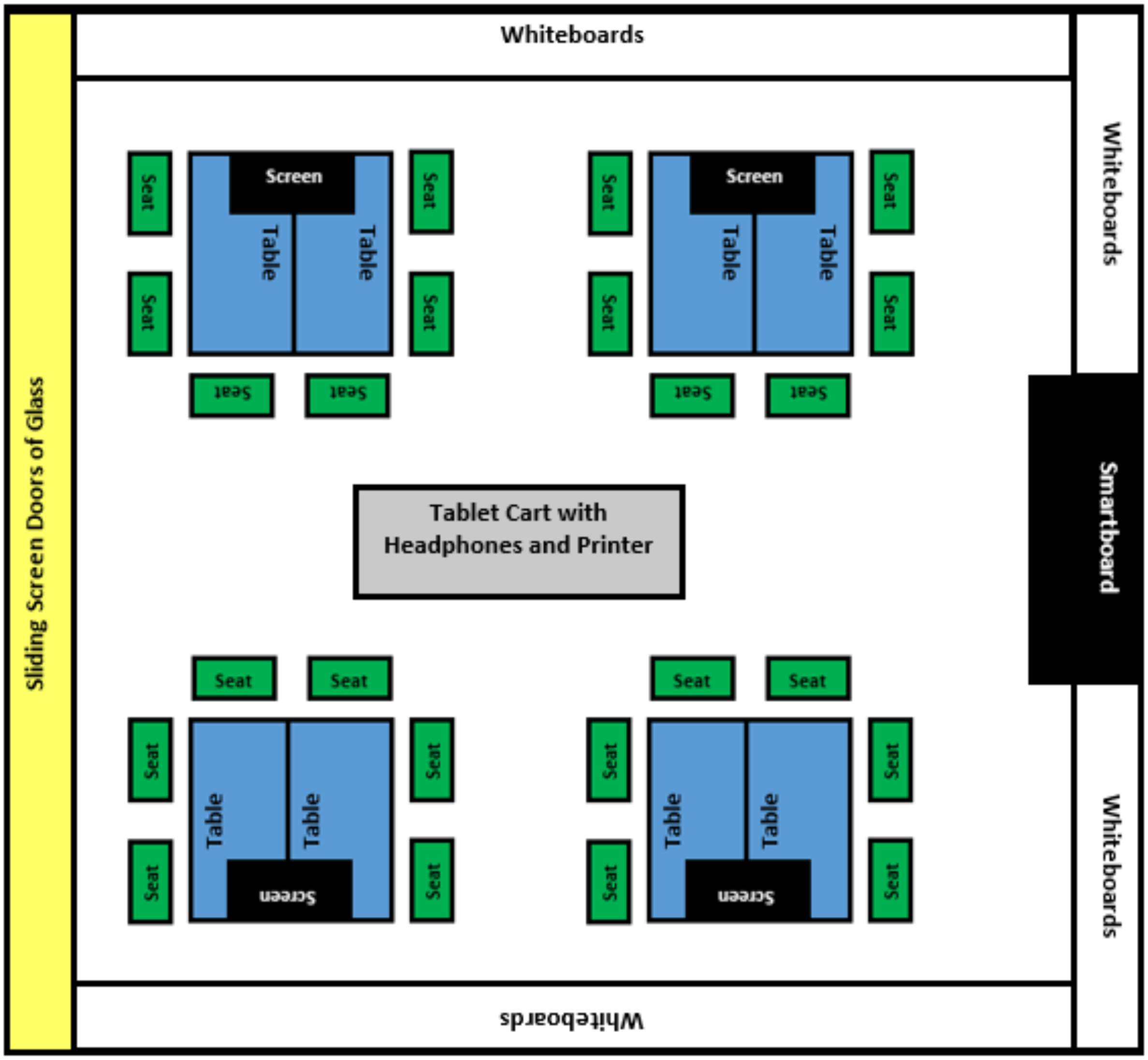
Narrative of the Lesson

Introduction

The following sequence of events is influenced by multiple theories of cognitivism, ranging from the cognitive theory of multimedia learning to Robert Gagné's (1985) nine events of instruction to interactivity. The learning environment is blended, meaning that part of the lesson, specifically the presentation of content, will be completed asynchronously before the in-class session. The classroom will be organized as shown in the image below in order to support a variety of activities that will reinforce student learning.

