Performance Assessment as an Anchor for Cross-Site Investigations of Customization

CILT Seed Grant Final Report

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Project Summary

The goal of this project is to create a community of researchers dedicated to a multifaceted investigation of customization across multiple sites. Our collaboration relies on assessment as a primary vehicle for understanding the implications of customization of student learning. The aim of our work is to develop a model for crafting robust assessments that provide a common platform for evaluating the outcomes of student learning across multiple, synergistic curriculum projects.

One of the challenges to understanding how curricular innovations are used in different contexts in clarifying the implications of local customization on student learning. This applies to different implementations of the "same" project as well as to implementations of different projects that aim to achieve similar learning goals. Our work aims to examine this challenge by engaging in a coordinated effort to develop assessment tools that bridge two different astronomy projects that are intended to address similar learning goals. To do this, we have engaged in an analysis of the relevant subject matter, the curriculum materials, and the stated learning objectives of these projects in order to develop a coordinated system of assessments that inform us of student achievement across implementations sites.

The context for this collaboration is student modeling in astronomy. Our work has accomplished the following:

- Identification of core learning objectives in Planetary Motion and mapping of these objectives to national standards.
- Analysis of core learning objectives in light of standards and relevant research on obstacles to student learning.
- Curriculum analysis to identify synergies across two different astronomy projects and to identify common tasks that address key learning objectives.
- Development of a "bridge task" (computer-based student modeling of planetary motion) for use across implementation sites. This task was (a) tailored to our core objectives and (b) tailored to fit within the curricular flow of each project.
- Development of assessment blueprint and instruments for measuring student progress at multiple levels, including "distal" and "proximal" test batteries, and a "close" measure consisting of a performance assessment task.
- One trial implementation of the modeling task and assessment instruments, and another implementation planned for the future.

This work will provide a model for other attempts to align cross-site curricular implementations by engaging in analyses of learning objectives and assessments to measure them.

Project Rationale: Assessment and Curricular Customization

There are at least three different levels on which to study customization of educational reforms: variations in curriculum implementation across sites, variation in teacher practice across classrooms, variations in student learning. Each of these approaches requires the examination of curriculum, instruction, and assessment—though often with different emphases. This project focuses largely on the role of assessment—in particular, performance assessment—in understanding the causes and consequences of curricular customization across sites.

The goal of this project is to examine the customization question from the "inside out" by focusing our attention on learning outcomes across sites and ways of measuring such results. This work complements other customization studies (Cheng & Rose, 2002; (Brown 2002) that have examined the instructional and curricular factors that influence these learning outcomes.

There are several arguments for adopting this focus:

- Customization studies that focus on variations in curriculum and instruction may document patterns of similarity and difference across sites, but do not describe the implications of these variations for student learning.
- While many customization efforts center on implementations of a common curricular module, our effort aims to find synergy across distinct but related projects (in this case, the WISE astronomy project and NASA's Astronomy Village project). By creating a common assessment framework that aligns with these projects, we are using assessment as a platform on which to examine cross-site variation in learning across two projects that emphasize common learning goals.
- Given the current policy climate, reform-based educational research must be mindful of national standards, be able to describe advanced modes of learning with respect to such standards, and provide convincing evidence of the benefits and legitimacy of more advanced modes of learning. By examining issues of customization from an assessment perspective, we aim to address concerns about learning outcomes that often arise with the wide scale implementation of reform-based interventions.

Participants

Core collaborators include:

Matt Brown, University of Illinois at Chicago
Britte Cheng, University of California, Berkeley
Dan Hickey, University of Georgia
Steven McGee, Wheeling Jesuit University
Ken Hay, University of Georgia

Christina Schwartz, Michigan State University

We were also pleased to welcome an additional collaborator, Adam Tarnoff, of the University of Illinois at Chicago. Adam's subject matter expertise in astronomy has proven to be an invaluable asset to the project. For various reasons, an intended collaborator, Lisa Bievenue of the Shodor Educational Foundation, was unable to contribute on a regular basis to the project.

The group is also grateful to two 7th grade science teachers in Hawaii who pilot tested our modeling activity and several of our assessment instruments as part of their implementation of the NASA Astronomy Village curriculum. Together, the teachers contributed at least 9 class periods to our study, and they engaged in several rounds of email-based correspondence prior to their classroom work.

Results and Implications

What findings/products did your work produce? What are the implications of those results for the field?

Standards & Learning objectives

We began our work by mapping two existing curricular projects onto three NSES standards (grades 5-8). The standards pertain to "Earth and Space Science" (Earth in the Solar System standards) and "Physical Science" (Motions and Forces" standard):

- D3.2. Most objects in the solar system are in regular and predictable motion. Those motions explain such phenomena as the day, the year, phases of the moon, and eclipses.

- B2.1. The motion of an object can be described by its position, direction of motion, and speed. That motion can be measured and represented on a graph.

- D3.3. Gravity is the force that keeps planets in orbit around the sun and governs the rest of the motion in the solar system. Gravity alone holds us to the earth's surface and explains the phenomena of the tides.

The results of our mapping task are exemplified in Appendix B.

The three standards were identified as common goals of both curricula. This mapping process uncovered key ideas that would influence our next steps and specifically, the design of the modeling task. First, it became clear where certain curricular activities did not sufficiently address learning objectives despite their design to do so. Within the context of each curriculum, the limited role of specific activities was not as apparent as when considered within a larger framework of a companion curriculum and standards.

Second, we noticed that robust, constructivist activities like modeling, as opposed to more didactic activities (e.g., reading and reflecting), were pivotal to curriculum design.

