

Gravity and Dynamical Properties in the Solar System Hypothetical Construct Map

PENNSSTATE



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Upper Anchor: Observable patterns in the locations, motion, and physical properties of the objects in the Solar System at the current time reveal that the Sun, planets, moons, and smaller bodies formed roughly 4.6 billion years ago from the same initial pool of material, which was a slowly rotating cloud of gas.

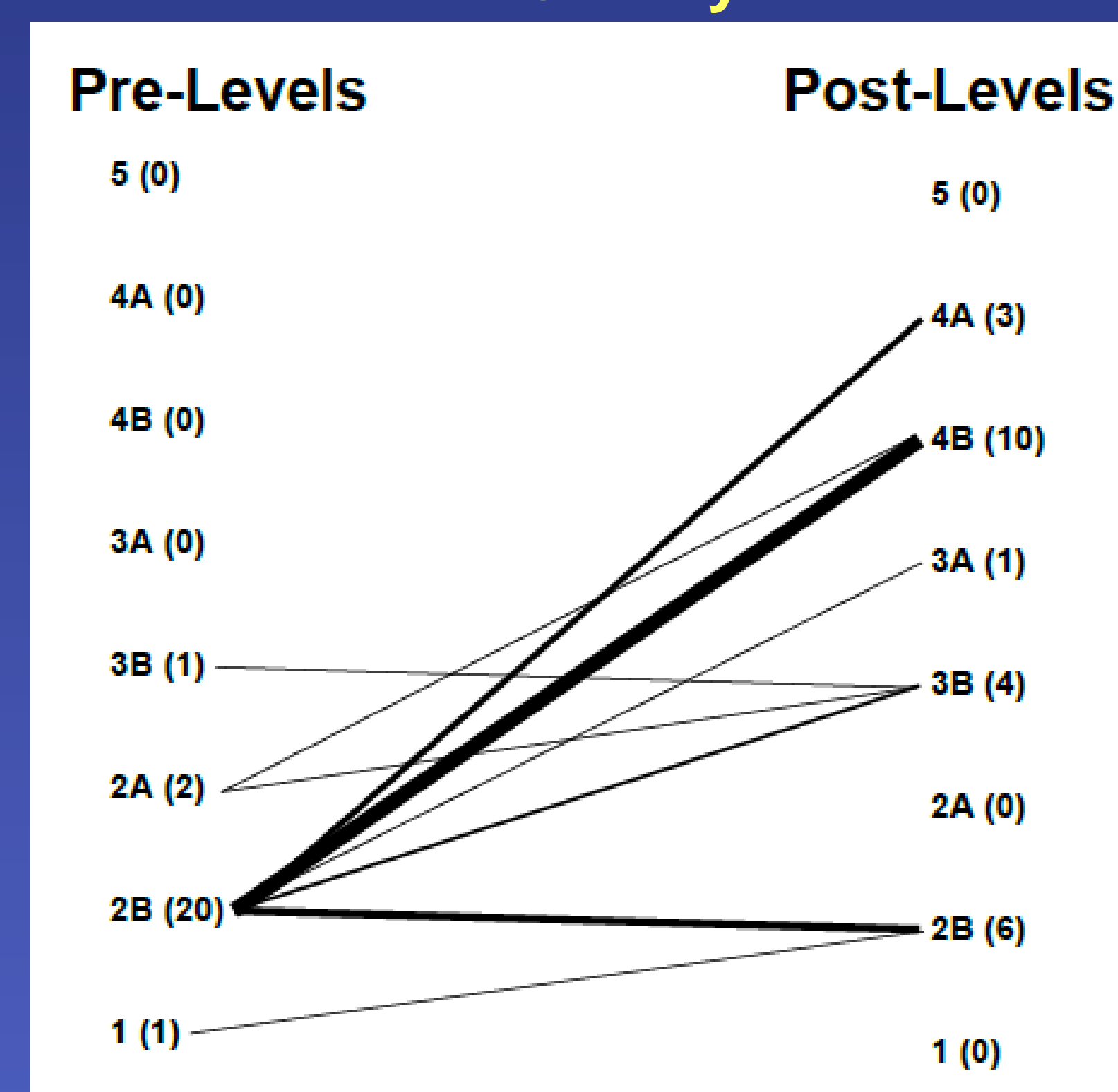
Research Question: How does instruction informed by our hypothetical LP alter student understanding of gravity and dynamical properties in the Solar System?
Classroom Sample: 6th grade students (n=24)
Data: pre/post interviews and classroom recordings

