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Gravity, Magnetism, and "Down": Non-physics College Students' Conceptions of Gravity

This study concentrates on exploring non-science majors' conceptual understanding of gravity and how they use this understanding while solving problems involving gravity.

I. Introduction

This study investigates college students' ideas of gravity in the context of an entry-level geology course in a North American university. The concept of gravity is central to many sciences, and level of understanding of gravity will influence how people apply knowledge from one domain to another. For example, students who believe that gravity only occurs on Earth may have difficulty applying geological principles to concepts in planetary geology. Entry-level college geology instruction assumes an understanding of fundamental physical science concepts such as atoms, friction, gravity, and density. These basic concepts provide an essential foundation for building students' sophisticated understanding of advanced geological concepts. Mass wasting, for example, is a geologic concept that describes the movement of material under the influence of gravity alone. As a consequence, understanding fundamentals of gravity can dramatically impact how students understand and internalize mass wasting concepts taught in a typical physical geology course. We set out to investigate how students enrolled in entry-level geology, most of whom would graduate from college without university-level physics courses, thought about and applied the concept of gravity while solving problems concerning gravity. The repercussions of students' gravity concepts are then considered in the context of non-physics courses, including implications for reform efforts in physics. Data were collected during the second week of an eleven-week term from two courses with an average enrollment of just over 100 students. Based on research literature (Claxton, 1993; diSessa, 1983; Vosniadou, 1994) and one author's experience of teaching this population of students, we hypothesized that students would have fragmented and loosely connected ideas about gravity.

II. Research Context

The investigation of children's and adolescents' ideas about various scientific models and the nature of science is a long-standing and well-developed area of research (Driver, 1985; Driver, Squires, Rushworth, & Wood-Robinson, 1994). Although a few well-known studies have extended this work to include adults, including college students and in-service teachers, there is very little research on the conceptual understanding of gravity on the parts of adults (Gunstone & White, 1981; Hestenes, Wells, & Swackhamer, 1992). In addition, the importance of physical concepts in understanding other sciences suggests that investigation of gravity ideas in related disciplines will have implications for the teaching of physics in both high school and college.

Existing literature on younger students provides a useful backdrop for framing our study of college students enrolled in entry-level geology courses. Gravity-related studies focus on students' ideas of the relationship between gravity/gravitational force and other important concepts in physical science such as height, weight, or velocity. Additionally, some have also examined how children relate orientation ("up" and "down") with reference to the Earth in space to weight and gravity (Driver, et al., 1994; Sneider & Pulos, 1983). Studies have been conducted in K-college settings (Nussbaum, 1976; Trumper & Grosky, 1997) and in a variety of countries (Mali & Howe, 1979; Sneider & Pulos, 1983; Za'Rour, 1975). The majority of studies conducted in college settings incorporate the concept of gravity into the study of students' force concepts, rather than explicitly studying gravity ideas themselves (Hestenes et al., 1992; Sadanand & Kess, 1990). Kavanaugh and Sneider (2006-2007) provide a thorough review of relevant literature on gravity conceptions; we elaborate on those studies of most importance here.

Conceptual understanding of the source of gravity is an intriguing line of research and is of particular relevance to this paper. *Gravity needs air to act* appears to be a widespread notion among children (Driver et al., 1994; Ruggiero, Cartielli, Dupre, & Vicentini-Missoni, 1985). Similarly, gravity is perceived to be caused by "air pressure" by high school and college students (Hestenes et al., 1992). Elementary and secondary students in several studies also thought that gravity only operated on Earth (Bar, Zinn, Goldmuntz, & Sneider, 1994; Stead & Osborne, 1980). Subjects generally supported this notion through the idea that gravity needs a medium, such as Earth's atmosphere, in which to operate.

The concepts of the geomagnetic field and the Earth's rotation also seem to influence students' ideas of gravity in cross-age models (Stead & Osborne, 1980). A number of investigations focusing on children's and adolescents' understanding of gravity and weight report the prevalence of the idea that gravity somehow only influences heavy things; some 15-year-olds believe that weight is independent of gravity such that objects can have weight without gravity (Driver et al., 1994; Osborne, 1984; Stead & Osborne, 1980).

Some students and even adults thought of "weight as a property of an object," while gravity was perceived as a "property of space," independent of the presence of an object (Ruggiero et al., 1985). In a study of pre-service high school teachers enrolled in a college biology course, Trumper and Gorsky (1997) found that 25-50% of these freshmen through senior college students rarely or never recognized the relationship between weight and gravity. Drawing on Piaget's work (Piaget, 1972), Galili (2001) points out two main schemes involved in children's naïve perceptions of weight: "weight is the pressing force featuring particular objects—the sensed heaviness related to a muscular effort", and "weight is the amount of matter" in an object (Galili, 2001, p. 1085). Several studies report a considerable degree of confusion in children's concepts of weight and gravitation (Galili & Bar, 1997; Galili & Kaplan, 1996; Gunstone & White, 1980; Ruggiero et al., 1985). The inability of secondary and advanced placement students to resolve their misconceptions about weight, gravitational force, and weighing is a consequence of the failure of physics instruction, argues Galili (2001).

Many of the students who held the idea that gravity is a force of attraction had difficulty explaining why gravity exists on Earth, often relying on functional (i.e., gravity's effects) aspects of gravity on Earth, such as gravity "keeps things from floating away," and "holds people on earth."

