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ABSTRACT

This study was part of a continuing exploration of the naive misconceptions of students in the physical sciences conducted within the context of current literature in alternative frameworks. The sample was selected from among those students registered for a liberal education physical science class at a small private college. The method used was a clinical interview, beginning with very open-ended questions, moving to that of "interview-about-instances," and ending with a paper-and-pencil test. During interviews about the nature of the solar system, the subject invariably turned to gravity. This appeared to be an exceptionally salient topic to the students and one about which they were very uncertain. Most subjects had some grasp of the concept that the mass and gravity of an object were related. A common interpretation was that, since the gravitational force acted from a point at the center of the planet, it was diminished at the surface as a planet became larger. The presence of the sun appeared to be a major factor in the judgments made by most students. The most salient relationship was between the sun and planets. The results indicated most had a reasonable concept of gravity. It was anticipated that the observed misconceptions could be corrected by an appropriately designed intervention. (Author/CW)

MISCONCEPTIONS ABOUT GRAVITY HELD BY COLLEGE STUDENTS

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Running Head: GRAVITY

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INTRODUCTION

This study is part of a continuing exploration of the naive misconceptions of students in the physical sciences. It is conducted within the context of current literature in alternative frameworks (Driver, Guesne and Tiberghien, 1985; Osborne and Freyberg, 1985), in which open-ended interiews about scientific concepts are used to probe the way in which individuals have constructed knowledge about physical processes.

Our interviews have generally begun with broad questions about the nature of the solar system, but almost invariably the subject turns to gravity. This appears to be an exceptionally salient topic to our subjects, and one about which they are very uncertain.

Our report is restricted to students' understanding of Newton's law of universal gravitation, and our inquiries have been conducted within the context of the distribution of gravitational force within the solar system.

Previous research

There have been a number of studies of students' conceptions of gravity (Gunstone and White, 1981; Stead and Osborne, 1980), and the topic has been reviewed by Nussbaum (Driver, Guesne and Tiberghien, 1985). However, the studies currently available were either conducted with younger students or were related to a more general exploration of the nature of forces.

This research began with a series of free-form interviews of Australian secondary school students, and led to the identification of persistent misconceptions about gravity, and the construction of a test to evaluate the frequency of these misconceptions with larger samples (Treagust & Smith, 1986). Smith and Treagust (1988) specifically identified four misconceptions: 1) a planet's gravity is related to its distance from the sun; 2) the sun's gravity influences not only the planets to orbit around the Sun, but also the gravity of the planet; 3) a planet's rotation or lack of it affects its gravity - zero or slow rotating planets have less gravity than fast rotating planets, and; 4) the rotation of a planet is dependent on its position with respect to the sun or to its size. In this report, the evaluation of these misconceptions is extended to an older group of students in the United States.

Research on misconceptions has, in the last decade, revealed a number of these puzzling points of view that students seem to develop in spite of, or perhaps because of, what they have been taught. Science teaching is relatively similar in most western countries, and this is certainly the case with regard to Australia and the United States. For instance, the biology text used uniformly throughout Western Australia is an adaptation of the BSCS text written by the Australian Academy of Science. Yet stereotypic misunderstandings seem to develop among students of a variety of ages and nationalities, and their origin is not understood.

Cognitive psychology posits processes by which which stimuli are transformed and integrated into schema for storage in long term memory. These are presumably quite complex, and their relationship to misconceptions has not been investigated carefully. Recently, Lawson and Thompson (1987) reported a study in which they found that "the only student variable conistently and significantly related to the number of misconceptions (about evolution and heredity) was reasoning ability."

Reasoning about logical propositions

A reasoning variable which has been shown to be highly related to success in science is the ability to reason about logical propositions (Piburn & Baker, 1988). This ability has been evaluated in a number of studies with the use of an instrument called the Propositional Logic Test.