Gravity Hypothetical Construct Map

Level*	Level Description of Student Understanding
5	Gravity is an interaction between two masses. It is a force and/or pull caused by all objects with mass. Gravity decreases with separation between both objects and goes on forever. Massive objects produce the strongest gravity or proximity to a massive object has the strongest gravity.
4A & 4B	All objects have gravity. Gravity is caused by mass. Massive objects produce the strongest gravity, the Sun has the strongest gravity, or proximity to a massive object has the strongest gravity.
3A & 3B	Specific objects have gravity (e.g., Sun, Earth, Moon, but not Jupiter). Gravity is caused by mass. Massive objects produce the strongest gravity or the Sun has the strongest gravity.
2A & 2B	Some objects, but not all, have gravity (e.g., Sun, Earth, Moon, but not Jupiter). The Sun may be identified as having the strongest gravity. Non-normative ideas about the cause of gravity.
1	Gravity keeps things down on Earth and is a specific trait of Earth (i.e. Earth is special). Earth's gravity has a set limit where it cuts off, and gravity is strongest on Earth.

* Note:
 All **A levels** include the idea that gravity decreases with distance and/or goes on forever.
 All **B levels** include the idea that gravity cuts off some distance from the objects in question.

Change in Students' Understanding of Gravity



Classroom Instruction Contributing to Change

Observed Changes

- Most students progressed from thinking that only some objects have gravity to the understanding that gravity is caused by mass; many understood that all objects have gravity.
- Many students continued to think that gravity cuts off at some distance from objects.
- No student progressed to an understanding that gravity is an interaction between two masses.



Instruction: Planetary Orbits: Gravity, mass, and density
 A student questioned how a gaseous planet can have more gravity than a rocky one. This led to class discussion on connection between gravity and density. Subsequent instruction includes activity connecting gravity, mass, and density.

Teacher and students made multiple mentions across instructional days that objects with mass have gravity.

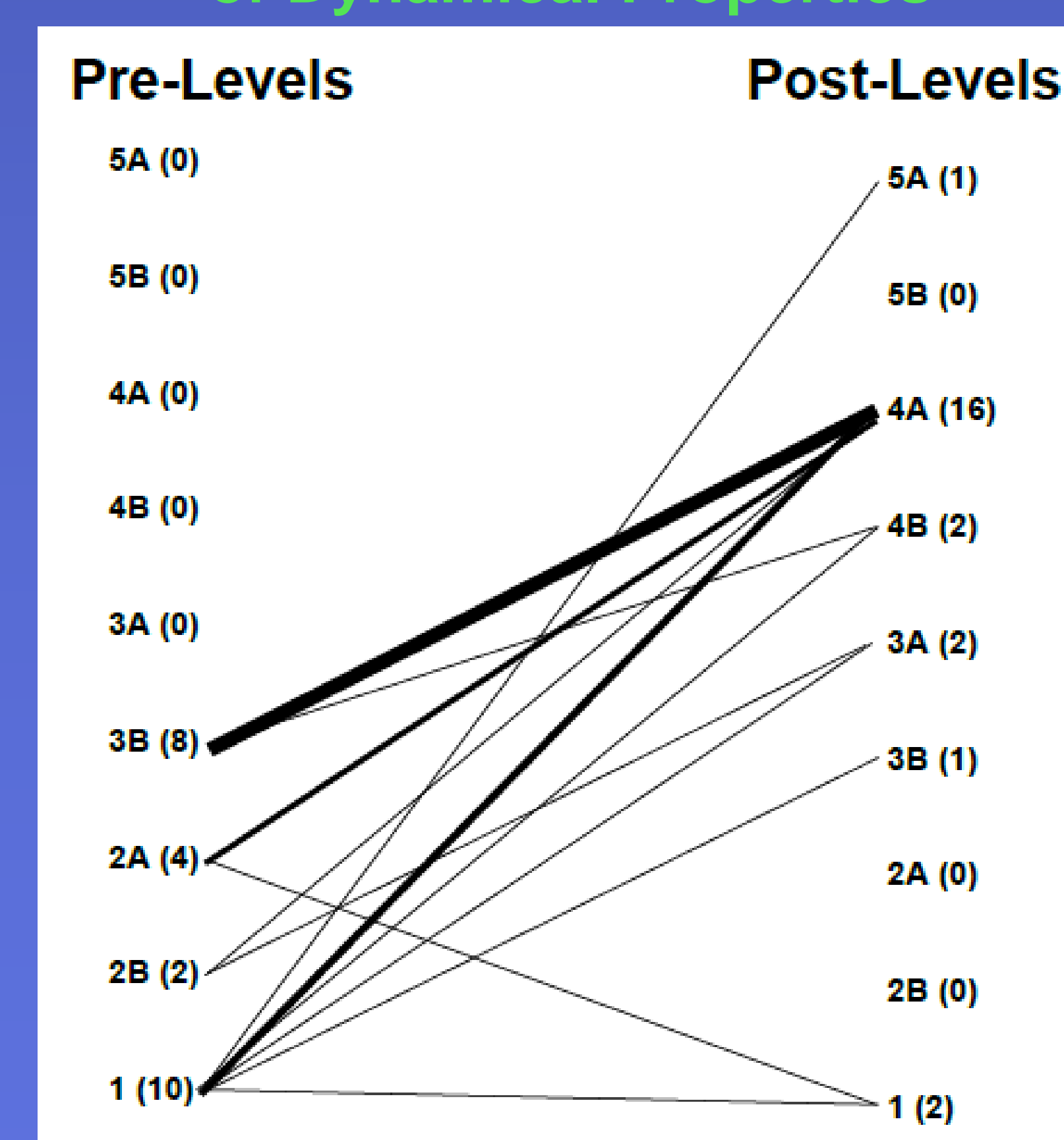
Instruction: Relative mass of Solar System objects
 Whole class discussion of gravity and inertia included many student questions about gravity, mass, and inertia. Teacher initially reasoned that Earth's gravity does not extend beyond its atmosphere, but later corrects this idea when considering the Moon.