For instance, all of the standards are addressed by the modeling activity in WISE. While this confirmed the group's intuition that modeling activities are pivotal within each curriculum, this discovery provided evidence of the importance of the modeling task we would design as well as the range of objectives the task would need to address.

In reaction to our first mapping activity, we deconstructed the focus standards and curricular goals into smaller 'learning objectives'. Although the standards, on first reading, are quite specific, the way in which student understanding of those standards might be observed is not obvious. This level of detail was the point at which our two curricula diverged. These differences were significant as they reflected specific activity designs. For instance, in both curricula, students learn that planets and stars exert gravity on one another. WISE students encounter this concept in the context of the red and blue-shifts produced by stellar wobble, while NASA students encounter this concept in the context of stellar pathways, as observed from Earth. The activities that support these different contexts and the expectations of students' conceptualizations of the role of gravity are, predictably, varied. Subsequent modeling task and assessment design therefore demanded a finer grain analysis. We engaged in an attempt to produce a 'standards-plus' document. This document would enumerate the group's vision of what each standard would realistically entail for students. 'Learning objectives' were an attempt to articulate this finer grain description. A literature review of learning challenges in astronomy (and related disciplines) also aided our articulation of these more specific learning objectives. Perhaps not by chance, hallmark student difficulties reported in literature easily translated into the objectives we worked to clarify. With these objectives specified, we then re-mapped curriculum tasks and the NSES standards. The results of the second mapping phase are depicted below in Table 1.

Table 1: Learning objectives & standards mapped to WISE and NASA Astronomy projects

	Target Content (aka Learning Objective)	NASA Curricular Tasks	WISE Curricular Tasks	NSES Standard
SOLAR SYSTEM COMPOSITION	Solar system definition		*Planetary formation activity*	
	Solar system scale		**Planetary Formation activity	
PLANETARY MOTION / ORBITAL DYNAMICS (GRAVITY AND ORBITS)	Planets move in regular, predictable paths (orbits) around stars.	Do Stars Move?; Search for Planets Around Nearby Stars, The (Lecture; Image Processing Activity; Detecting Planetary Systems	Modeling activity	D3.2
	The motion (orbit) of objects (planets & stars) in a solar system is governed by gravity.	"Gravity & Center of Mass"; Modeling activity; Do Stars Move; Detecting Planetary Systems	Modeling activity	*D3.3*
	Mutual gravitation -- all bodies in a system exert gravitational forces & all bodies are subject to the effects of gravitational forces.	"Gravity & Center of Mass"; Wobbler Activity; Modeling activity	**Modeling activity	D3.3
	Strength of gravitational attraction between bodies is determined by their mass and their radius of separation	"Gravity & Center of Mass"; Modeling activity	*Modeling activity*	
	The mass of a planet and its orbital radius has an effect on the speed and direction of its motion (period and shape of orbit).	Modeling activity; Wobbler activity	Modeling activity	B2.1
	Because physics is the same everywhere, the laws of orbital dynamics (planetary motional) apply in all solar systems… even our own!	Do Stars Move?; Modeling activity	Modeling activity	
	Our own solar system is a model of some of the phenomena that are observed in other solar systems.	Modeling activity	Inferences activity; Modeling activity	
	Multiple body systems are complex.	Modeling activity	Modeling activity	
SURFACE CONDITIONS / SUITABILITY FOR LIFE	The distance of a planet from its star affects the surface temperature of the planet.		Inferences activity; Knowledge Files activity	
	The mass of a planet can be used as a clue to make inferences about its density (composition).		Modeling activity; Data Table Analysis activity	

This second mapping activity identified points where curricula differentially ‘covered’ objectives. We were able to see how the curricula were similar and different in ways that were useful and set our agenda for designing the modeling activity.

With this second mapping done, we could also see where the standards we were focusing on did not encompass integral learning objectives. Other NSES standards do cover some of this territory missed by the focus standards; we see, however, that standards need to be linked within a framework of conceptual domains in order to be maximally effective at the level of specificity we found so useful for design, the level of ‘learning objectives’. We consider this experience with designing around standards an important result of our mapping activities and evidence of consensual wisdom in the educational research community. That is, the standards we focused on initially masked the learning objectives that emerged from a close analysis of the curricula. Cherry picking standards to teach -- a common classroom practice -- can lead to an obligation to cover an impoverished set of learning objectives that only become visible when standards are translated into the fuller set of curriculum goals and the context of instruction. In our case, this translation occurred in the process of designing classroom activities.

We also identified additional objectives relating to students’ perception and use of models. Christina Schwarz offered the group a perspective on students’ ‘modeling’ skills. Specifically, we used Schwarz’s four categories of ‘modeling ability’: the nature of models (what counts as a model), the process of modeling, the evaluation of models, and the utility of models and modeling.

These learning and modeling objectives defined the goals of the modeling task. This is where we initiated design of the modeling task.

Modeling Task

Summary the modeling task.

(Note: A detailed account of the task is presented in Appendix A.)

Part I. The first part has students examine models of mass, velocity, and orbital radius for each of the familiar 9 sol-system planets and assess for each planet (a) it’s habitability, and (b) it’s effect on the motion of the sun (i.e. does the planet cause the star to move enough that we could detect the presence planet from far away). In so doing, they confront preconceptions (identified in our literature review) about planetary motion and apply their knowledge of how mass, velocity, and radius interact to determine the speed and trajectory of a planet’s orbit. Note: We provided students with pre-constructed models of all 9 sol-system planets.