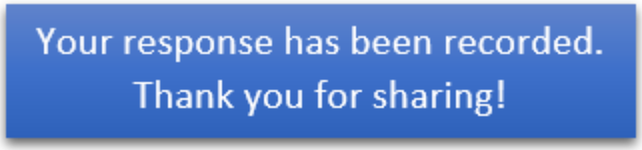
During the first portion of the in-class session, the instructor will review the advance organizers as well as the multiple choice questions using the Smartboard. Students will then individually use the tablets from the tablet cart to engage in a supported drawing activity during which they will produce models of different orbits in our solar system. Students will then discuss the accuracies and inaccuracies of their models using the large screen at each of their table groups of five other peers. The table groups will be arranged with ample space between them so that the instructor can circulate, listen to the students' discussions, and provide feedback and guidance as needed.

The tablets will then be employed during the activity based on the Phet simulation, which will also feature video clips to assist students who are struggling with navigating the simulation and that can be heard using the headphones. Each student will be responsible for printing a screenshot of one of their orbits with a typed explanation and taping it on the whiteboards as part of the subsequent gallery walk. Afterwards, students will complete their K-W-L's as further evidence of their learning. The glass sliding screen doors through which all will exit are intended to infuse light throughout the room in support of a positive classroom atmosphere.



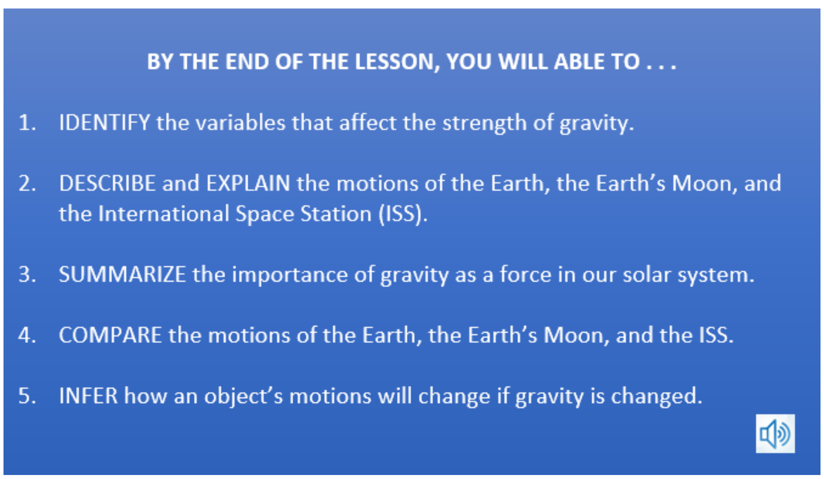
Gaining Attention

The students will log into the class website and click the link for this lesson. The first page of the lesson will begin with the questions, “Why does our Earth not get pulled into the Sun?” and “Why don’t we float off our Earth into space?” In order to psychologically engage the students, a space will be provided where students can write and submit their initial thoughts to these questions. Upon submission, no explanatory feedback will be immediately given, but the following message will be displayed.



Informing the Learner of the Objective

The students will then be able to click to the next page of the lesson which will display the five learning objectives that are listed in the **Learning Objectives** section. There will be an audio button which students can choose to press in order to listen to the learning objectives as they are read by the instructor.