Dynamical Properties Hypothetical Construct Map

Level^	Level Description of Student Understanding
5A & 5B	Orbits in the Solar System are the result of a balance between the object's tangential velocity and the gravitational force between the object and body it is orbiting.
4A & 4B	Orbits in the Solar System are the result of a balance between inertia/acceleration and the gravitational force between the object and the body it is orbiting. The role of velocity and/or gravity is not clarified.
3A & 3B	Orbits in the Solar System are the result of the gravitational force between objects, holding one in orbit about another. Unclear or non-normative reasoning for why objects do not crash into the object they orbit.
2A & 2B	The planets orbit the Sun and the Moon orbits the Earth. Non-normative reasoning for why objects maintain their orbits.
1	The Moon does not orbit the Earth and/or the planets do not move, or do not move along distinct orbits about the Sun.

^Note:
 All **A levels** include the idea that the Solar System is flat, and that the planets orbit in the same direction.
 All **B levels** include non-normative ideas about the shape of the Solar System and/or the direction of planetary orbits.

Change in Students' Understanding of Dynamical Properties



Classroom Instruction Contributing to Change

Observed Changes

- Most students progressed from non-normative ideas to the understanding that the Solar System is flat, and that the planets orbit in the same direction.
- Many students progressed from attributing gravity as the cause of orbits in the Solar System to the understanding that orbits in the Solar System are the result of a balance between inertia/acceleration and gravity, but did not clarify the role of both.



Instruction: Planet and asteroid orbits
 Extended instructional activities to develop understanding of flatness of the Solar System (data collection by students using astronomy software; use of Claims-Evidence-Reasoning; multiple modes of representation).

Instruction: Planetary Orbits
 Constructing explanation for why planets orbit at different distances from the Sun (data collection by students using simulation; use of Claims-Evidence-Reasoning).

Instruction: Tides
 Class discussion about roles of inertia (initial velocity) and gravity in maintaining planetary orbits.

Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15
Size / scale of Earth Sun system	Reasons for the seasons		Phases, eclipses, & tides	Tides	Meteors, comets, & asteroids		Planet and asteroid orbits		Relative mass of Solar System objects Planet properties	Spring Break	Grouping planets by their properties	Planetary orbits Exoplanets	Gravity, mass, & density	Astronomical Technology
Modeling phenomena with Earth's rotation	Earth's motion in the Solar System	Sun Earth Moon system						Size / scale of the Solar System				Solar system formation – accretion theory		Solar System formation – Solar nebula theory