Part II. In the second part, students are given a data table describing the orbital characteristics of several exosolar planets. Students then apply their knowledge by making qualitative (i.e. yes/no) predictions about habitability and delectability for each new planet. After justifying and discussing their predictions, students return to the modeling environment to test their hypotheses. In this stage, students are applying their understanding of habitability (distance of planet to star) and delectability (ration of mass of planet to mass of star) to make predictions. Again, student preconceptions were expected to reappear and in testing their predictions, students have the opportunity to work with models to test their ideas (whether preconceptions or new ideas uncovered in the first modeling stage).

Part III. By now students will have noticed that they have not yet encountered any planets that are both habitable and detectible. In part three, they will be asked to (a) explain why none of the planets detected so far are habitable (b) determine if it is possible for a planet to be both habitable and detectible and (c) propose a method for detecting habitable planets. Students are building on ideas from both the first and second stages of this activity to consider larger questions about the means of identifying habitable planets. This extension also reinforces connections among students' earlier work (searching for life in the universe, comparing methods of searching for life, observing stars from Earth, etc.).

How does the task address identified modeling objectives?
In each stage of the modeling activity, students are using the models in increasingly sophisticated ways. In the first stage, students are primarily observing planetary-system models. In this second stage, students are introduced to models as means of testing hypotheses. In the third stage, modeling is used as a means of supporting student generation of new questions or lines of thinking. Students are also asked to consider the limitations of the models they are using. Students are considering the utility of the visual models constructed in Gravitation, as well as the scientific model of 'habitability' and 'delectability' underlying the activity – supporting students' recognition of multiple 'forms' of models or what counts as a model.

How does this address identified NSES standards?
The modeling task addresses the standards by focusing students on the interaction of the motion of planets and their host stars. Students analyze the motion of planets in models created for them and modify the motion of planets to help them answer questions about which planets might be habitable and/or detectable using the 'stellar wobble' method of planet detection. The 'wobble' method is predicated on the notion that observed irregularities of stellar motion signal the existence of an orbiting planet. Students deduce that in absence of an orbiting planet, the motion of stars is regular and predictable. Students also come to see that in multiple-body systems, motion is still predictable and regular albeit altered.

Students learn that planetary motion and stellar motion are determined by mutual gravitation and that they can describe this motion in terms of the position, direction, and speed of each planet-star system or model. The modeling tool requires that students specify the position of orbiting planets. Based on the mass of the two bodies being modeled, speed is calculated by Gravitation. While students do not calculate speed themselves, the apparent speed of planets is controlled by students' designation of position and mass.

Understanding the implications of stars' irregular, though predictable, motion (as influenced by orbiting planets) is key to connecting this task to previous curriculum activities that focus on the search for life in the universe and observing the motion of stars from Earth.

Modeling Software: Gravitation vs. Virtual Solar System

We originally intended to use the Virtual Solar System modeling environment developed by Ken Hay. However, we were forced to abandon this plan at the last minute due to the fact that the computers at one of our schools (in Hawaii) used Mac OS, not Windows, and currently VSS is only available for Windows. Instead we used a modeling environment called "Gravitation", previously developed by the team working on NASA curriculum.

Assessment blueprint

Our assessment blueprint is based on the following themes:

Backward Design.

We have modeled our work on the Backward Design approach of Wiggins and McTighe (1998). Wiggins's & McTighe's *Understanding by Design* model lays out a three stage "backward" design model of curriculum development. It is consistent with contemporary views of knowing and learning, especially the notion that all students must understand the deeper conceptual structures of a domain, and that these structures provide a context for learning specific facts and skills (rather than vice versa).

In contrast with many other modern constructivist approaches, this approach provides a much more structured learning environment and affords detailed objective assessment and accountability. Wiggins is one of the leading experts in assessment, and McTighe directed the highly regarded assessment-oriented reform efforts in Delaware; hence the model is essentially an assessment-driven approach

While the model was designed for creating new curricula, many are using it to define existing curriculum. We applied this framework when attempting to define a set of shared learning objectives that triangulated across our two curriculum projects and our chosen national standards. It provided a means to separate enduring, important, and familiar knowledge and a model for engaging in a "backward design" process in which identifying desired results and considering what constitutes acceptable evidence of these results then informs the design (or in this case, the adaptation) of curriculum materials.

Shavelson's levels of curricular sensitivity.

For the design of our assessment framework, we adapted a "multi-level" approach to the design of classroom assessments (Ruiz-Primo, Shavelson et al. 2002). This approach, and how we applied it, is presented below.

DISTAL. The distal measure forms the basis of claims of standards-based learning. It is designed to measure individual student achievement with respect to the standards. Key to the evidential validity of the distal measure is the fact that it plays no role in driving curricular decisions (i.e., it is not shown to the teacher and does not influence classroom learning tasks). For our distal measure, we randomly selected 40 test items—consisting of multiple choice, short answer and completion questions— from the Assessment Items Listing of the Holt Science & Technology Earth Science textbook. The distal measure is intended to be used as a pre- and post-test and can be administered to a control group.

PROXIMAL. The proximal measure consists of "cherry picked" test items that directly target the intended learning goals of the interventions. While the proximal measure is implemented as a standard test at the end of the unit, it is highly visible during implementation—teachers can teach directly to its content and use it as a way to determine if the curriculum is working on a day-to-day level. However, it is administered formally enough to compare how different students in the same classroom are doing or to compare different implementations of the same curriculum.

CLOSE. The close measure consists of a "zero transfer" task, highly embedded in the curriculum, in order to provide formative feedback on student accomplishment. In our case, we created an assessment that essentially mirrored the modeling task used in the classrooms, using screenshots from the modeling software and highly similar tasks that targeted precisely the intended learning objectives for that activity. The close measure is administered immediately after its corresponding classroom activity.