Conceptions of the reasons that objects fall also provide insight into gravity understanding. Children generally tend to think that objects fall because nothing is holding them up, because the person dropping the object causes the fall, or because things just fall "naturally" (Gunstone & White, 1981; Ruggiero et al., 1985; Selman, Krupa, Stone, & Jacuette, 1982). Adolescents (12 to13 year-olds) were found to have three main non-scientific explanations for falling: (a) an integrated view of gravity and weight where gravity is acting on the weight of a falling object, (b) a clear distinction between gravity and weight, where they both act separately to cause the fall, and (c) an absence of gravity or weight conceptions where objects fall in the absence of support due to "natural motion" (Ruggiero et al., 1985; Selman et al., 1982). A prevalent notion among people of all ages is that heavier objects fall faster because they have a greater acceleration due to gravity (Gunstone & White, 1981; Hestenes et al., 1992; Osborne, 1984; Selman et al., 1982). For example, Gunstone and White (1981) found that approximately 10% of first year physics students hold this belief. In addition, although several studies found that teenagers overall think that gravity decreases with height, a considerable proportion of students thought that gravity actually increases with height above the Earth's surface (Driver, 1985; Driver et al., 1994; Ruggiero et al., 1985).

Research on children's ideas about gravity has also focused on their notions of gravity with respect to spatial orientation. Several studies have reported that children's ideas about "down" with reference to the Earth in space progress through different stages (Baxter, 1989; Driver et al., 1994; Nussbaum, 1985; Sneider & Ohadi, 1998; Sneider & Pulos, 1981). Children appear to develop an understanding of gravitational down as early as two years of age (Hood, 1995). Children usually start off with an "absolute view of down" that is independent of Earth, eventually developing an "Earth-referenced view of down" at around the age of 14 (Nussbaum, 1985). In a study with 15- and 16-year-olds, Baxter (1989) found that about 80% of students had an earth-referenced view of down based on the Earth's surface rather than the center of the Earth. This Earth-referenced view usually translates into an "up" position for the Earth. Typically, the Northern Hemisphere is "up" relative to the Southern Hemisphere, but we should caution that this view may be dependant upon the Northern Hemisphere populations studied. For example, in two studies in England, Baxter (1989) and Arnold et al. (1995) found that the majority of 7 to 16 year-olds viewed the Northern Hemisphere of the Earth as "up." As a consequence, students believed rain fell away from the Earth, towards space, in the Southern Hemisphere.

A few researchers have investigated pre-teenager (7 to 12 years-old) student conceptions of objects falling through a tunnel in the Earth, as reproduced in this study (Nussbaum 1976, 1979). These investigations are embedded in larger studies of student understanding of Earth's shape and gravity, with a primary purpose of understanding the general gravity orientation that students hold. Three conceptual orientations are considered in existing studies: (a) objects falling towards the center of the Earth, (b) objects falling towards the surface of the Earth, and (c) objects falling down in space. Generally, these studies consider a drawing depicting an object falling and stopping immediately at the Earth's center as "correct", rather than the more accurate model of an object oscillating about the Earth's center. Using a series of activities prompting elementary-aged students to depict the path taken by a rock, Nussbaum (1976) found that young students often have perspectives of "down" that are reference frame specific. Students drew rocks (a) falling towards the bottom of the page, (b) falling towards the Earth's surface but not the center, (c) falling away from the Earth, and (d) falling towards the Earth's center. Nussbaum (1979) extended this work by providing students with four drawings and asking them to choose the one that they thought best represented what would happen to an object falling through the tunnel. These results were similar to those of earlier work, and revealed that the gravity orientation of most young students is not in reference to the Earth's center. The studies tend to explain students' responses to these problems, but do not attempt to probe the ways in which students understand the problems. Students' mental images or perceptions of the tunnel are not clear from existing work; for example, do students think that the tunnel has air or water in it, or do they consider variables such as the Coriolis effect?

Through this and other future studies we hope to engage in a conversation about these issues across the disciplinary boundaries that may exist between physicists, other scientists, and science educators.

In related work, Sneider and Ohadi (1998) investigated elementary and middle school students' conceptions of shape and gravity in the context of evaluating the effectiveness of an instructional intervention. This study found that, prior to instruction, only 7-30% of 4th through 8th graders thought that objects fall towards the Earth's center. After instruction, only 60% of 8th grade students acquired this concept. This suggests that some alternative ideas about the orientation of gravity are entrenched and may be prevalent even in older students.

Although there is ample existing literature on children's and adolescents' (K-12 students) ideas about gravity, there is a dearth of literature on college students' and pre-serivce teachers' understanding of gravity. This study specifically concentrates on exploring non-science majors' (typical undergraduate students including pre-service teachers and child development majors) conceptual understanding of gravity and how they use this understanding while solving problems involving gravity. More specifically, we examine the ways in which student ideas resonate or conflict with the scientifically accepted idea of gravity. Additionally, we seek to closely examine alternative frameworks about the nature of gravity through a qualitative analysis of student written and pictorial responses. In particular, we wanted to answer two questions: (1) How do non-science major college students enrolled in a science course other than physics understand gravity? (2) In what ways do they apply their understanding of gravity while solving problems related to gravity? Additionally, we looked at the relevant literature to compare the participants' understanding of gravity to models of gravity held by

K-12 students. For the purpose of this study, we defined gravity very simply as the force of attraction between two or more objects that have mass.

III. Methods

The narrowly constrained research focus of this study allowed for implementation of methodologies used previously by other researchers. In particular, we adopted gravity problems that Nussbaum (1976, 1979), had originally used with elementary students for use with our non-science major college population. We specifically targeted students enrolled in geology courses in which an understanding of physics concepts is generally assumed.

A. Participants

The study population (n=216) consisted of students enrolled in two entry-level university geology courses taught by one of the authors during winter 2004 (n=96) and fall 2005 (n=104) at a mid-western North American university. The two courses participating in this study were almost evenly divided between men and women, with a total of 117 men and 99 women enrolled in the courses overall (48% female). Students had mixed levels of college experience. 49.5% of the students were in their first year of college. 2nd, 3rd, and 4th/5th year students made up 28%, 13%, and 9% of the study population, respectively. At the start of the term, 28% of the students were education or early childhood majors, including one Earth Science Education major, 20% were undecided, and six students had declared Geosciences as their major. Remaining students were enrolled in diverse majors, including finance, sociology, English, plant biology, forensic chemistry, mechanical engineering, and art. Of these majors, 17% were declared as math, science (including geo-science), computer science, or engineering majors (Table 1).