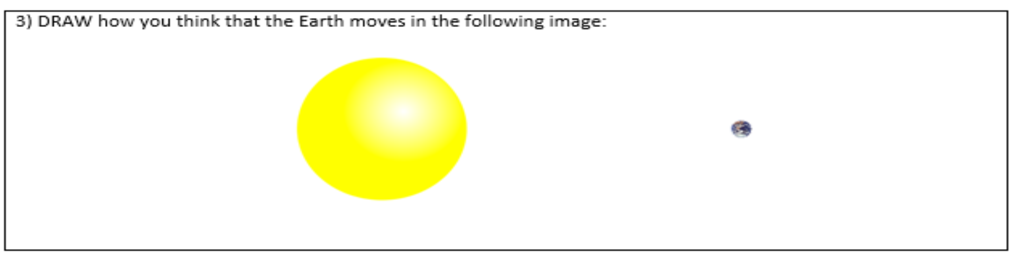


Stimulating Recall of Prerequisite Learning

Students will click to the next segment which will feature the following K-W-L chart. They will be able to complete and submit responses for the first two boxes in order to activate their prior knowledge of this lesson's topic, gravity and orbits.

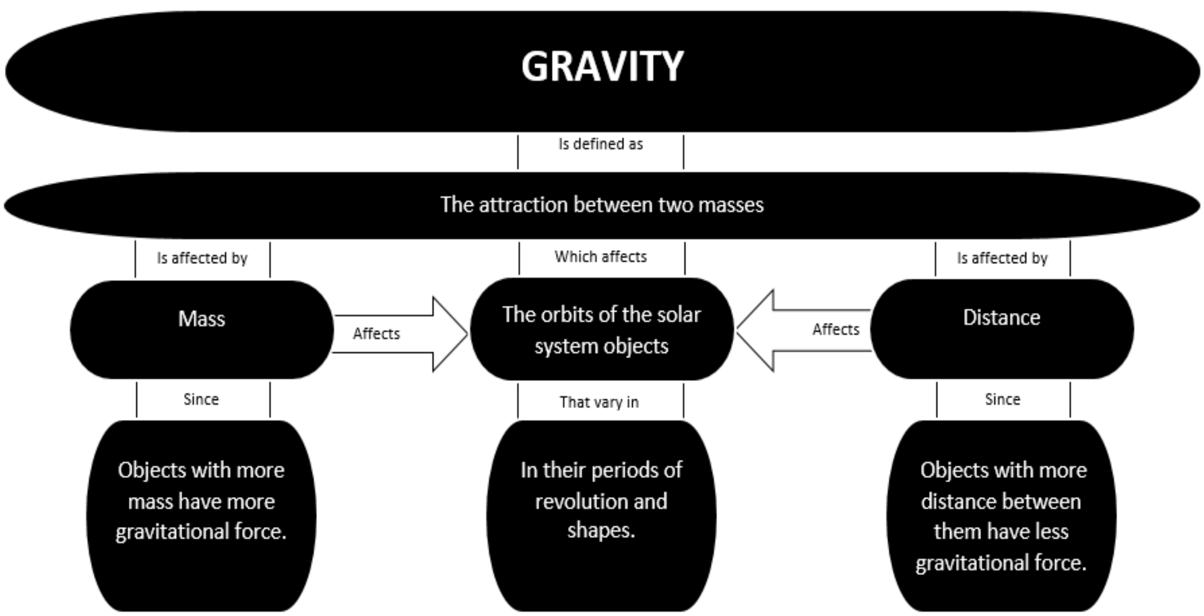
K-W-L CHART ABOUT GRAVITY AND ORBITS		
What do you KNOW about how the objects in our solar system move?	What do you WANT to know about these movements and their causes?	What did you LEARN? DEMONSTRATE your new understanding with words and/or pictures with captions.

Students will then click to the next page which will explain, “You will now take an assessment to show your knowledge. Try your best. This assessment will ONLY be used to help me to know how to best support you in the upcoming lesson.” Students will then complete questions, such as the sample question included below, that will allow the teacher to estimate the ability of each student for this topic as novice or expert. Such estimations of ability are crucial for assigning appropriately-designed content to each student and for creating heterogeneous groups where more knowledgeable students can support students with less knowledge to complete activities within their zone of proximal development.