Trial Implementations

Description of Hawaii implementation

Steven McGee coordinated two implementations of the modeling task with two NASA Classroom of The Future teachers. These implementations, involving 7th grade classrooms, involved the collection of qualitative data (using video) and pilot testing of related pre- and post-assessments (distal, proximal, close, and immediate).

Two seventh-grade science teachers at a private middle school in Hawaii, agreed to devote four class periods to insert the Gravitation activity into the AV2 sequence. Teacher K's classes were in the middle of the core research investigation on Search for Life. Teacher R's class had not yet started AV2. For homework, the students read either Hunting for Hidden Planets or an article on wobblers from Space.com plus an article about center of gravity. Teacher K felt that Hunting for Hidden Planets was too complicated for students, but gave it as an option for them. Some of the students accepted the challenge to read the article. One student actually built a physical model of the wobbler effect. Steven took pictures of the model and collected video of him describing his model.

The initial discussions of the lessons also included 1-2 class periods for students to conduct the wobbler NIH Image activity from AV1. However, technical difficulties and confusion over the pretest prevented Teacher K from being able to implement the NIH Image activity. Teacher K gave the pretest, the day before Steven arrived. Steven chose to implement the modeling activity with the students and forego the NIH Image activities.

It was his impression that the students developed a decent understanding of wobbler from the article.

The schedule of classes is such that the teachers see each class five times every six days. This creates a situation where each section does not meet at the same time everyday. The driver for scheduling is the music program. Band/orchestra members are grouped together and the choir members are grouped together. Both teachers have hypotheses about band/orchestra members being academically superior to choir members. The table below shows the eight sections that are implementing the activity and the number of times that Steven taught those sections. Both teachers completed the activities based on how Steven modeled the activity. Then they each administered the proximal and close post-tests.

Section	**# of Classes Taught**
Teacher K	
7-2	1
7-3	2
7-4	2
7-5	1
Teacher R	
7-12	0
7-13	2
7-14	1
7-15	0

Description of Berkeley implementation

Plans are currently underway by Britte Cheng to implement the WISE curriculum and modeling task in 5 eighth grade classrooms in a suburban middle school in May, 2003.

Data collection

One team of students in each classroom was (or will be) videotaped according to the human subjects requirements of the host project.

Pre and post-instruction assessments were (or will be) implemented to help researchers' gauge students' content understanding of planetary motion. Items targeted to concepts integral to the modeling activity and students understanding of modeling (cf. Schwarz) will also be used.

In the Berkeley implementation, a closer look at students' use of the modeling activity will be possible. Students modeling will be examined through think-aloud reflections throughout the two-day activity. Screenshots of students' models will capture phases of the activity. Final 'inquiry reports' will be constructed by each student team to capture students intentions (what they wanted to model), what modifications (if any) of planetary characteristics or orbital motion characteristics the model embodied, what the model is meant to communicate, and whether their model succeeds in performing students' intended functions.

Resources

Include a list of available resources, perhaps to be posted via a website? The list might include:

- Content analysis table (Standards-Plus Document)
- The modeling activity
- Assessment instruments

Lessons Learned: Collaboration

- *How successful do you consider this collaboration to have been?*
- *What did you learn about the challenges of cross-institutional collaboration and ways to combat those challenges?*
- *Many of you used yahoo groups (aka egroups) to communicate. Was this tool useful? In what ways? Are there others tools and support that would have made the process easier for you?*

Given what now appear to be our own unrealistically high expectations for a seed grant, our collaboration was a success. In addition to our development work, the primary success of this project was the learning of its participants. Our diverse expertise—including curriculum development, assessment, modeling, astronomy subject matter, and classroom implementation—provide to be highly complementary, and group members learned a great deal from one another. Furthermore, multiple group members have reported that the work done in this collaboration will benefit (or already has benefited) their work in other areas.

The primary challenge to our work was the amount of time required to engage in our planned development, and the limited resources we had to support the time demands placed on participants.

To address the challenge of coordinating across distributed sites, we adopted a team-based structure for accomplishing our work. These teams centered around each participant's area of expertise, and generally involved one "lead" and another "helper". This structure helped to assign accountability, which was essential given that this project was not the primary priority of most members.

The teams were divided as follows: subject matter, curriculum, assessment, and modeling. Work in each team proceeded across three subsequent cycles, each culminated with a teleconference check-in, and punctuated with frequent distributed communications (emails and phone calls) among individual group members.

The first cycle of work, following our kickoff meeting at ICLS in Seattle (which was described in mid-term report), involved the following tasks:

In the first cycle of work, the team goals and responsibilities were as follows:

- Curriculum team analyzed our two chosen astronomy projects to identify points of synergy between them and tasks in each that addressed target standards (see appendix).
- Subject matter team unpacked the standards in light of the domain content, identified conceptual challenges and barriers to learning, and relevant research in the area. The goal here was to have some sort of nascent model of how students represent knowledge and develop competence in the sub-domain (see appendix).
- Assessment team developed a framework that would allow us to measure student accomplishment of the learning objectives in light of both the chosen national standards and the more fine-grained learning issues identified by the subject matter team. Initial work focused on identifying theoretical work to support our goal, as well as the preliminary investigation of test questions and other assessment tasks that map to the relevant subject matter.
- Modeling team examined the affordances of various available modeling environments and ways that modeling tasks could be used to target the learning objectives.

The second cycle of work involved coordination across teams. For example, the assessment team shared two theoretical frameworks, "Understanding by Design" (Wiggins & McTighe, 1998) and Ruiz-Primo and Shavelson's (2002) levels of distal, proximal, close, and immediate assessments. The former provided a framework for the subject matter team to classify target knowledge as either "enduring, important, or worth being familiar with"; the latter provided the modeling team with a useful construct that stimulated the development of a "close" modeling performance assessment task. Also, the subject matter, curriculum, and modeling teams coordinated to develop a modeling "bridge task" that fit within both the Astronomy Village project and the WISE Astronomy project and that addressed the target learning goals and the expected barriers to student learning.