Table I: Course and participant demographics.

	Female	Male	1st-year students	Education or Child Development majors	Undecided	Geology majors
Winter 2004	60	46	57	36	20	0
Fall 2005	44	66	50	25	22	6
TOTAL	104	112	107	61	42	6
Participants	104	104	—	—	—	—
% participation	100%	92.8%	—	—	—	—

The response rate to the questionnaire from both courses was 96% (n=208). The institution where this study was conducted is situated in the rural mid-west, although the majority of students are from suburban homes near small cities. The collection of gravity conceptions data from students was conducted with a dual purpose: as part of instructional pre-assessment and as conceptions research. All students enrolled in the courses participated in the pre-assessment. Attendance rates for F2005 and W2004 classes were 100% and 93%, respectively. 68% of students enrolled in these courses reported previous high school Earth Science or Physics courses, suggesting a significant level of exposure to gravity concepts in high school, although instruction on gravity occurred in this course only after these data were collected.

B. Data Collection

The questionnaire utilized in this study included an open-ended question and two gravity tasks. The open-ended question asked students to explain what gravity is and the cause of gravity on Earth (What is gravity? Why is there gravity on Earth?). The gravity tasks had previously been investigated with elementary-aged children (Nussbaum, 1976, 1979). The gravity tasks asked students to pretend that a tunnel was dug all of the way through the Earth from the North to the South Pole, imagine that a person standing at the surface dropped a rock, and draw a line from the person's hand showing the path taken by the rock. Students were also asked to explain their response. In a second task, the frame-of-reference of the first task was modified to show a tunnel oriented along the equatorial plane (Arnold, Sarge & Worrall, 1995) in order to allow for investigation of the reference dependence of gravity concepts. This allowed differentiation between those students who believed objects fall towards the center of the Earth and those who believe objects fall towards the bottom of the page.

The questionnaires were distributed and collected before instruction and had no impact on students' grades. In order to provide for anonymity, questionnaires were numbered before analysis. 96% of the 216 students enrolled in the courses completed some portion of the questionnaire. Specifically, 208 students completed the drawing tasks, and 197 completed the open-ended gravity question. These data provide a unique look into the gravity conceptions of typical college students, as well as a large subset of pre-service teachers and child development majors.

This study did not probe students' mental picture of the north-south and east-west tunnel, although, based on the written responses, we have no indication that students are considering phenomena such as the Coriolis effect. We feel that future studies would benefit from probing during interviews to elicit a more accurate and richer picture of students' ideas.

C. Data Analysis

Each of the researchers analyzed one dataset completely, and conducted repeat analysis on the other dataset to establish inter-rater reliability as discussed below. We analyzed the student responses and the drawings. Questionnaire responses were analyzed via thematic content analysis (Patton, 1990), wherein themes are allowed to emerge naturally from the data. The data were divided into two sets for the purpose of analysis: (a) responses to the open-ended gravity question and (b) drawings related to the gravity tasks. Students' qualitative responses to the open-ended question and explanations of their gravity task drawings were tabulated electronically. The responses were coded thematically to capture important ideas and misconceptions expressed by the participants in relation to gravity. Codes were grouped into broader categories and general themes as shown in Table II. Responses to each of the two gravity tasks were also analyzed and coded thematically, with dominant categories of responses emerging from the data.

Table II: Common alternative conceptions of gravity identified in the study population.

Alternative conceptions	Exemplar student responses (Gravity is…)
Gravity as an outside force	• force acting on the objects of the universe in varying degrees
Gravity associated with the atmosphere	• nature's force pulling down because of the atmosphere
Gravity associated with celestial objects and/or earth's spin	• a force created by objects in space, there is gravity on earth because it is spinning in space • There is gravity on earth because of rotation of the earth • the pull or push of mass towards the earth. Because of Earth's mass and constant rotation and the pull of the moon
Gravity associated with the sun	• a force that pulls everything down. There's gravity on Earth because of its relationship to the sun
Gravity as the pull or attraction of Earth's core	• the pull the earth's core has on everything • Force of attraction from the center of the planet that holds things together. If there was no gravity, things would not be held together and everything would just float into space and not stay on Earth
Gravity associated with pressure	• the pressure that is forced onto an object at 9.8m/s^2
Gravity associated with size and earth's position	• a force that pulls on all objects. Depending on the size of the planet, gravity's pull is stronger. Caused by [earth's] position in solar system and closeness to sun
Gravity associated with magnetism	• a force that holds everything on the earth, gravity is here because the earth spins and revolves and maybe because its magnetic • a magnetic force caused by the star or the sun. • a force within the earth caused by metallic substances rotating in the molten core, this also affects the magnetic field… • There is gravity on Earth because of the magnetic field of the solar system. Gravity is related to mass
Functional definition of gravity on Earth	• the force that holds everything in place on Earth to keep everyone in place and everything • a force that pulls on objects. Gravity is here to keep everything in its place on earth otherwise we would just float away with no control

1. Validity and reliability

The gravity tasks included in this questionnaire were adopted from previous studies[23] that have already undergone validation for elementary-aged students. We view this prior use and validation as a significant measure of the usability of these tasks for eliciting gravity concepts. The application of materials developed for K-12 to the college population required further validation. Both the drawing tasks and the open-ended gravity questions created for this study were first used in a pilot study. This piloting occurred in a similar entry-level geology course taught before the courses included in this study. Responses to the pilot questionnaire indicated that students were able to understand and respond to the tasks and questions. In addition, college students did not feel that these tasks were too simplistic for a college level course.

