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Dimensions of a learning progression for the formation of the Solar System

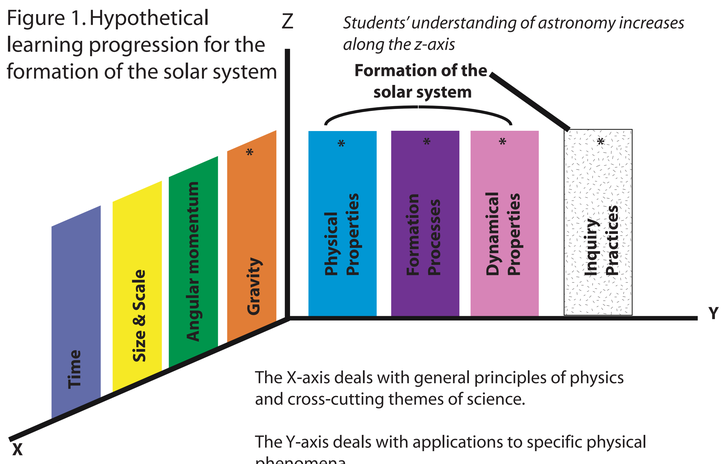
Abstract: The goal of this project is to develop a learning progression for Solar System formation that illustrates potential levels of sophistication that teachers can use to assess student progress and design instruction. The explanation for the Solar System's formation allows students to see the connections between the current physical and dynamic properties of the Solar System and the ways in which physics govern observable phenomena. Such an approach is uncommon in most astronomy instruction, which focuses on celestial objects individually, rather than as a coherent system.

What is a learning progression?

Learning progression research supports the development of standards and curricula that focus on big ideas in ways that help students see the major themes and concepts tying phenomena together (Corcoran et al., 2009; NRC, 2007, 2010). **Learning progressions describe how:**

- Learners may grow in sophistication towards a big idea in science (Corcoran et al., 2009; NRC, 2007).
  - Big ideas describe unifying concepts that help make sense of a broad variety of phenomena, offering robust explanatory power (Smith, et al., 2006).
- Intermediate levels of sophistication can be valued and built upon.
- Understanding is developed across many grades, though grain-size of analysis varies (Heritage, 2008).

Figure 1. Hypothetical learning progression for the formation of the solar system



The X-axis deals with general principles of physics and cross-cutting themes of science.

The Y-axis deals with applications to specific physical phenomena.

* *Constructs for which we have data.*

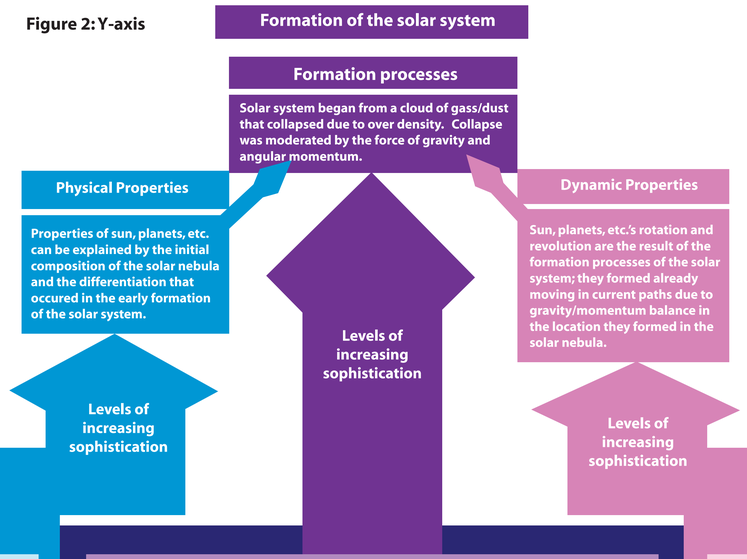
Data & Analysis

Interview protocol developed to illicit students' ideas about the solar system's properties and motions, the role of gravity in the solar system, and the formation process of the solar system.

Semi-structured interviews conducted with students in grades: 6th: 18; 9th: 4; 11th: 8; 12th: 5; College: 6

Coding protocol developed from repeated interrogation of interview data. Codes within categories were organized in order of increasing sophistication from naïve to scientific.

Figure 2: Y-axis



Next Steps

Iterative process of revision and evaluation

- Look for patterns in how codes grouped together. Refine descriptions of levels and look for links between dimensions of the LP.
- Revise interview protocol to hone in on important features and uncover additional information about student reasoning along the LP dimensions. (e.g. Students' understanding of angular momentum, deep time, etc.)
- Look for patterns in how students' improve along the LP after instruction.