Presenting the Stimulus Material (Content)

After submitting the assessment, the students will be able to continue to the next page which will feature the video clip, “What is Gravity” from https://www.youtube.com/watch?v=xICEt51A-Ac. Students will have control over the pacing of the video as well as the ability to view the transcript of the video clip (suggested for experts) or a hierarchy of knowledge (suggested for novices to view before the content and shown below). After viewing the video clip as much as needed, the students will respond to three multiple choice questions about the variables that affect gravity. Upon submission, the correct answers will immediately appear as well as feedback about why such answers are correct. Students will then be able to reflect by submitting any questions that they still have about the multiple choice questions, which will be addressed during the in-class session. In the bottom portion of the screen there will be an Exit button which the students can click to leave the lesson. Upon exiting they will receive the personalized message, “Thank you for all of your hard effort, which is crucial for your successful learning. We will continue this lesson in class.”



Providing Learning Guidance

During the next in-class session, the instructor will regain the attention of the students by reviewing the importance of learning about gravity and the learning objectives. The instructor will then highlight examples of student responses in the advance organizer that are of high quality in order to provide scaffolding via modeling for future responses connected to this topic. The instructor will also review the multiple-choice questions as needed, based on the students' reflections.

During the following activities, various types of guidance will be offered to novices. Examples of interpretative support include copies of the hierarchy of knowledge for novices and the elaborated feedback that the instructor will provide to all students on their models and their responses in the "L" box of the K-W-L chart. Experimental support will be provided in the form of guided questions in the worksheets pertaining to the simulation activity for novice students, a worksheet that supports the level of inquiry appropriate for the expert students (part of which is shown below), and video clips that novices can click and watch about how to use different features in the simulation. Reflective support will take the form of prompts to help each group to discuss all of their members' models of planetary orbits and the activity of encouraging students to evaluate their own understanding by completing the "L" box of the K-W-L chart.

- SELECT one question to examine with the simulation.
- FORMULATE a hypothesis from your observations.

Question:
Observations:
Hypothesis:
Evidence:

- SUMMARIZE the relationship between the force of gravity and the motion of objects in our solar system.
- EXPLAIN its importance.

Eliciting the Performance (Practice)

Using the tablets, students will illustrate digital models of different objects around the Sun (including the Earth, the Earth's Moon, and/or the International Space Station). These digital drawings will be supported in the sense that the students will be able to drag different objects like the Sun to different locations as well as to draw circles, arrows, or labels as needed. The amount of detail that each student will be expected to include in their drawing will vary according to ability. For instance, expert students will be asked to correctly position the Sun and its orbiting objects as well as to draw the arrows that represent the gravitational forces that each object exerts. Students will then project their models on the large screen at each of their tables and discuss the accuracies and inaccuracies of each model among their peers.