Additional aspects of qualitative validity were addressed during this study. Students were also consulted through in-class discussions to obtain their feedback on the analytic categories to address the credibility of the interpretations made by the researchers (Patton, 1990). Students in both courses agreed that their personal models fell within one of the described models. This process helped in ascertaining the level to which the study participants agreed with the research findings. For the purpose of creating inter-rater reliability, each researcher also coded 20 responses from the alternate dataset. The scores and codes were compared and will be discussed later in this article. The inter-rater agreement was 100% for drawings, and was 80% to 100% for open-ended responses, based on discussion of thematic codes. The context of this study and the assessment tool may have influenced student thinking; however, we noticed similar responses on both the written explanation and the drawing task.

IV. Findings And Discussion

In this section, we discuss the salient conceptions emerging from students' responses to the gravity problems. More specifically, student notions of gravity and causes are analyzed, as well as responses and explanations for the gravity tasks.

A. Notions of Gravity

The open-ended questions were used to elicit students' ideas about gravity. Student responses (n=197) revealed a diverse and complex array of notions about both gravity and the relationship between gravity and the Earth (Table II; Figure 1). It is particularly important to note that the majority of the students' responses exhibited a combination of misconceptions about gravity. We did not notice any truly coherent framework emerging from the responses, except for perhaps the scientifically accepted model held by a very small proportion of students. Although we have identified some salient themes arising out of students' responses for the purpose of this analysis, we are not suggesting that students hold only these distinct ideas. In fact, the data suggest that a multitude of alternative ideas co-existed in participants' minds, albeit mostly reflecting incoherent frameworks.

Students tend to reason from familiar concepts, and when these concepts are non-scientific, conclusions can be far removed from the concepts we think we are teaching.

1. Gravity as a force of attraction

Students' responses suggested that, surprisingly, only 21% of the participants had the correct scientific idea that gravity is a force of attraction. The specific idea that the force of attraction exists between masses was ultimately not coded as very few students incorporated all three concepts of attraction, mass, and force in their explanations. Many of the students who held the idea that gravity is a force of attraction had difficulty explaining why gravity exists on Earth, often relying on functional (i.e., gravity's effects) aspects of gravity on Earth, such as gravity "keeps things from floating away," and "holds people on earth." Furthermore, merely 12% of students held the correct conception that gravity is a force without simultaneously holding common alternative conceptions. The 9% of the study population with dual scientifically accepted/non-scientific models held misconceptions that were mostly in relation to why gravity exists on Earth. A number of students thought that Earth's "rotation," "spin," "magnetism," and "atmosphere" cause a force of attraction between the Earth and other objects. In fact, one student mentioned all of these concepts in her definition of gravity, explaining that gravity is a force of attraction and that "… Gravity is a force due to spinning of the earth around the sun, magnetism, and atmosphere". The following selected excerpts illuminate students' reasoning for various misconceptions:

"Gravity exists on the earth, because of Earth's mass and constant rotation and the pull of the moon."

"Gravity is on earth to keep things on earth."

"There is gravity on earth because of the earth's core."