Physical Properties -- Examples of Student Ideas

Begins to account for composition using formation processes: Student #30, 12th grade: "Every planet has a different amount of element. Like Jupiter, its so big but also dense. I learned that if you put Jupiter in an ocean, it would float."
Are all planets made of gas?
"Rocky, matters, like, the way planets formed or most like a spiral version. Mostly rock and dust particles, hit each other and with the pressure of the gravity started to stick together. They could still compress big molten magma ball, and then different elements hit the rocky ore that also brought like ice, we know that ice didn't originate from here, it came from a meteor with ice, frozen."

Organizing planets according to their composition: Student #14, college - English major: "We've got inner and outer planets" separated by the asteroid belt. "Inner planets are rocky planets and outer planets are gaseous planets."

Organizing planets, not with composition: Student #8, 6th grade: "Maybe they would describe them to temperature, or kind or rock. Like Mars would go with Saturn because Saturn also has red on it, red-orange color. Maybe they would put Saturn and Jupiter, put these 4 together because they are so cold. Might put for biggest together, and then the smallest. They could put them in order."

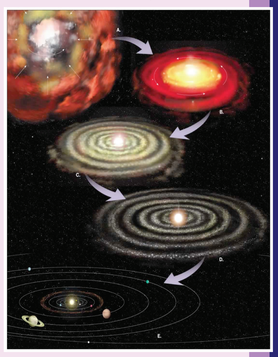
Gravity dimension - X-Axis of the LP

How does improvement in understanding of gravity relate to improvement in the Solar System?

Categories for gravity:
1. What is gravity? 3. What is the extent of gravity's effect?
2. What causes gravity? 4. Where is gravity strongest?

Formation Processes -- Examples of Student Ideas

Identifies beginning of formation as a contraction event: Student #14, college: "After the Big Bang, there were these pockets, these clusters of dense hot gas, that compressed, these are the clouds that compressed. I don't know where fusion would begin, somewhere in here, the formation of the sun. The sun would be formed, its established mass that would draw in the planets and asteroids that orbit around the sun."

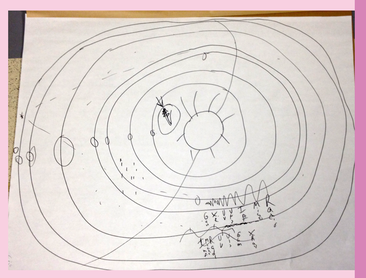


Explosion combined with productive formation elements: Student #30, 12th Grade: Example of big bang with productive idea of dust, accretion and spin; confusion between solar system & galaxy.
How did the solar system form?
"From what I have read, Big Bang. Everything was dust so the nova exploded a big wave energy …this energy created spirals that later formed different stars…once it calmed down it started pulling more particles … kept smashing into different particles, creating planets."

Student #7, 6th Grade: Example of explosion combined with collisions to form planets
"There was like a ball of fire that exploded; and the middle part is turning into the sun. The rocks collided and made planets... It heated up and it was really hot and it overheated and it exploded... The molten rock would hit and the asteroids would collide and get stuck together." *What was the role of gravity?* "If there was gravity they would all go down because gravity holds you down and they would all move down" *Do you see anything that had to move down?* "No."

Dynamic Properties -- Examples of Student Ideas

Uses gravity to explain orbits, but does not account for momentum: Student #14, College - English major: "Because they are orbiting the sun because its gravitational pull." *Tell me more about how gravity works.* "It has to do with the mass of an object. Sun is significantly more massive than the planets. **The larger the mass of the object, the stronger the gravitational pull.** Because the mass of the sun is so much greater than the planets, they're bound in that. **They don't have the velocity to shoot out. If they reach escape velocity then they could leave the orbit.**" *Why don't we crash into the sun?* "I know that we stay a consistent distance away. I guess just because the masses aren't changing significantly? **It's a constant orbit because the gravitational pull isn't changing.**" "Technically because we're orbiting we have a velocity established. If you switched off gravity, we'd just shoot out. There would be nothing holding us to bring us back around."



Uses gravity to explain orbits, but includes alternative theories about gravity: Student #30, 12th Grade: "(Planets orbit the sun) because of the same gravity force (from the sun). See how sun releases energy? It can also pull them more close... The way that they are moving around, mostly moving in a circular way, but also in a spiral belt. Gravity is from here (sun). Just like when you spin a ball it keeps moving, it doesn't go that way, it goes a certain way, inside (he shows a path that curves around the sun."

Uses alternative descriptions of forces to explain plantary orbits: Student #8, 6th Grade: "The planets move, but they, they just don't like go off in this direction. They stay in a circle because of the tension between them. The contractions that hold them together."

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