The Propositional Logic Test (PLT) is a sixteen item test which measures a subject's ability to interpret truth-functional operators by identifying instances that are consistent or inconsistent with a stated rule. It contains four subtests of four items each; the conjunction, disjunction, material equivalence and material implication. The last two subtests each evaluate the ability of a subject to understand and use conditional reasoning as exemplified in propositional statements using the 'If...then' construction. Reliabilities have been reported of .82 for 226 year 10 Australian students (Piburn & Baker, 1988), .94 for a sample of 34 high school students (Pallrand & Vandenberg, personal communication), and .90 for a sample of 30 college students (Enyeart, et al., 1980).

Summary

Cognitive psychology is moving away from molecular explanations of the reasoning process, as witnessed by the rise of interest in such topics as schema theory, information processing, or generative learning. These 'top-down' models describe learning as a process that "organizes the information selected from the experience in such a way that makes sense to us, that fits our logic [italics added], or real world experiences, or both" (Osborne & Witrock, 1983, pg. 493). The relationship between students' understanding of science and their ability to interpret formal logic should help clarify the manner in which information is transformed and stored, and shed light on the origin of persistent misconceptions about scientific phenomena.

METHOD

The sample was selected from among students at a small liberal arts college who were enrolled in either a liberal arts physics course or an educational psychology course. Since most students wait to complete their science requirement as long as possible, the sample was largely upper division junior or senior, and contained no science majors. It was relatively evenly divided between males and females, and between traditional-aged and non-traditional students.

The sample was stratified on the basis of responses to the Propositional Logic Test (Piburn, 1985), and two students chosen from each of four response types. These subjects were administered a clinical interview, beginning with very open-ended questions about the nature of the solar system, then moving to an 'interview about instances' (Osborne and Gilbert, 1980). In addition, the entire sample was given a pencil and paper test (Treagust and Smith, 1986). The 'interview about instances' and the test focused on a series of diagrams showing

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insert Figure 1 about here

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spaceships taking off from a variety of planets, and the most common question was "Which planet would be easiest for the rocketship to 'take off' from." All interviews and tests were completed near the beginning of the semester, before any discussion of universal gravitation in the physics class.

Statistical analysis of the relationship between reasoning ability and misconceptions was conducted by dividing the sample into two groups. The first, consisting of 15 subjects, included those who consistently used conditional reasoning on the material equivalence and material implication subtests of the PLT. The second, consisting of 25 subjects, consisted of those who did not. All statistical analyses were conducted on an Apple IIc microcomputer (Bolding, 1985).

RESULTS

Interviews

Most subjects had some grasp of the concept that the mass and gravity of an object were related. However, there were a variety of interpretations of this relationship when the issue of a spaceship was raised. A common interpretation was that, since the gravitational force acted at a point from the center of the planet, it was diminished at the surface as the planet became larger, leading to the consequence that a spaceship could depart from a large planet more easily than a small one. A slightly different, but related inference was that the increasing mass and increasing diameter cancel one another with the result that, although larger planets have more gravity, spaceships will leave as easily from all planets.

It is not surprising that no person had a clear idea of the origin of gravitational forces. About half of those interviewed knew that they are a function of the mass of an object, and could relate this in some way to both the size and the composition of a planet. The rest offered a surprising variety of explanations for gravity. Several thought it had something to do with temperature, and judged that the gravity of a planet would decrease with distance from the sun for this reason. One person offered an exceptionally well reasoned argument for the existence of gravity as a result of heat generated through frictional forces, and judged that a planet that was not rotating would have no gravitational field. Several students a showed confusion between gravitational and magnetic fields, and one thought that gravity was what made a compass point to the north pole. One person thought that gravity was somehow related to the ozone layer in our atmosphere.

The presence of the sun appears to be a major factor in the judgments made by most students. For most, but by no means all, the orbital motion of planets about the sun is the major evidence for the presence of gravity. One person saw this as so key a factor that s/he assumed that a planet not orbiting the sun would have no gravity, and that if the earth moved into such a position we would all float off into space. Most recognized that the gravitational force of the sun decreases with distance from it, but then equated this phenomenon with the gravity of the planet itself, stating that the planet farthest from the sun would have the smallest gravitational force. Only one person correctly saw that the gravitational forces of sun and planets would be independent of one another.