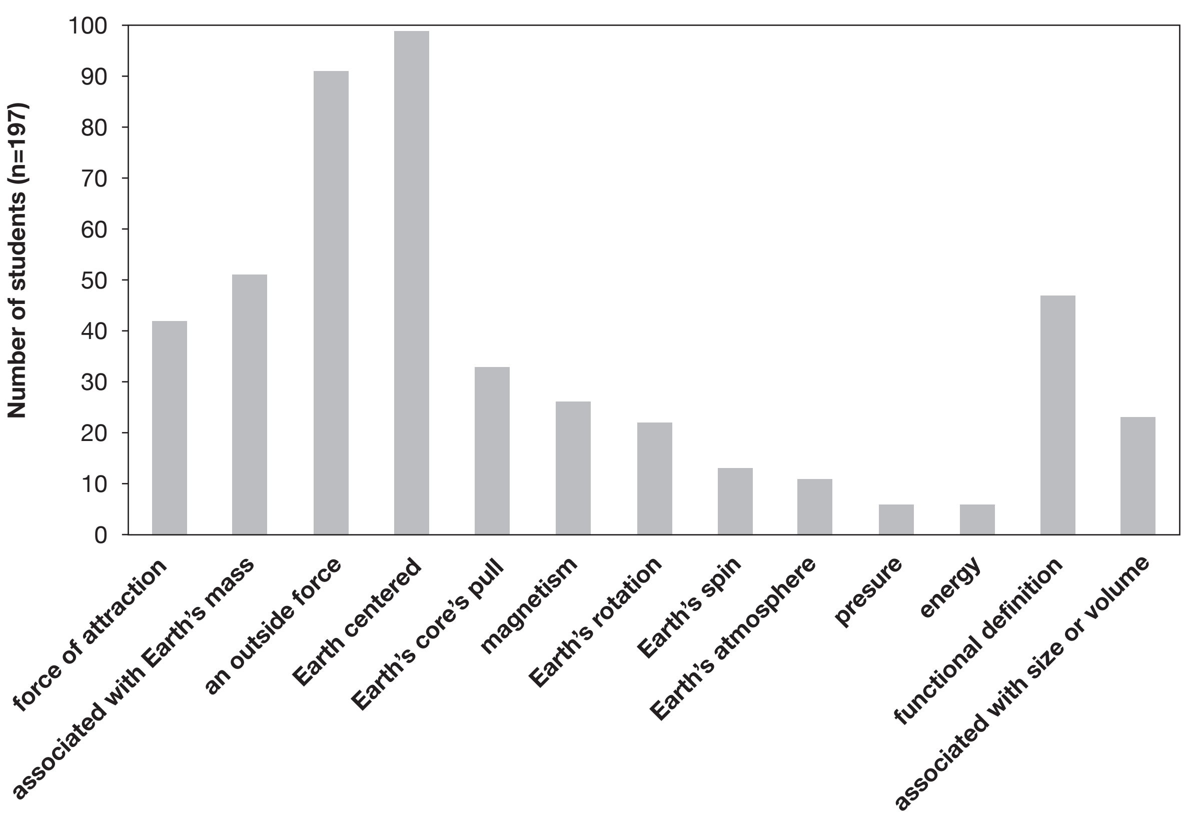
2. Gravity as an outside force

Approximately 46% of the participants seemed to view gravity as an outside force acting on an object, which might (a) exist independently of the object and (b) originate from something other than the Earth plus the attracted object. For example, 93% of those who perceived gravity as an outside force associated it with the Earth specifically. As observed in other categories, responses reflected multiple alternative conceptions about gravity. Not only did students think of gravity as a force acting on the Earth, they also suggested that gravity exists on Earth because of "magnetism," "earth's rotation," "earth's spin," "atmospheric pressure", and Earth's "relative position to the sun". About 29% of students in this category also mentioned the function of gravity on Earth (i.e., gravity prevents objects from "floating away"), either citing it as the sole reason for the existence of gravity on earth or coupling it with other phenomena, such as magnetism and Earth's rotation. A few students also associated gravity with the movement of objects. A large number of those who thought of gravity as an outside force acting on objects also invoked several other concepts that may or may not be connected to one another. The following responses reflect the diverse ideas these students carried in relation to gravity:

"Gravity is a force, acting on earth keeping everything on the ground. There is gravity because of the position in the solar system as well as the rotation of Earth."

"Gravity pulls on everything keeping it in place. There is gravity on Earth because of the way the Earth rotates."

Figure 1: College student conceptions of gravity and its causes. Alternative conceptions as illustrated in Table II and additional ideas identified in the study population. Notice that over 90% of the students in this study had an earth-centric perspective of gravity, and believed that gravity was a force acting on the Earth, rather than something that was an inherent characteristic of Earth (and all objects with mass). A wide array of other alternative conceptions were observed; see text for details.



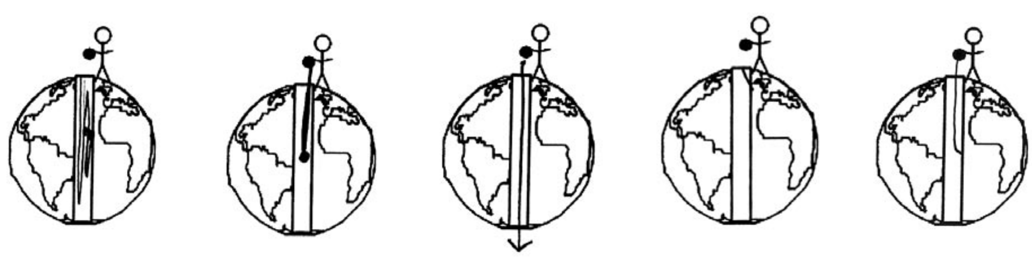
"Gravity is the force put upon earth due to earth's rotation around its axis and the sun."

"Gravity is the force pushing things down on the earth. Attraction of one object to another. Energy that pulls. Large objects have stronger [gravity]. With out [sic] [gravity] things would float."

"It's a magnetic like force that pulls everything towards the earth. If we didn't have it every thing [sic] would float off the earth that wasn't held down."

Although these five participants' responses seemed to imply that gravity is an external force "acting on earth" that "pulls" or "pushes" all objects on the Earth towards the "center of the earth" in order to "keep" objects "in place", they tended to give divergent explanations for why gravity exists on Earth. Two participants said that gravity is caused by the "rotation" of the Earth, and one of them also cited the relative "position" of the Earth in the solar system. One student said that Earth's spin and the "sun" caused gravity on the Earth. Two students mentioned only the function of gravity (i.e., without gravity things would "float away") in their explanations to account for gravity's existence on the Earth. One of these students also mentioned gravity as the force of "attraction" between objects while simultaneously viewing it as an external force "pushing" objects down on the Earth. Additionally, not only did this student define gravity as a "force," she also described it as "energy that pulls." She was applying the concepts of force and energy to gravity in an incoherent way, which suggests a faulty understanding of these concepts as well. Participants' responses suggest that they may be using several technical terms, such as "energy", "magnetic force", or "spin", to explain their ideas of gravity without a clear understanding of what these terms mean.

Figure 2: Exemplars of categories of student drawings for a N-S oriented tunnel. Category 1 is the correct conception, depicting the rock oscillating about the Earth's center. Category 2 is the most commonly observed conception, where the rock follows a direct path and stops at the Earth's center. Category 3 represents the concept that the rock will travel to the opposite side of the Earth. Three variations of category 3 were observed: the rock falls out the opposite side of the Earth, shown here, the rock will stop at the opposite side of the Earth, and the rock will fall out the opposite side of the Earth, curve and hit the Earth's surface. Category 4 and Category 5 were related but distinct concepts. Category 4 is the idea that the rock will curve and come to rest at the side of the tunnel very early in its journey down the tunnel. Category 5 blends Categories 2 and 4, yielding the notion that the rock will fall to the center of the Earth and curve into the side of the tunnel.