The third cycle focused on the necessary preparations for a trial classroom implementation. This implementation involved a portion of the NASA Astronomy Village project, and allowed us to test our modeling task, as well as our distal, proximal, and close assessments.

It is important to note that, as with many distributed collaborations, coordinating our work across sites was a significant challenge. Key obstacles included scheduling meetings, meeting milestones, and supporting each participant's work given the limited resources of the grant. As a result, we made every effort to draw synergistically off each participant's existing work. However, significant original work was required for this project and this posed constant conflicts of time and resources.

Our primary mode of communication was email; however we relied extensively on telephone conversations (including group telecons) for synchronous communication. These telecons proved essential for getting members on the same page and were far more productive than asynchronous communications.

One significant implication of this is that we needed to scale back our expectations for the outcomes of the project. Early on, we shifted our focus from supporting and studying cross-site implementations of our astronomy projects to laying the groundwork for such as study and developing the required tools, instruments and work plans for accomplishing this (though, as mentioned, limited classroom testing was accomplished). In hindsight, work involving classrooms involves a level and degree of coordination that was simply beyond our means. This is largely due to the need for flexibility when dealing with classrooms—something that is not possible given the time it takes to coordinate cross-site efforts.

Next Steps

Where will you go from here? Has this project resulted in any subsequent grants or proposals, or ideas that you will carry forward to future work?

1. Additional implementation in Berkeley (by Britte Cheng)
2. AERA paper, including attempts to analyze data from implementations in Hawaii and Berkeley
3. Creation of a website containing this document as well as links to additional resources we generated.

Appendices

Appendix A: Modeling Activity:

FINDING LIFE IN THE UNIVERSE: Modeling Planets and Orbits
(Teacher Packet. Pages 1-2 describe the goals of this activity. Remaining pages give a lesson plan including teacher notes that point out possible student obstacles, etc. Text in *italics* is the text that students see in their version of this packet. Plain text is information for teachers.)

Modeling Exosolar Planets: Where might life exist?

Curriculum Learning Objectives:

SOLAR SYSTEM	Solar system definition
	Solar system scale
PLANETARY MOTION / ORBITAL DYNAMICS (GRAVITY AND ORBITS)	Planets move in regular, predictable paths (orbits) around stars.
	The motion (orbit) of objects (planets & stars) in a solar system is governed by gravity.
	Mutual gravitation -- all bodies in a system exert gravitational forces & all bodies are subject to the effects of gravitational forces.
	Strength of gravitational attraction between bodies is determined by their mass and the square of their radius of separation
	The mass, velocity and radius of separation between two bodies determine the characteristics of their orbital motion (period and shape of orbit).
	Because physics is the same everywhere, the laws of orbital dynamics (planetary motional) apply in all solar systems… even our own!
	Our own solar system is a models of some of the phenomenon that are observed in alien solar systems.
	Multiple body systems are complex.
HABITABILITY	The distance of a planet from it's star effects the surface temperature of the planet.
	The mass of a planet can be used as a clue to make inferences about it's density (composition).

Modeling Activity Goals

Using the *Gravitation* environment to model the effects of mass, velocity, and orbital radius on planetary motion, students will demonstrate an understanding of the way these impact (a) a planet's **habitability**, and (b) whether the planet's presence will cause a **detectable** change in the motion of it's host star.

Modeling Activity Summary (3 parts)

I. Following a short introductory class discussion about the purpose of modeling in this activity, the first activity has students examine models of mass, velocity, and orbital radius for each of planets in our solar system. Students assess for each planet (a) it's habitability, and (b) it's effect on the motion of the sun. In so doing, they confront preconceptions about planetary motion and apply their knowledge of how mass, velocity, and radius (distance between the planet and its sun) interact to determine the speed and trajectory of a planet's orbit.

II. In the second part of this activity, students are given a data table describing the orbital characteristics of several exosolar planets. Students then apply their knowledge by making qualitative (i.e. yes/no) predictions about habitability and detectability for each new planet. After justifying and discussing their predictions, students return to the modeling environment to test their hypotheses.

III. By now students will have noticed that they have not yet encountered any planets that are both habitable and detectible. In part three, they will be asked to (a) explain why none of the planets detected so far are habitable (b) attempt to alter a modeled planet to determine if a planet can be both habitable and detectible, and (c) explain why it is impossible for a planet to be both habitable and detectible.

Lesson Plan (two 40 minute periods).

Student should work in pairs.

Activity (1) Intro to Modeling - 15 minutes

Teacher should discuss how modeling has been used in previous classes. Discussion should lead to the purpose of this modeling activity (i.e. to examine the important characteristics and gauge their effect on habitability and detectability). Discuss how model is like reality and not like reality. Note: modeling in this activity is not only a representation activity; students are modeling in order to answer open questions about exosolar planets.

Teacher note: Students may need to review the following terms: velocity, radius, eccentricity, jovian, terrestrial, habitable (habitability),

Activity (2) Models Part 1: Eliciting student pre-conceptions - 20 minutes

Students look at planets in our solar system to highlight key issues about habitability and detectability. With the exception of Earth and Mars, each planet may have one or more reasons why it is not habitable -- i.e., Mass: is it jovian or terrestrial; Radius: is its mean oribital radius in the zone of habitability with respect to the star; Velocity: is the orbit so eccentric that are certain points fall within the zone of habitability while other points are outside the zone? Students will also observe the sun and look for detectable motion resulting from gravitational interaction with the planet. One goal of this phase can be to develop a set of "rules" that describe the role of the 3 factors with respect to habitability and detectability. Students will enter data that has been prepared for them in a structured worksheet. Because we want to help students resolve (or at least confront) faulty prior conceptions, some planets may illustrate one 'habitable' characteristic' and one characteristic that make it unlikely to be habitable.