Almost all of those interviewed reached their conclusions on the basis of some concept of Newton's laws of universal gravitation. However, for them the most salient relationship was between the sun and planets. Only one was able to formulate a relationship for the attractive force between a planet and an object on its surface, and that was not correct. For all of those interviewed, including even those who had a reasonably good intuitive understanding of this subject, the distance from the sun was <u>the</u> most important factor in making judgments about rocket ships leaving the surface of a planet. The size and nature of the planet in all cases seemed to be much less significant variables.

It is heartening to note that only one person interviewed had no reasonable concept of gravity. S/he appeared to have a theory of 'social utility' with regard to gravity, and stated that it existed because we need it...without it we would just float off into space. S/he consistently argued that planets without life would not have gravity.

Statistical analysis

The pencil and paper test which was administered to all subjects had a true/false section which contained three questions that apply to the misconceptions identified above.

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insert Table 1 about here

The results of these, shown separately for conditional and non-conditional subjects, and for the sample as a whole, are shown in Table 1. About 50% of the total sample believed that the gravity of a planet depends on its distance from the sun, and 20% that it depends on the the temperature. There are striking differences here between conditional subjects, who more commonly prefer composition as a major factor and don't care much for temperature, and non-conditional subjects who see distance from the sun and temperature as quite important variables.

The written versions of 'interview from instances' presented the same diagrams as shown in Figure 1, but with written responses. In the first set, students were allowed to choose Planet A, B or C, the same, or can/t tell. In the second set they were allowed to check a reason for their answer, or to write one in. The intersection of the first and second set of choices yielded categories of response that involved both choice and reason.

When given a choice between three planets of equal size, at

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insert Table 2 about here

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increasing distances from the sun, the most popular choice from among those offered was "the farthest planet, because there is less gravity from the sun". This was chosen by 36% of the non-conditional subjects, but only by 20% of the conditional reasoners. The next most popular choice was one which had to be written in, and it was that "you need more information about the composition of these planets". This was added by 40% of the conditional reasoners, but only by 12% of the non-conditional subjects.

The second instance, which shows three planets increasing

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insert Table 3 about here

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in size away from the sun, yielded results that are similar to the previous item (Table 3). In addition, the choice of the smallest planet because it has less gravity, and the bigger planet because the rocket is farther from the center, were appealing to both groups, the first more so to conditional reasoners and the second to non-conditional subjects.

The final instance reconfirms these results (Table 4). The

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insert Table 4 about here

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conditional reasoners prefer the smallest planet or need more information about the composition of the planets. Non-conditional reasoners favor the farthest planet from the sun. Both groups are slightly attracted to the largest planet, because the rocket is farthest from its center.

Only two types of write-in responses as alternative reasons for choosing a planet were observed. The first, already mentioned, notes the need for more information about composition of the planet. Examples of such responses, taken from the test papers, are:

- The density of a planet will greatly influence escape velocity.
- Although the size may be the same, their masses may be different.
- I need to know the material makeup of the planet.

On the other hand, the written answers for non-conditional subjects seemed to evidence a sense of despair, to suggest that they need to know a lot more, or maybe even that they could never know:

- I cannot tell because I need more tangible information so I can form a clearer mental picture in my mind.
- It is hard for me to figure out, and I don't like these questions.
- I am not sure about this answer. It seems practical.

These latter responses were coded for analysis as "You can't know," and appear on Tables 2-4 in this form. In every instance, conditional reasoners used this response much less frequently than non-conditional reasoners.

Significance testing was conducted using chi-square analysis. Since the relatively small sample of 40 subjects was divided into two groups, and seven responses were possible, division of subjects into a complete contingency table resulted in frequent empty cells. In order to avoid this violation of the assumptions of chi-square, it was necessary to aggregate responses.