3. Earth-based notion of gravity

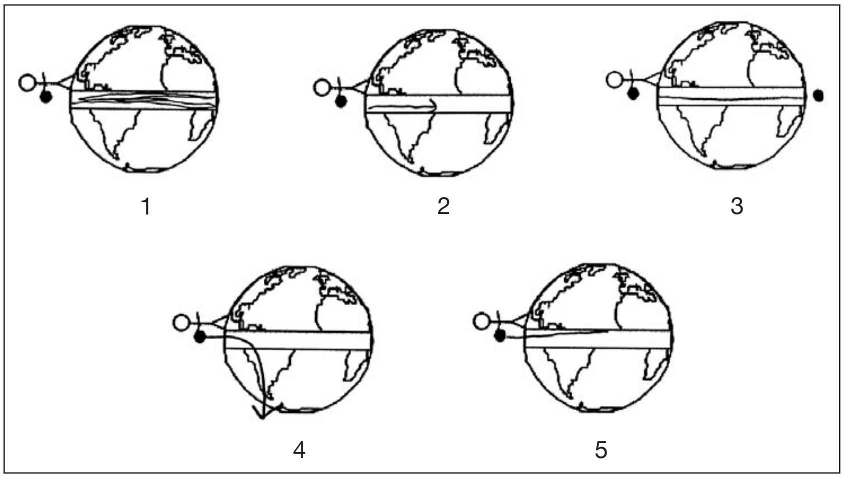
About 50% of the students in this study seemed to think of gravity only in relation to the Earth, and most held other alternative ideas along with this idea. As examples, students described gravity as "a force that the earth is exerting on us", "a pull the earth's core has on everything", "a force that earth's mass creates because of its size", or a "magnetic pull caused by the earth's core". A number of participants also correctly connected gravity on Earth to Earth's mass in their responses. As one student put it, gravity is a "pull on an object towards the center of the earth by the earth … the mass of earth in the solar system creates the pull".

Again, several participants mentioned magnetism, Earth's rotation, Earth's spin, or a functional view of gravity to explain why gravity exists on Earth. A few mentioned the Sun's and "moon's pull" as reasons for Earth's gravity. Surprisingly, some students thought of gravity as "energy" "pulling on" objects. According to one student, gravity is "energy that pulls you." Interestingly, some used the concept of Earth's "size" instead of mass while explaining their understanding of Earth's gravitation.

Student application of their understanding of gravity to the two simple gravity tasks also suggests a limited understanding of gravity. Overall, 73% of students drew the same pathway for both the N-S and E-W tunnels, and the likelihood of holding the same model regardless of tunnel orientation depended upon the student's overall understanding of gravity. Conceptions were evenly distributed across the two studied course populations.

Five categories of rock paths dominated the student responses for both N-S and E-W tunnel orientations, and two additional categories of response are worth discussion (Figure 2; Figure 3; Table III). Category 1 drawings depicted a rock oscillating about the Earth's center, which was the correct idea, and all students (10%, n=21) who held this idea for the N-S tunnel also held it for the E-W tunnel. One additional student held a Category 1 idea for the E-W tunnel and a Category 2 idea for the N-S tunnel. Category 2 drawings showed a rock path that stopped abruptly at the center, and these were the drawings most commonly observed. Overall, 49% (n=98) of students held this idea for both tunnel orientations, six held it for the E-W tunnel only, and thirteen students expressed this idea for the N-S tunnel only. These students were mixed between Categories 3, 4, and 5 in their choice for the other orientation or believed the rock in the E-W tunnel would simply fall off the page (Figure 4). Category 3 drawings depicted a rock that fell through the Earth. Once on the other side, the rock fell out of the tunnel, fell out and curved back down to the Earth's surface, or simply stopped moving. While 45 students held this model for the N-S tunnel, only 20 drew similar paths for both tunnels. Category 4 and 5 were related, and both showed the rock curving and coming to rest at the side of the tunnel. Category 4 paths ended near the tunnel entrance, while Category 5 paths ended at the Earth's center. Nearly twice as many students believed the rock would curve towards the tunnel surface for the E-W oriented tunnel (n=31) than the N-S tunnel (n=18).

Figure 3: Exemplars of categories of student drawings for the E-W oriented tunnel. Categories as in Figure 2.



Category 6 and 7 ideas (Figure 4) were held by fewer students than other models and were observed predominantly for specific tunnel orientations. Four students indicated that the rock in the N-S tunnel problem would fall away from the Earth, "slide" around the Earth, or orbit the Earth. An additional student indicated that, while he believed most strongly that the rock would fall to the opposite side of the tunnel and stop (Category 3), the rock moving around the Earth instead of into the E-W tunnel was a possibility. Another student preferred the model of the rock stopping at the center of the N-S tunnel (Category 2), but suggested that the rock might also "fall straight down due to gravity". This explanation was accompanied by a crossed-out path that showed the rock moving perpendicular to the N-S tunnel (that is, off the page). Finally, twelve students believed that the rock would fall off of the page rather than move into the E-W tunnel. Of these, two also held the conception that the rock would move away from or around the Earth for the N-S tunnel orientation (Category 6).

Student explanations of their drawings did not always indicate deep understanding or firmly held beliefs, but they provided interesting insight into student thought processes. Although Category 1 represented a correct concept, students were generally unable to provide a detailed explanation of this phenomenon or demonstrate alternative ideas. For example, our Category 1 student in Figure 2 explained his drawing by stating "The center pulls it there by 9.8 m/s and it rubberbands back + forth till [sic] it gets to the center". This student depicted an identical path for the E-W tunnel, stating simply, "Earth is round". Another student explained this oscillating phenomenon in the N-S tunnel with an alternative conception about the cause of the attraction between the rock and the Earth, stating "Gravity and earth's rotation will balance out".