Providing Feedback

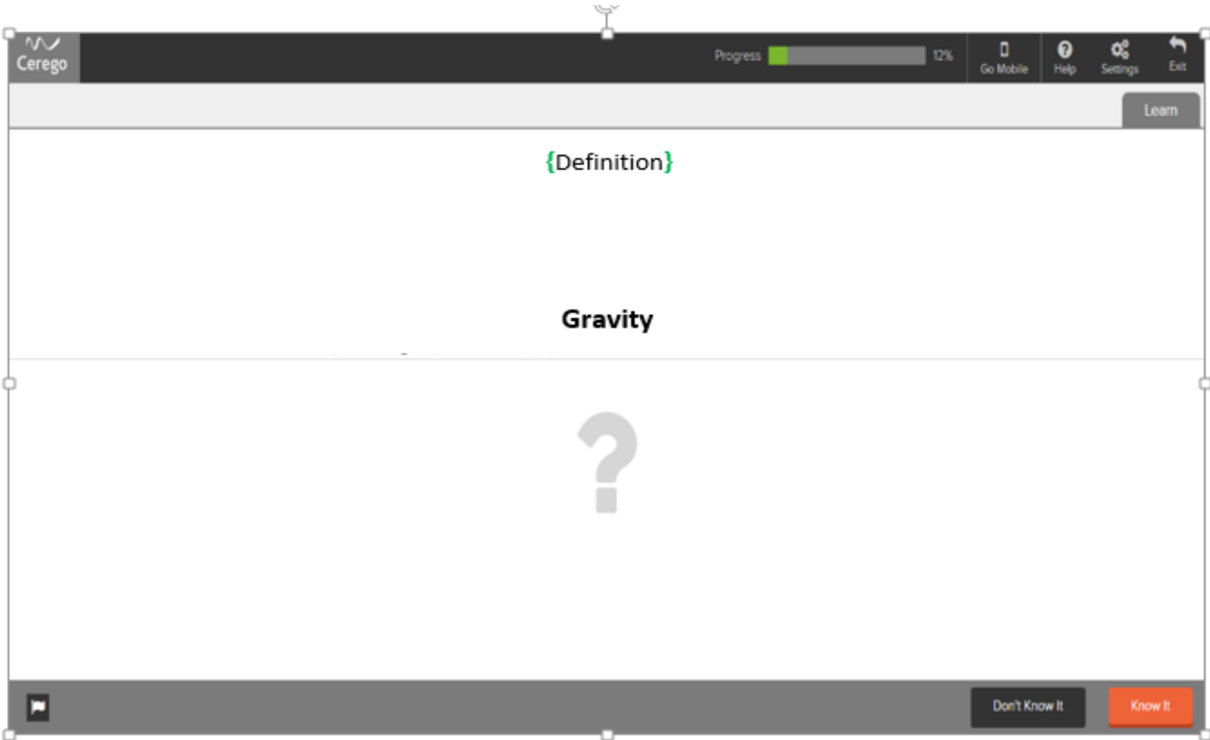
As the groups discuss each member's models, the instructor will circulate and provide feedback as needed. In line with motivational theories, the feedback should emphasize that the teacher's evaluation is task-involved, meaning that the teacher is reviewing it in comparison to the student's past performances, not the performances of other students. The students will take notes on ideas for revisions to their models which they can then implement after the presentations.

Assessing the Performance

After revising their models, students will utilize the "model" Phet simulation from https://phet.colorado.edu/en/simulation/gravity-and-orbits to apply and extend their understandings about gravity and orbits. Novice and expert students will receive differentiated worksheets: the worksheet for novices will represent guided discovery learning, while the worksheet for experts will represent inquiry learning. There will be about three expert students and three novice students at each table group for scaffolding. Afterwards, each student will be responsible for printing a screenshot of one of their orbits with a typed explanation and taping it on the whiteboards as part of the subsequent gallery walk. At the end of the lesson, the students will complete the "L" box of the K-W-L chart which the teacher will use as a method of assessing performance in addition to any observations made in the classroom and/or from the collected worksheets.

Enhancing Retention and Transfer

In order to enhance retention, after the class session, students will log into the class website and quiz themselves about important definitions (like that of gravity) and facts (like “as the mass of an object increases, its gravitational force increases”) via the Cerego program (as shown below). In order to enhance far transfer, during future classes, students will apply their knowledge of the variables that affect gravity in order to predict the orbital paths of different exoplanets from solar systems other than our own.



Critique of the Simulation

Design Aspects of the Simulation:	Strengths:	Weaknesses:	Possible Improvements:
Information Design	-Uses iconic representations for the Sun, the Earth, and the Earth’s Moon instead of symbolic (textual) representations, which is particularly beneficial for novices (Mayer, 2005b).	-Does not “use representations appropriate to the task at hand” (Mayer, 2005b, p. 750); the way in which the simulation is scaled will likely create misconceptions for novice learners and also	-Clarify the scaling factor: are the sizes and/or distance between the objects being scaled, and if so, by which number? -Redesign the simulation as a