Worksheet questions will scaffold consideration of these target concepts (students should turn this worksheet in to their teacher at the end of day one and get it back for their work in day two).

Student Worksheet: Life in our Solar System

1) On what kind of planet might life exist?

Put a check mark in the column labeled "Terrestrial" if you think the planet will be terrestrial or rocky, like Earth. Put a check mark in the column labeled "Jovian" if you think the planet will be gas-based, or jovian, like Jupiter.

Planet	**Mass (Earth Masses)**	**Terrestrial?**	***Jovian?***
Mercury	0.055		
Venus	0.82		
Earth	1	√	
Mars	0.107		
Jupiter	317.8		√
Saturn	94.3		
Uranus	14.6		
Neptune	17.2		
Pluto	0.0025		

We know life exists on Earth. Might life exist on Jupiter or other Jovian planets? Based on mass alone, which of the planets in the solar system is most likely to harbor life?

Is a planet that is Terrestrial of Jovian most likely to harbor life?

Teacher Notes: Jovian planets, are characterized by their high mass and low density. These planets, also known as gas giants, do not have a solid, rocky surface like the terrestrial planets. Rather, Jovians are gaseous all of the way down to their liquid cores. Like Earth's core, the temperature and pressure at the core of a gas giant planet is much too high to sustain life as we know it. Because of these conditions, Jovian planets are generally considered to be not habitable. Some students may know about hypotheses that life exists on Europa (a rocky moon of Jupiter). Other students may come to consider the possibility of life on satellites (moons) of big gaseous planets. This isn't something that is easily modeled in Gravitation. Teachers should decide how to deal with students who wish to follow up on these ideas.

Student Prompt Suggestion: In order for life to exist on Jupiter, what conditions might life have to contend with? Do you know of any life-forms that exist in gas-based environments? If there was a rocky-core deep, deep 'within' Jupiter, could life exist in the very center of Jupiter? How would the 'atmosphere' of Jupiter affect conditions at the planet's core?

2) How will this distance between planets and their sun affect habitability?

Check off whether each planet is too far, too close, or just the right distance from the sun for life to exist on each planet.

Planet	*Distance to the sun (AU)*	*Too Far from the sun?*	*Too close to the sun?*	*Just right?*
Mercury	*0.390*			
Venus	*0.723*			
Earth	*1*			√
Mars	*1.524*			
Jupiter	*5.203*			
Saturn	*9.539*			
Uranus	*19.18*			
Neptune	*30.06*			
Pluto	*39.53*			

What is an AU? 1 AU is the average distance from the Earth to the Sun. How far is that? 1 AU = 149,597,870.691 km or 93,000,000 miles. At 100 miles per hour it would take over 100 years to go 1 AU.

Teacher prompts: Although there are very cold and very hot places on Earth at all times of the year, how would life on Earth be affected if the Earth were half as far from the sun as it is now (twice as close)? How would life on Earth be affected if the Earth were twice as far from the sum as it is now?

3) Open the file "Earth". This is a model of Earth orbiting the sun.
Each planet orbits the sun at a different velocity. Experiment with raising and lowering the velocity of Earth (try moving in increments of about .5). Describe how changing the velocity changes the planet's motion, and how you think it would impact Earth's habitability.

Teacher notes: Students might not know that orbits of planets are not always circular or how a non-circular orbit might affect habitability.

Student prompt suggestion: "Look at how close the planet is to the sun when it is closest. Look at how far the planet is from the sun when it is farthest? How *much* farther from the sun is the planet when it is farthest from the sun than from when it is closest to the sun? Do all planets with non-circular orbits show the same 'range' of distances from the sun as they orbit? What difference does the 'range' of distance make in deciding whether a planet is likely to harbor life?"

Activity (3) Models Part 2: Applying Concepts - 30 minutes

In the second part of the modeling activity, students are given a data table describing the orbital characteristics of several exosolar planets (all real planets). Students then apply their knowledge by making qualitative (i.e. yes/no) predictions about habitability and detectability for each new planet. After justifying and discussing their predictions, students return to the modeling environment to test their hypotheses.

Make Your Predictions.

In the table below, you will find information about 5 planets. Based on what you know about life on Earth and life on Jupiter, as well as the data provided here, predict whether or not each planet is habitable (suitable for life). Next, hypothesize whether you think each planet would have an effect on its sun – enough to be detected by scientists using 'stellar wobble' methods.

Note that each planet's mass is calculated in Earth Masses. The value in each column represents how many times greater the mass of each planet is than the mass of Earth.

Planet	*Mass (Earth Masses)*	*Distance to star (AU*)*	*Habitable?*	*Detectable?*
1	*10.96*	*0.351*		
2	*14.68*	*0.768*		
3	*0.20*	*0.284*		
4	*16.96*	*2.87*		
5	*0.92*	*3.39*		
Earth	*1.00*	*1*		
Jupiter	*318.00*	*5.203*		

** 1 AU = the distance from Earth to the sun*

Teacher notes: Student may have difficulty with the concept of Earth Masses. Spot check for consistency of student understanding.

Were you right?

Test your predictions by using Gravitation, the modeling environment. Enter the data in the table below. Remember: Planet One (Star) Mass always = 900. The data in this table has been recalculated for use in Gravitation.