The dominant conception that the rock will follow a straight path and come to rest at the Earth's center was often explained by a tug-of-war between the two ends of the tunnel ("The rock will not fall the entire way through the center of the earth b/c the gravity will pull the rock in the center of the 2 ends") or by the perceived attractive nature of the core ("core pulls things towards it”). The final motion of the rock at the end of the tunnel, whether continuing to move into space, falling to the Earth’s surface, or simply stopping, often changed as the tunnel changed orientation. A few students used their explanation for the rock’s path in the N-S tunnel to justify a similar depiction for the E-W tunnel (“He is still standing next to a hole and when he drops it it will still fall straight down through the tunnel”). One student who believed the rock would fall straight through the N-S tunnel and out the other side (“The rock will fall until gravity is unable to act upon it without another for [sic] acting up on it) also believed the rock would fall off of the page rather than into the E-W tunnel (“The rock will fall and have gravity enforced on it until there is no more gravity”). Eight of the twelve students with the “off of the page” conception believed the rock would fall all of the way through the N-S tunnel to the other side. The remaining four students were evenly divided between a rock that stopped at the center of the N-S tunnel and a rock that curved away from the Earth or began to orbit the Earth (Figure 4; “Because of the earths rotation the rock would slide away from the tunnel”). Finally, students with Categories 4 and 5 models believed that gravity pulls objects down (“The rock would go into the Earth but then move downwards because of the gravity pulling it down”) or towards a surface (“Gravity would eventually draw it to some sort of surface”). One student emphatically described her Category 4 conception as shown in Figure 2, “The rock will fall quickly to the Earth. It will not go through the tunnel”. Interestingly, for most students the surface in the tunnel to which the rock falls could be orientated vertically or horizontally relative to the page. It appears that these students had an earth-referenced conception of up/down relative to the surface of the Earth.

A few students provided explanations of the rock’s path that fell outside of the categories described here. One student believed that the rock would fall into the tunnel and come right back to the surface for both tunnel orientations. This student did not have an explanation for this phenomenon and simply stated that he “saw it in a magazine”. Four students believed the rock would not move at all in the E-W tunnel, with one of these students holding the identical belief for the N-S tunnel. The student with the “no motion” conception for both tunnels firmly stated that “the rock won’t move” without further explanation. The remaining three students with no motion in the E-W tunnel all held the conception that the rock would follow a direct path in the N-S tunnel and stop at the Earth’s center. These students explained their ‘no motion’ model in various ways. One student thought the rock would “fall to ground” but not into the tunnel. Another student similarly explained that the rock would “drop and stay in that area”, and a third student indicated that the rock “would just stop”.

Table III: Seven categories of student drawings.

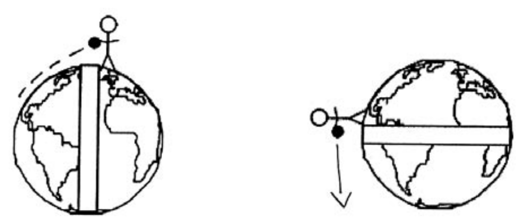
Drawing Category	**N-S Tunnel** # of students (% of n=201)	**E-W Tunnel** # of students (% of n=201)
Category 1 drawings depicted a rock oscillating about the Earth’s center, and this represents the correct idea.	21 (10%)	22 (11%)
Category 2 drawings depicted a rock that stopped abruptly at the center.	111 (55%)	104 (52%)
Category 3 drawings depicted a rock that fell through the tunnel to the opposite side of the Earth.	45 (22%)	20 (10%)
Category 4 drawings depicted a rock that fell into the tunnel (not to the center) and curved to the tunnel’s surface.	5 (2%)	15 (7%)
Category 5 drawings depicted a rock that fell to the Earth’s center and curved to the tunnel’s surface.	13 (6%)	16 (8%)
Category 6 drawings depicted a rock falling away from, or curving around, the Earth.	3 (1%)	0
Category 7 drawings depicted a rock falling off the page.	0	12 (6%)
Total number of responses in these categories	196	189

C. Undergraduate versus K-12 Students' Conceptions of Gravity.

This study was an attempt to explicitly link gravity conceptions and problem-solving approaches of K-12 students with those of non-physics college students. Surprisingly, college students' conceptions of gravity seem remarkably similar to conceptions identified in younger populations, particularly elementary-aged students. In particular and as described earlier, the research literature abounds with non-scientific models of gravity held by children. For instance, children tend to think that gravity either needs air to act or is caused by air pressure. Another prevalent misconception is that gravity operates on Earth only. Many K-12 students tend to associate gravity with magnetism or Earth's rotation. An "Earth-referenced view of down" based on the Earth's surface rather than the center of the Earth is also prevalent among children. While solving the gravity task in a similar study, elementary and middle schools students also drew rocks (a) falling towards the bottom of the page, (b) falling towards the Earth's surface but not the center, (c) falling away from the Earth, and (d) falling towards the Earth's center (Nussbaum & Novak, 1976; Nussbaum, 1979). Alarmingly, college student misconceptions are not dramatically different from those of K-12 students, and a significant number of students in our study population held ideas similar to those of elementary students. The notions that gravity exists because of magnetism, air pressure, the special nature of the core, or the Earth's rotation are all well-documented in pre-college populations and were also observed in abundance here.

Overall, the solutions and explanations that college students provided for the gravity tasks were generally more advanced than observations made of elementary students in the 1970s (Nussbaum, 1979). However, over 5% of the studied college population held the idea that gravity worked down relative to a piece of paper, and 21% believed a ball would simply fall out of a N-S oriented tunnel and into space. Almost 50% of the college students mentioned in their responses that a dropped object will immediately stop at the Earth's center; this was classified as a "correct" model by earlier researchers investigating young children. Finally, very few students were able to provide coherent explanations for object behavior, suggesting that college students hold incoherent ideas about gravity and related phenomena.

Figure 4: Other common rock paths produced by the study population were dependent upon tunnel orientation. Category 6: Four students depicted the rock falling away from the Earth or curving around the Earth. This was only observed as a primary model for the N-S oriented tunnel, although one student suggested this as an alternative model for the E-W tunnel. Category 7: Twelve students indicated that the rock would fall off of the page for the E-W oriented tunnel only.