	-Applies Multimedia Principles, including the **spatial contiguity principle** (since corresponding words and pictures are presented in the same vicinity) and the **temporal continuity principle** (since corresponding words and pictures are shown within the same time frame).	increase extraneous load for expert learners who will struggle with integrating what they know about the size of the Sun compared to the Earth with the scaling of the Sun and the Earth as shown in the simulation. -Assumes prior knowledge of the International Space Station, which many novices will lack.	multiple representation by adding a graph with the mass of an object as the x-axis and the amount of its gravitational force as the y-axis. -Allow students to identify the satellite as the International Space Station by hovering their mouse over it.
Interaction Design	-Includes “a measure of learner control” (Mayer, 2005b, p. 750) since students can easily display or hide different variables--such as gravity or velocity--by clicking or unclicking checkboxes.	-Includes a measuring tape tool that is difficult to use since it does not attach to any objects; this could lead to user error as well as frustration that negatively impacts student learning.	-Redesign the measuring tape tool so that it attaches to objects and the distance between objects can be easily measured.
Instructional Guidance	-Supports sense-making by utilizing “familiar objects [like arrows for gravity] to help students integrate information” and create mental models of the interactions among different objects in space.	-Does not include any opportunities for reflection.	-Supplement simulation with reflection opportunities like the “L” box of the K-W-L chart.

Theories to Support the Design of Lesson Plan

By showing a hierarchy of concepts to novice learners, the **pretraining principle** is utilized within the preliminary assignment for the lesson. The pretraining principle ensures that the students know the key elements before expanding their knowledge of a topic (Mayer & Pilegard, 2014). The important key elements of this lesson include vocabulary terms like period of revolution, orbits, mass, and distance. Without pre-training and prior knowledge of these concepts, it may be difficult for the novice students to later identify the relationship between the mass of an object and its gravitational force or to infer the trajectory of an object if the gravitational pull increases. The assignment before the in-class session is also written in a conversational tone (as evident in the opening questions) in order to make the worksheet more relatable to the students, thus applying the **personalization principle** within the lesson (Moreno & Mayer, 2010).

Not only does the hierarchy chart incorporate different concepts that the students can review before watching the video, it is also available for reference as the students are watching the video and completing the integrated questions. There is an audio feature of the video that can be turned on or off, and students can also view a transcript of the material, which is available for all learners to utilize if they choose. Expert students in the class can choose to read the objectives, instead of watching the full video, avoiding the **expert reversal principle**. Novice students in the classroom can hide the transcript of the video clip and, as predicted by the **modality principle**, learn better from spoken narration and images, rather than printed text and images, which could overload their visuospatial sketchpad. Similarly, novices can choose to listen to the learning objectives by turning on the audio feature. The learning objectives are the foundation of any lesson, so it is critical that all students fully understand what they are working towards achieving within the lesson.

Cognitive Information Processing--the model that includes different levels of memory in storing, retrieving, and transforming information--is critical for the long-term success of the learning objectives (Driscoll, 2005). In utilizing multiple choice questions throughout the assignment, the learners have the opportunity to analyze, process, and retain small segments of information in the overarching topic and lesson. There are three different assumptions in the **cognitive theory of multimedia learning**; one of which is **active processing** during which the learner can focus on, organize, and integrate the relevant information being learned to a mental model that connects with their prior knowledge (Mayer, 2014). When the students are focused on the questions, they are actively sourcing their mental models to answer the questions. When they answer--correctly or incorrectly--they are able to continue to organize and to integrate the information into their mental models of our solar system.

Simulations are proven to be most effective when incorporated in traditional lesson plans, especially with **learner control** and proper **guidance and feedback** (Domagk, Schwartz, & Plass, 2010). Learner control is enhanced by a variety of means: the ability to self-pace the simulation by playing, pausing, stopping, and resetting it; the ability to segment the content by adding circular lines for the orbital paths or different arrows for gravitational force; and the ability to change the modality, specifically the different combination of orbiting objects (Domagk et al. 2010). When the students are able to have some control over their learning, they start to take ownership and pride over their work. It increases their will to complete assignments and strengthens neural connections by requiring them to actively process and retain information. In sum, these aspects of learner control enhance the emotional, cognitive, and motivational development of the students (Domagk et al. 2010).