The first analysis involved testing the three instances only for choices concerning the planet's distance from the sun and its composition. In this case there were significant differences between conditional and non-conditional subjects on instance two (chi-square = 4.667, p = .031) and instance three (chi-square = 4.900, p = .027). The hypothesis of a significant difference failed for instance one (chi-square = 3.636, p = .056).

In the second set of analyses, the response "you can't tell" was added. Instance two (chi-square = 7.398, p = .025) and instance three (chi-square = 6.689, p = .035) continued to reveal significant differences between the choices of conditional and non-conditional subjects.

In a final analysis, all responses were aggregated into

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insert Table 5 about here

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four categories. In this case, only instance two continued to reveal statistically significant differences between the responses of conditional and non-conditional reasoners (Table 5).

In summary, a series of misconceptions about gravity are revealed in these data. While nearly 90% of the subjects agreed with the statement that the gravity of a planet depends on its composition, only 20% requested additional information about composition in specific instances. The most common choice in instances, occurring as often as 30% of the time, was that the gravitational force depends upon the distance from the sun, and 50% of the subjects agreed with the statement that the gravity of a planet depends on its distance from the sun. While fewer than 10% chose instances of cooler planets having less gravity, almost 20% agreed with the statement that the gravity of a planet depends on its temperature. The incidence of these responses was significantly related to whether the subject was able to correctly interpret propositional statements in the form f material equivalence or material implication, the 'nditional' statements of propositional logic.

Conclusions

The college students involved in this study share a set of misconceptions about gravity with Australian secondary school students. This raises a number of serious questions both about students and the instructional processes which they have experienced.

Physics is a complex, axiomatic subject that is taught through a series of deductive proofs. The principles of nature which it claims to represent are far removed from any intuitively obvious connection with experience. This is particularly true with regard to the gravitational force, which has long puzzled physicists. Newton himself noted in Principia the 'occult' nature of gravity, and that he included it only because it was required to complete his system.

Deductive proof requires the use of conditional statements. Indeed, the forms of Greek syllogism, modus ponens and modus tollens are based upon tests of the implication. The method through which physics teachers ask students to arrive at conclusions about gravity, and of course most other topics in physics, involves the assumption that they are capable of such thought.

Subjects in this study who understood conditional statements had a reasonable general understanding of Newton's law of universal gravitation, and could correctly interpret most instances. Although rarely expressed complete and correct mathematical formulations, they were aware of the relevant variables and the relationships that pertained among them.

The remainder seemed to rely upon a number of poorly understood associations between phenomena and prior knowledge to explain the gravitational force. Many referred to magnetism, temperature, speed and distance from the sun, relating them to one another and to gravitation.

Position with respect to the sun was exceptionally salient for subjects. Most knew that temperatures and periods of revolution decrease with distance from the sun. This seemed intuitively consistent with experience with other phenomena such as light, heat and sound. Since the sun is the source of the gravitational force which maintains planetary motion, they reasoned that gravitational forces must also decrease away from the sun.

The concept that motion was related to gravitational forces came from experience, and subjects gave many examples. The most common were the centrifugal forces felt on carnival rides and the accelerations experienced in automobiles. Their responses to specific instances depended idiosyncratically on theories which they had about the way in which distance from the sun would effect periods of rotation.

Temperature was associated with gravity and motion in the minds of several subjects. They argued that planets that were either moving faster or spinning faster, or closer to the sun, would experience more friction and thus be hotter and have higher gravitational fields. One subject suggested that s/he had learned in school that high gravity in the earth's core had made it melt, and another spoke about the loss of gases from planetary atmospheres as a result of high temperatures. Apparently many people have been exposed in the past to some connection between temperature and gravity in cases which they did not understand and later apply incorrectly.

The final and most common characteristic of subjects who did not use conditional reasoning was a sense of powerlessness. They often said that they didn't know or understand much about science, and that they weren't very good at these kind of problems. They were rarely able to identify relevant variables, and to exclude those which were not, and they never attempted to express logical relationships.

