# Development of a learning progression for formation of the Solar System

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## Proposed Levels: Dynamic Properties

★ Level 4a: Orbits in the Solar System are close to a flat plane, in the same direction, and are a result of a balance between the object's tangential velocity and the gravitational force between the object and body it is orbiting.

★ Level 3a: Orbits in the Solar System are close to a flat plane, in the same direction, and the result of gravitational force between objects. Non-normative reasoning why objects do not get pulled into and collide with the object they are orbiting.

★ Level 2a: Planets orbit the Sun in distinct orbits in the same direction. Non-normative reasoning for why objects maintain orbit.

***Correct astronomical context fork***

★ Level 4b: Orbits in the Solar System are a result of a balance between the object's tangential velocity and the gravitational force between the object and body it is orbiting. Non-normative reasoning about the shape of the Solar system and/or direction of planetary orbits.

★ Level 3b: Orbits in the Solar System are the result of gravitational force between objects. Non-normative reasoning why objects do not get pulled into and collide with the object they are orbiting and for the shape of the Solar System and direction of planetary orbits.

★ Level 2b: Planets orbit the Sun and the Moon orbits the Earth. Non-normative reasoning for shape of the Solar System, directions of planetary orbits, and for why objects maintain these orbits.

***Physics with no astronomical context fork***

★ Level 1: The Moon does not orbit the Earth and/or the planets do not move at all or do not move along distinct orbits around the Sun.

## Upper Anchor Statement

Observable patterns in the locations, motion, and physical properties of the objects in the Solar System reveal that the Sun, planets, moons, and smaller bodies formed at roughly the same time from the same initial pool of material, which was a slowly rotating cloud of gas.

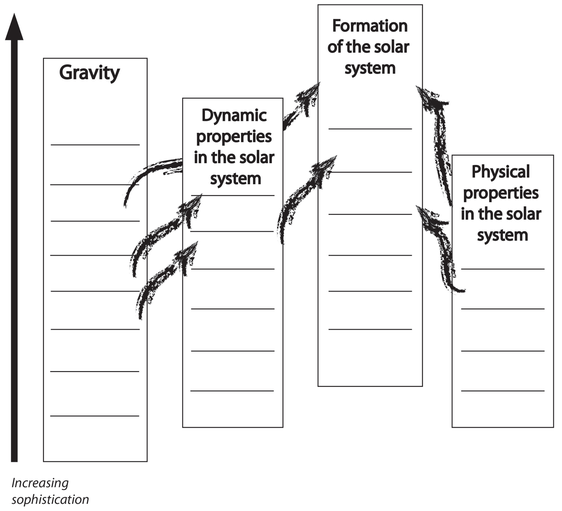



***Figure 1: Construct Maps in the Solar System learning progresssion***

There are four individual construct maps that link together in the hypothetical learning progression. The arrows represent hyphothetical relationships between levels in these individual construct maps that are being revealed in our analysis of student ideas.

## Proposed Levels: Solar System Formation

★ Level 6: Solar System objects formed at the same time from the gravitational collapse and accretion of microscopic materials.

★ Level 5: Solar System objects formed from an explosion followed by contraction and accretion of macroscopic materials. Gravity assisted the contraction.

★ Level 4: The Solar System formed in a vague accretion-like process. Gravity holds system together during formation, but does not cause accretion.

★ Level 3: At least part of the Solar System formed from materials in the system, but no mechanism for formation is known. Gravity plays some unspecified role in the formation.

★ Level 2: Material that formed planets or planets was drawn in by the Sun. Gravity may have played a role in holding it together.

★ Level 1: The Solar System began in an explosion, and gravity played no role.

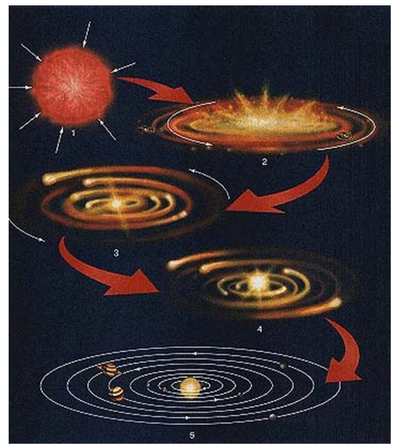
## Next Research Steps

★ Refine levels presented here for each hypothetical construct map

★ Continue analysis of physical properties of the Solar System and gravity codes

★ Align all four construct maps, as illustrated in Figure 1, to inform our overall formation of the Solar System learning progression

★ Completed: Used results of this data analysis to iteratively refine interview protocol



★ Ongoing data collection using pre/post interviews (new protocol) and classroom instruction video in 6th grade science and HS physics classes

★ Analyze how instruction in these two classes move students along the progression

★ Feed results of this work into our concurrent professional development program for teachers in this content area

## Abstract

This study describes the process of defining a learning progression for astronomy around the big idea of solar system formation. At the most sophisticated level of the learning progression, students can explain how the formation process leads to the current solar system through chemistry and physics principles, such as chemical change, conservation of angular momentum, and the law of gravitation. In this first step towards understanding student progress in this domain, we interviewed middle school, high school, and college students (N=44), asking them to describe properties of the current solar system and to explain how the solar system was formed. Our analysis reveals potential levels of sophistication within the hypothetical learning progression while also revealing common barriers to progress; many students' understanding of solar system phenomena was limited by either alternative ideas about gravity or limited application of momentum in their explanations. Few students approached a scientific-level explanation, but their responses revealed possible stepping-stones that could be built upon with appropriate instruction. Our findings also point to critical deficiencies in how state and national standards address solar system astronomy. Future research that examines student progress across instruction will help clarify and validate this hypothetical learning progression.

## Data & Analysis

Interview protocol developed to elicit students' ideas about Solar System 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 (N=18), 9th (N=4), 11th (N=8), 12th (N=5), and college (N=6)

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

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