Guidance and feedback are also topics that have similarly positive effects on the learner. The opening questions in the pre-class session assignment provide learners with feedback from the teacher that assists them with correctly forming their mental models on the subject matter. Since the feedback is delayed, the students are able to complete the self-explanation assignments with more critical thought because they are not anticipating immediate feedback on their responses (Martinez, 2010). This correlates back to emotion, motivation, and volition in learning but also, the **feedback principle**, which proves that people learn better from multimedia when they are given feedback or “explanative input” on the solutions to problem sets (Johnson & Priest, 2014).

Some aspects of **guided inquiry**--specifically **interpretative support**, **experimental support**, and **reflective support**--are valued components of this lesson and simulation. Interpretative support refers to an educational design feature that “guides the learner in structuring knowledge from the domain” (Domagk et al. 2010, p. 7). Tools, such as the hierarchy chart that activates prior knowledge and constructive feedback that the students receive from the teacher about their K-W-L boxes, is intended to strengthen their schematas and generative processing (Domagk et al. 2010). Students also benefit by experimental support that includes “setting up and interpreting experiments by hints, guiding questions and feedback on experiments, for instance in a simulation” (Domagk et al. 2010, p. 7). The learners can access this hierarchy chart and their student worksheets at anytime throughout the lesson. There are also some tutorial videos provided to the students to help them to understand the navigation of the simulation. These videos allow the novice students to be exposed to potential questions on how to operate the simulation as well as key learning aspects of the simulation.

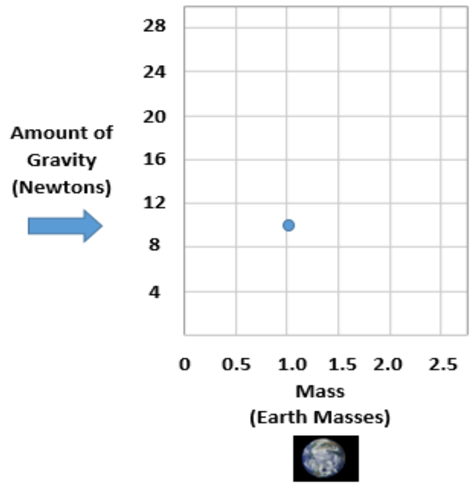
The simulation, in many ways, is based on **Schema Theory**--a theory where schema facilitates the use of knowledge for its users. There is schema signaling with features like the “reset button” at the bottom right corner of the screen, which is a very clear design heuristic, and the arrows for velocity and gravitational force. These arrows should cue the strength and direction of the object’s velocity and which objects are connected by gravity to the learner. The lesson incorporates a K-W-L chart, which helps the students to organize and to develop appropriate mental models for the topic of gravity and orbits. The general lesson itself is organized in a way where the large ideas of the lesson are introduced first to the learner, followed by increasingly specific concepts discussing the orbital systems of our solar system.

Cognitive Load Theory is the marriage between instructional design and human cognitive structures (Sweller, 2014). The lesson uses differentiated student worksheets based on the learner’s level of knowledge and understanding in the topic area. The working memories of the learners are not overloaded with unnecessary and unproductive information; these students are then able to apply the appropriate amount of effort in schema construction. In completing their student worksheets, the learners are testing their knowledge of the topic, fermenting the facts they know, and engaging in **generative processing**--"the achievement in learning goals by fostering appropriate cognitive processing during learning" (Clark & Mayer, 2016, p. 226).

According to Clark and Mayer, there are six components that add to student engagement and increase attachment to their learning, many of which are included in the lesson (2016). The student worksheets ask the learners to make self-explanations and to answer relevant questions--two components of engaging students in such a way that leads to generative processing. Other components include the supported drawing activity and the collaborative observations of tutoring when the students are recreating the orbital paths of varying objects during the lesson.

Although there are no **multiple representations** in the simulation, the lesson could have been enhanced by utilizing this principle. A possible multiple representation could be a graph that represents the relationship between the mass and gravitational force of an object, alongside the original simulation. Since it can be difficult to decipher the simulation at first glance, this could be an instance where the student could learn better from more than one example presented at once (Ainsworth, 2014).