Planet	*Mass*	*Position*		*Velocity*		*Habitable ?*	*Detectable?*
		X	*Y*	*X*	*Y*		
1	9.4179	*0*	53	8.83	*0*		

2	12.6145	*0*	115	6.52	*0*		
3	0.1891	*0*	43	11.73	*0*		
4	14.574	*0*	431	3.35	*0*		
5	0.7906	*0*	509	2.68	*0*		

Teacher Notes:
1) In Gravitation, to model a star, students can only model planets. In this activity, however, students create large 'planets' to represent stars.
2) Data in this second table are not associate with any 'unit' of measure. These values are for use in Gravitation. Student may become confused by this.
2) These velocities are calculated based on an initial starting position of the planet that is directly over star (position X = 0). If students wish to 'start' the planet in a position other than directly above the star (X doesn't equal 0), then the velocities will have to be re-estimated.
3) Scaffold student observations about the shape of the planets' orbits. Planet 3, for instance, has an elliptical orbit. Students should consider how the end points of these types of orbits affect the planet's habitability. That is, at the points where the planet is farthest form the star, is the planet still within a 'zone of habitability'?
4) Try to get students to articulate 'rules' they are discovering. For instance, what range of mass should be considered habitable? What radius range? A good rule of thumb for radius is 1.0 – 2.0 AU (note: on the Gravitation screen, 1 AU = approximately 2 grid dots). A good rule of thumb for mass rage is about 1 Earth Mass.

Activity (4) Models Part 3: Expanding Concepts – In remaining class time

*If time is running short, #3 and #4 could easily be given to student as a homework assignment.

By now students will have noticed that they have not yet encountered any planets that are both habitable and detectable. These questions help students articulate their reasoning.

1) Explain why the planets you modeled were detectible but not habitable. Be sure to include in your explanation why a planet's mass and the distance to its sun are important.

2) Go back to Gravitation. Pick one of the five planets in the Table at the bottom of page 5 of this packet. Use the data in the table to model the planet. Can you alter this planet to be both habitable and detectible? What alterations would have to be made?

3) As it turns out, none of the 100 planets found outside our solar system so far are habitable. Do you think scientists will ever detect habitable planets using the 'stellar wobble' method? Why or why not? Be sure to include in your explanation why a planet's mass and the distance to its sun are important to consider.

4) If you answered "yes" to question 3, why do you think we have not yet found any habitable extra-solar planets? If you answered "no" to question 3, describe how you *might change or modify our current detection method in order to detect habitable planets.*

Appendix B: Sample Mapping of Standards to Curriculum Activities

Target Standards (NSES): Planetary Motion

1. Most objects in the solar system are in regular and predictable motion. Those motions explain such phenomena as the day, the year, phases of the moon, and eclipses.

2. The motion of an object can be described by its position, direction of motion, and speed. That motion can be measured and represented on a graph.

3. Gravity is the force that keeps planets in orbit around the sun and governs the rest of the motion in the solar system. Gravity alone holds us to the earth's surface and explains the phenomena of the tides.

Other concepts possibly in standards:

- Spectroscopy
- Role of heat, food in life cycle
- Role of water in creation and sustainability of life
- Inquiry based learning
- Technology based learning
- Nature of science – epistemological perspectives, scientific practice

Framing Questions

- Description of relevant student activities
- Activity Structure (difficult to link to 'goals')
- Can we expect any students to reach 'standard' level of understanding based on their engagement with this activity alone?
- What alternative understandings might students develop (standards-plus understanding)? How?
- How are concepts integrated/revisited into the larger body of knowledge or other activities?
- What are common obstacles to 'standards-plus' understanding? How does this activity avoid common obstacles to student learning?
- Embedded assessment possibilities
- Customization Recommendation

Curriculum Details

As part of 'An Awful Waste of Space', students develop understanding of the above standards in two ways. First, in exploring the methods used by astronomers to search for exosolar planets, students learn that stellar 'wobble' or irregular motion (1) is explained by the existence of a companion planet. Second, in order to understand how astronomers make inferences about characteristics of those companion planets, students are introduced to planetary motion and, informally, physical laws that govern planetary motion (1,2,3).

Standard One

(1). The first standard is not well covered in this unit – but could be easily revised to include a specific reference to the 'regular and predictable motion' of the stars and planets in question. Implicitly, introduction to Doppler Wobble requires that students first understand the regularity of stellar motion (or non-motion), however, it is not an explicit focus of the curriculum materials. Moreover, this motion is never applied to the concepts of Earth's orbit or phases of the moon. This standard is also addressed by the Exploring Orbits modeling activity.

a) Doppler Wobble.
Activity Structure: Reading and reflection.

Will students reach 'standard' level of understanding? Some students will see that this is a necessary condition as they come to understand Doppler Wobble. However, students could easily overlook the logic behind these concepts. Students may also independently apply the ideas relating to Doppler Wobble to Earth. Students do read that Jupiter pulls our sun out of it's normal path and this might spark the connection to Earth's orbit. Phases of the moon are not included in this project whatsoever and it is unlikely that any students would connect concepts in this activity to our moon, let along phases of the moon.

What further understandings might students develop? How? This activity is based upon previous lessons in the semester based on spectroscopy. As an activity wherein those concepts are revisited, students understanding of spectroscopy, the EM spectrum, and the Doppler effect, could all be improved or elaborated.

How are concepts integrated/revisited? See above. In addition, the theme of the search for life in continued by elaboration on techniques for searching for planets. Also, process of science ideas are continued (e.g. scientists are still developing methods of answering old and new questions, scientists don't agree on how to conduct research, etc.)