6 7

Despite more than a decade of diverse national efforts to modify and improve physics instruction in the K-college classroom, we observed little difference between current college student models and those of young children documented almost three decades ago. For example, only 10% of our college population held the simplest scientifically accepted model of gravity without also simultaneously holding alternative ideas, suggesting little change in gravity understanding from K-12 to college. The alternative ideas observed here were quite similar to those of elementary students, and a high percentage of both groups of students equated gravity with magnetic or rotational forces (Table I; Figure 1). Ideas of gravitation that have long been considered to be exclusive to young students, such as the "off-the-page" model classified here as Category 7 (Figure Z) and documented by Nussbaum (1979), were also observed in our adult population. These findings suggest that gravity models are either resistant to change, are prone to reversion from scientific models to original alternative conceptions, or are not being explicitly targeted by instruction.

Student responses to the gravity problems also revealed a host of alternative ideas about other fundamental physical and geological concepts. The connection of gravity with magnetism, Earth's rotation, atmospheric pressure, and the core of the Earth suggests a limited understanding of these phenomena. Other studies also suggest that many children and adults relate air, atmosphere, magnetism and Earth's spin to gravity (Ruggiero et al., 1985; Stead & Osborne, 1980). Additionally, half of the students in this study believed that a falling rock would reach the center of the Earth and stop, and many students explained this by saying that there would be "no force" at the center. While the students are correct that there would be no net force at the center of the earth, they are incorrect in their depiction of the rock stopping at the center. This indicates that these college students may be confused in their usage of the concepts of force, velocity, and acceleration. It appears that students need to develop a clear understanding of force and motion to understand gravity as a force of attraction that is mediated by a field. These data bring to mind a number of interesting questions about the relationships between physics reform efforts, pre-service preparation, in-service continuing professional development, and instruction in K-12 classrooms. Through this and other future studies we hope to engage in a conversation about these issues across the disciplinary boundaries that may exist between physicists, other scientists, and science educators. What would it take to help students and teachers to develop coherent models of foundational ideas in physics? How do we supplement or follow up on "good teaching" practices so that students retain content and develop a coherent and lasting understanding of scientifically accepted models?

V. Conclusions and Implications

We found that entry-level college students enrolled in geology courses were unable to provide any coherent scientific explanation of gravitationally related phenomena. Neither weak explanations, such as the simple regurgitation of the gravity definition, nor strong explanations, including those that connect meaningfully to other scientific ideas, were present in our population. Students' own ideas about gravity reflect a lack of understanding about many fundamental ideas in science, including pressure, gravity, magnetism, and Earth's rotation (Figure 1). Additionally, non-physics college student conceptions of gravity are remarkably similar to ideas held by elementary-aged students reported nearly three decades ago. This suggests that physics instruction in pre-college grades may need to explicitly address gravitation ideas held by students, rather than more common approaches that focus on the effects of gravity. The impact of alternative ideas on reasoning in other domains, such as Earth and Space science, cannot be understated. For example, the Earth-centric models of gravity held by many of the students in our study resulted in some who believed that gravity only existed on Earth. Other students (in related work with this same population of students), felt that gravity did not exist on Mars, because Mars does not have a magnetic field. The likelihood that students will confuse these foundational ideas with other conceptions suggests that curriculum developers may need to identify and address students' prevalent misconceptions in physical science by including multiple experiences that help them to transform and develop their initial ideas into coherent explanations of these basic scientific ideas.

Students tend to reason from familiar concepts, and when these concepts are non-scientific, conclusions can be far removed from the concepts we think we are teaching. It then becomes paramount that we explicitly target the most basic ideas in our instruction, rather than assuming, as certainly many college faculty do, that students have "already had that material" in an earlier class. The findings presented here suggest that college faculty in all sciences, not just physics, may want to identify, discuss, and clarify students' confusions related to gravitation, weight and other related concepts as a core element of effective instruction. For geoscientists, misunderstanding the fundamentals of gravity can have serious implications for teaching any number of larger ideas, including mass wasting, plate tectonics, and planetary geology. Furthermore, many geology majors are required to take geophysics classes, since geophysics is a fundamental tool used in oil exploration, mining, and other geologic industries. Some of the students in our study were enrolled as geology majors, and at the very least, these majors should understand gravity in order to be able to reason about gravity anomalies and planetary systems. This study suggests that for faculty in interdisciplinary fields such as geology, it may be a good idea to probe about fundamental ideas before engaging in a discussion of concepts that require an a priori understanding.

One of the main limitations of this study is that it was based on a relatively simple tool to elicit college students' ideas about gravitation. We employed this tool to replicate studies originally conducted with children with the college level population. We propose that future research and effort in teaching gravity concepts may need to focus on 1) Interview-based probing of high school and college students' understanding of the concepts of gravitational force, weight, the inertial mass, and the gravitational mass (Gönen, 2008) to attain a deeper knowledge of their mental images and conceptions of these ideas; 2) Conducting pre-post and experimental studies to examine the effect of instruction on students' prior knowledge of gravitation; and 3) Investigating how teachers translate concepts learned via reform efforts to K-12 classrooms. K-12 teachers are exposed to reform-based methods, but are not always able to translate these experiences to classroom instruction. Certainly, we know that reform-based courses are effective at engendering conceptual change (Shaffer & McDermott, 2005), but it is less certain if these approaches are being applied effectively (Le et al., 2006). We also wonder if reform-based instruction targets the most common misconceptions about the natural world (Vosniadou & Brewer, 1992). Finally, it might be useful to consider these fundamental concepts from the theoretical perspective of threshold concepts (Meyer & Land, 2005). Threshold concepts are ideas that can act as barriers to a curriculum, wherein understanding a threshold concept may provide a gateway to deep understanding of related concepts. We as faculty may need to seriously reconsider the assumptions we make about students, in terms of both what students are bringing to and taking from the classroom. Ultimately, we as a community need to decide which concepts are absolutely necessary for deeper learning in a domain, and teach accordingly.

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