As discussed throughout the paper, the theoretical elements included before and during the class session are all intended to help the students to strengthen their schemas on astronomy by building interest and motivation via behavioral, cognitive, and metacognitive activities. **Intrinsic motivation** refers to the emotional associations that lead a person to



engage in an activity for [their] own sake, rather than for rewards that lie outside the activity" (Martinez, 2010). When the K-W-L charts are repeatedly reviewed throughout the lesson, the students are internalizing the importance of the topic and the rationale for learning it. This motivates them more than if they were focusing on receiving a "good grade" on their assignments (the extrinsic reward). Furthermore, the learning objectives that are set for the students are specific, or **proximal goals**. Such goals tend to promote "positive effects on interest and intrinsic motivation when they are challenging--when they are closely matched to ability" (Martinez, 2010). In developing the lesson according to each student's ability, one is able to help the learner to enter the realm between what they can do without guidance and what they cannot do without guidance, otherwise known as the **zone of proximal development** (Driscoll, 2005). The educational "boosts" that are purposely incorporated throughout the lesson are designed to provide students with just enough scaffolding and support to challenge their cognitive processing, while still ensuring the opportunity for successful learning.

References

Ainsworth. (2014). The multiple representations principle in multimedia learning. In R. Mayers (Ed), *The Cambridge Handbook of Multimedia Learning* (Chapter 20). New York: Cambridge University Press.

Clark, R. C., & Mayer, R. E. (2016). E-learning and the science of instruction: Proven guidelines for consumers and designers of multimedia learning. Hoboken, NJ: John Wiley & Sons. (Chapter 11)

Domagk, S., Schwartz, R., & Plass, J.L. (2010). Interactivity in Multimedia Learning: An integrated Model. Computers in Human Behavior.

Driscoll, M. P. (2005). Psychology of learning for instruction (3rd ed.). Needham Heights, MA: Allyn & Bacon.

Johnson, C. I., & Priest, H.A. (2014). The Feedback Principle in Multimedia Learning. In R. Mayer (2nd Ed.), The Cambridge Handbook of Multimedia Learning (Chapter 19). New York: Cambridge University Press.

Lohman TG (1986): Applicability of body composition techniques and constants for children and youths. In *Exercise and Sport Sciences Reviews*, ed. KB Pandolf, pp 325–357. New York: Macmillan.

Martinez, M. E. (2010). Learning and cognition: The design of the mind. Boston: Merrill. (Chapter 6)

Mayer, R.E. (Ed.) (2005a). *Cambridge Handbook of Multimedia Learning*. New York: Cambridge. Chap 24 - The Expertise Reversal Principle in Multimedia Learning.

Mayer, R.E. (Ed.) (2005b). *Cambridge Handbook of Multimedia Learning*. New York: Cambridge. Chap 30 - Multimedia Learning with Simulations and Microworlds.

Mayer, R.E. (Ed.) (2014). *Cambridge Handbook of Multimedia Learning*. New York: Cambridge. Chap 1 - Introduction to multimedia learning.

Mayer, R.E., & Pilegard, L. (2014). Cognitive Theory of Multimedia Learning. In R. Mayer (2nd Ed.), *The Cambridge Handbook of Multimedia Learning* (pp 43-71). New York: Cambridge University Press.

Mayer, R.E., & Pilegard, L. (2014). Principles for Managing Essential Processing in Multimedia Learning: Segmenting, Pre-Training, and Modality Principle. In R.

Mayer (2nd Ed.), *The Cambridge Handbook of Multimedia Learning* (Chapter 13). New York: Cambridge University Press.

Moreno, R., and Mayer, R.E., (2010). Techniques That Increase Generative Processing in Multimedia Learning: Open Questions for Cognitive Load Research. In Plass et al. (Ed.), Cognitive Load Theory. New York: Cambridge University Press). [PDF]

Sweller, J. (2014). Implications of cognitive load theory for multimedia learning. In R. Mayer (2nd Ed.), The Cambridge Handbook of Multimedia Learning (pp. 27-41). New York: Cambridge University Press.