These results indicate that the current mode of science instruction is relatively successful with students who are capable of reasoning about logical statements. Although they do not have the depth of understanding we might expect of science students, their responses do not reveal serious misconceptions.

Students who are not successful with logical statements are also not successful with science, and they are the source of the majority of the observed misconceptions. Lacking understanding of the conditional statements that connect variables in physics, they seem to rely on associations between things that 'go together', but are not causally linked.

It is not easy to arrive at a solution to the dilemma posed by these results. Teaching using concrete physical phenomena does not appear to be a good approach to correcting misconceptions in physics. In fact, the problem appears to be too much reliance on just those phenomena without the ability to exclude logically from consideration those which do not apply.

Physics teachers who deal with general education students may need to deal specifically with misconceptions such as those revealed in this and other studies, and in a quite different manner than they have been. If elimination of irrelevant relationships by deductive argument is not successful, they may need to explicitly deny irrelevant associations and reinforce those which are correct. Whether such an approach can lead to deeper uderstandings and more meaningful learning is a question yet to be addressed.

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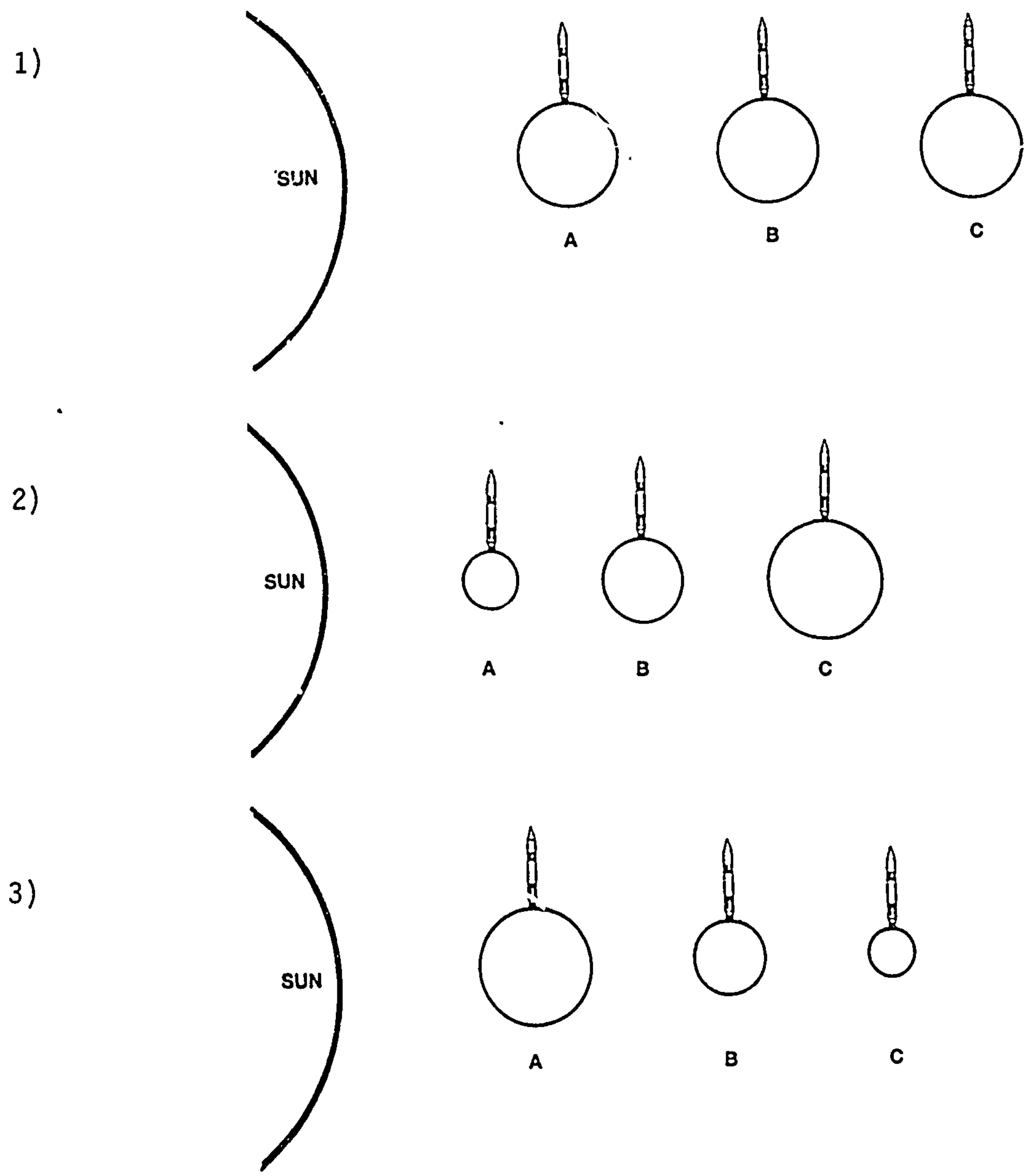
Figure 1.