What are common obstacles to 'full' understanding? Students typically had trouble remembering relationships between wavelength and poles of the EM spectrum. Additionally, when thinking about Doppler, students often confuse velocity with acceleration (a common occurrence is many physics lessons).

How does unit avoid common obstacles to student learning? First, the lesson does not stand on the need for students to hold a normative model planetary motion. However, we hope to re-engage students with these difficult concepts over the entire project as part of solving larger problems.

Embedded assessment? Students' reflections serve as informal embedded assessments. Teachers and students can review these notes.

Customization Recommendation: Make explicit the expected regularity of stellar motion – and that unexpected motion is the keystone of Doppler Wobble techniques. Revise activity structure to be less didactic.

b) Exploring Orbits.
Activity Structure: Reflections and observations of a modifiable simulation of planetary motion around a star. Students are given several parameter values to get them going with the simulations, but are free to vary values to explore relationships on their own.

Will students reach 'standard' level of understanding? Students will most definitely come to see that planets and stars are in regular motion. Whether they will generalize this observation to 'most objects in the solar system' is not a foregone conclusions. Moreover, the day, year, phases of the moon, eclipses, etc. are not covered, so no students will be expected to achieve 'standard' level performance.

What further understandings might students develop? How? Students might also be engaged in discussion about the use of models in scientific activity as well as in their own classroom. Independent of explicit discussion, students might cultivate a better understanding of the many purposes of modeling (testing their ideas as opposed to simply representing physical phenomena).

How are concepts integrated/revisited? After modeling planetary motion around a host star, students are asked to reason about data collected by astronomers observing planets outside our solar system. Based on what they observed in this activity, students hypothesize about planets' size, composition, proximity to a host star, etc. in the context of searching for a planet that would be suitable for life. Students explore planetary motion so that they can reason about data presented to them.

What are common obstacles to 'full' understanding? As with standard two, students often confuse acceleration with velocity. This isn't a huge stumbling block with regard to this standard, but it is a problem in this particular activity. More basically, some students require, at this step, a refresher on astronomical distances and scale.

How does unit avoid common obstacles to student learning?
Embedded assessment? Students' observations of the 'given' simulations are collected on a worksheet and later used to gauge their understanding.

Customization Recommendation: To better meet Standard One, students might try to model our solar system – with the goal of representing Earth's motion as accurately as possible. This accuracy could be judge by measuring the 'day and year' of the simulated Earth. Time permitting, students could model our moon. We might design a 'test' your ideas' section around modeling Earth to reinforce that models are not simply used to represent reality, but can also be used to construct and test hypotheses.

Standard Two

(2). The second standard is touched upon in the Exploring Orbits activity. Students are asked to characterize planetary motion and it's consequences on the motion of the planet's host star in informal terms of position, direction of motion, and speed. Graphs are not used in the unit. Formal discussion of these concepts could be incorporated into the anticipated VSS activity as well as graphing. Graphing, especially, would be a welcome addition.

a) Exploring Orbits

Activity Structure: Reflections and observations of a modifiable simulation of planetary motion around a star. Students are given several parameter values to get them going with the simulations, but are free to vary values to explore relationships on their own.

Will students reach 'standard' level of understanding? Direction of motion is not explicitly addressed in this activity, but position and speed are. This standard does not specify how students should be ale to 'describe' the motion of an object. Students, supposedly, should be able to recognize the variables listed in the standard (position, direction, and speed). Graphing is not currently part of this activity, so students will not be expected to perform well in this regard.

Embedded assessment? Students' observations of the 'given' simulations are collected on a worksheet and later used to gauge their understanding.

Customization Recommendation: Incorporate a graphing activity to accompany this step.

Standard Three

(3). The third standard is well covered by the unit. In on activity about planetary motion, students learn that planets and stars are formed when gravity pulls together material, creating more mass, creating more gravity, etc. Students also explore gravity in other activities in which they alter the mass of a simulated planet and the shape of it's around a star. In this activity, gravity (as well as mass and orbit) determines the velocity of the orbiting planet and why that velocity is not constant. Students also learn that the planet's gravity exerts a pull on the planet's host star. The effect of gravity on tides or its role in holding 'us' to the Earth's surface is not addressed in this project.

a) Planetary Formation.

Students learn that planets and stars are formed when gravity pulls together material, creating more mass, creating more gravity, etc. While this doesn't address the standard directly, this activity would make a nice starting point from which to introduce 'forces' at work (i.e. gravity). From here, the standard could be more fully addressed in conjunction with the modeling activity.

Activity Structure: reading and reflection
Will students reach 'standard' level of understanding? In conjunction with the modeling activity, this standard should be fairly well covered.

What further understandings might students develop? How? This activity was originally designed to help students see the cyclical nature of stellar formation and how planets are formed. Students used this information to contextualize the 'orbits' they would be thinking so much about later in the project.

How are concepts integrated/revisited? Not at all really. But it could be a nice complement to the modeling activity. In that case, the activity would be more of a general description of formation – which would lessen the reading and didactic nature of the activity – and would focus students' attention on gravity. This would lead nicely/better into the modeling activity.

What are common obstacles to 'full' understanding? Students vary in their understanding of elements and atomic structure. Obviously, a better understanding helps. However, the revisions suggested here would shift the focus away from these details and more toward thinking about gravity.

How does unit avoid common obstacles to student learning? See above.

Embedded assessment? Currently, there exist a few student reflection points that were mostly designed to check that students' were okay with the ideas presented in the activity. These notes should reflect whatever learning goals are set for the previous activity and help students make connections to other concepts in the project.

Customization Recommendation: I'd like to delete this from the project if it isn't customized (as described above) to better serve the modeling activity.

b) Exploring Orbits (see above)

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