Instances used in interviews and written test of understanding of gravity.



IN THIS SOLAR SYSTEM, THERE ARE THREE PLANETS

AN IDENTICAL ROCKETSHIP IS READY TO LEAVE EACH PLANET.

WHICH PLANET WILL BE EASIEST FOR THE ROCKETSHIP TO "TAKE OFF" FROM?

Table 1.

Percentage of subjects identifying the following statements as true.

	conditional	non-conditional	TOTAL
-The gravity of a planet depends on its composition.	87%	68%	75%
-The gravity of a planet depends on its distance from the sun.	27	60	48
-The gravity of a planet depends on its temperature.	7	24	18
n =	15	25	40

Table 2.

Percentage of subjects choosing among responses to instance #1: Three planets of the same size, at increasing distances from the sun!

	conditional	non-conditional	TOTAL
-The farthest planet, because there is less gravity from the sun.	20%	36%	30%
-The farthest planet, because it it is cooler and has less gravity.	13	4	8
-The farthest planet, because it is slower and has less gravity.	13	4	8
-The middle planet, because it is neither too hot, too cold or too close to the sun.	0	8	5
-All the same, because they are all the same size.	7	16	13
-You need more information about the composition of these planets.	40	12	23
-You can't tell	7	20	15
n =	15	25	40

Table 3.

Percentage of subjects choosing responses to instance #2: Three planets, increasing in size away from the sun!

	conditional	non-conditional	TOTAL
-The farthest planet, because there is less gravity from the sun.	13%	20%	18%
-The farthest planet, because it is cooler and has less gravity.	0	0	0
-The farthest planet, because it is slower and has less gravity.	0	12	8
-The biggest planet, because the rocket is farther from the center.	20	28	25
-The smallest planet, because it has less gravity.	20	16	18
-You need more information about the composition of these planets.	40	4	18
-You can't tell.	7	20	15
n =	15	25	40

Table 4.

Percentage of subjects choosing responses to instance #3: Three planets, increasing in size toward the sun!

	conditional	non-conditional	TOTAL
-The farthest planet, because there is less gravity from the sun.	18%	32%	26%
-The farthest planet, because it is cooler and has less gravity.	6	0	2
-The farthest planet, because it is slower and has less gravity.	0	8	5
-The biggest planet, because the rocket is farther from the center.	12	12	12
-The smallest planet, because it has less gravity.	24	16	19
-You need more information about the composition of these planets.	29	4	14
-You can't tell.	12	28	21
n =	15	25	40

Table 5.

Results of a Chi-square analysis of the responses of conditional and non-conditional reasoners to instance #2:
Three planets, increasing in size away from the sun!

Response	Frequency conditional	Frequency non-conditional
-The farthest planet, because there is less gravity from the sun.	2	5
-You need more information about the composition of these planets.	6	1
-You can't tell.	1	5
-All other responses.	6	14

Number of observations	40
Chi-square	8.7721
Significance level	0.0325
Contingency Coefficient	0.4241
Cramer's Phi Prime	0.4683