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Detecting Gravity-Related Misconceptions of First Year Medical Students Using the Newtonian Gravity Concept Inventory

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ABSTRACT

Misconceptions create their problems and must be clarified. One of the misconceptions that often arises is the concept of Newtonian gravity. In this report, we discuss first-year medical students' understanding of the concept of gravity examined using the Newtonian Gravity Concept Inventory (NGCI). Four domains of the concept of gravity are covered by the NGCI utilizing 26 multiple-choice questions: Directionality, Gravity as a force, Independence from other forces, and threshold. One of the goals of this study is to evaluate the effectiveness of our teaching materials and methods. Therefore, the test was given to students twice as a pre and post-test relative to in-class gravity-related instructions. In this article, we're reporting on gravity-related misconceptions found with our students in the pre-test only. 511 students participated in the test with a recorded average score of 39.9%. We documented a complete list of misconceptions with eleven dominant ones found in the pre-test: Gravity is affected by magnetism, Gravity is affected by objects' density, misconceptions related to the dependence of the force of gravity on the distance, and more.

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Introduction

Whether we notice it or not, gravity is part of our everyday lives (Smith & Treagust, 1988; K. Williamson et al., 2016; K. E. Williamson, 2013; K. E. Williamson et al., 2013; K. E. Williamson & Willoughby, 2012). Our understanding of gravity is usually an accumulation of different experiences over the years plus the official knowledge we get from schools and learning materials (books, documentaries, and, of course, nowadays, the ever so easily available internet materials). It's one thing to be exposed to suitable learning materials about a particular concept but another to understand. This is why some people end up with misconceptions. Our goal as responsible educators at any level is to detect these misconceptions and try to help students replace them.

Assessment tools are available in most areas of education research to help us acquire the needed knowledge about misconceptions. Concept inventories with multiple-choice questions are considered excellent and appropriate choices when dealing with a large number of students because of their easy and quick implementation (H. Bani-Salameh et al., 2017; H. N. Bani-Salameh, 2017b; H. N. Bani-Salameh et al., 2017; H. N. Bani-Salameh, 2018; Ding & Beichner, 2009; K. Williamson et al., 2016; K. E. Williamson et al., 2013). These concept inventories have one correct answer for each question and carefully chosen wrong answers, known as distractors. Each one reflects a specific misconception related to the concept being examined. Students carrying a certain misconception will be tempted to choose one of the distractors over the correct answer, and therefore, the misconception will be documented.

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To maximize the benefits of using a concept inventory, researchers usually give these tests twice to students: once before (pre-test) and once after (post-test) any in-class topic-related instructions. Students usually perform differently on the two tests, which will allow for the gain calculation. The gain is a direct measure of the effectiveness of the learning process in its many folds: teachers, students, curricula, teaching methods, and other things (H. Bani-Salameh et al., 2017; H. N. Bani-Salameh, 2017b; H. N. Bani-Salameh et al., 2017; H. N. Bani-Salameh, 2018; Ding & Beichner, 2009; K. Williamson et al., 2016; K. E. Williamson et al., 2013). In this article, we're reporting on the pre-test results only; the initial results revealed a complete list of misconceptions held by our students.

Methods

This research is part of our university's ongoing project to evaluate and improve the educational process(H. Bani-Salameh et al., 2017; H. N. Bani-Salameh, 2017a, 2018; H. N. Bani-Salameh et al., 2017; Ding & Beichner, 2009). We used the Newtonian Gravity Concept Inventory (NGCI) for this research (K. Williamson et al., 2016; K. E. Williamson, 2013; K. E. Williamson et al., 2013; K. E. Williamson & Willoughby, 2012).

Table 1
A List of Misconceptions Probed by the NGCI

Domain	Sub-Domain	Code	Description
Directionality	Multiple objects	MO1	The direction of the total force is toward the larger object only
		MO2	Direction of the total force is toward the closer object only
	Relative motion	RM	Direction of the force is determined by the direction of motion
	objects on the surface of large body	SO1	Direction of the force is determined by the direction of apparent weight
		SO2	Direction of the force is always perpendicular to the surface
Force Law	Determination of magnitude	DM1	Can be blocked or diminished by another massive object
		DM2	Can be estimated by the apparent weight
	The role of distance	RD1	Distance is measured from the surface of an object
		RD2	Distance is measured by the radius of an object
		RD3	Distance and force of gravity are inversely related.
		RD4	Distance and force of gravity are related in another way
		RD5	Distance and force of gravity are not related.
	The role of mass	ROM1	Only the larger mass matters
		ROM2	Mass and force of gravity are related in another way.
		ROM3	Mass and the force of gravity are not related.
	Effects of density	ED1	Changing density does change the gravitational force experienced by an object in space.
		ED2	Changing density does not change the gravitational force experienced by an object on the surface.
Independence of other forces	Air pressure	AP	Gravity is affected by air pressure.
	Magnetism	M	Gravity is affected by magnetism
	Rotation	R	Gravity is affected by rotation
Threshold	Distance threshold	DT1	There is a distance for which the force of gravity suddenly stops.
		DT2	There is a distance for which the force of gravity becomes constant and nonzero
	Mass Threshold	MT	There is a minimum mass for an object to experience a gravitational force
	Atmospheric threshold	AT	A sudden shift in the gravitational force experienced by objects does occur at the edge of Earth's atmosphere.
	Orbital threshold	OT	Gravitational force always causes relative motion between objects.

There are 26 multiple-choice questions on the NGCI probing students' understanding of gravity in four domains: Direction, the concept of gravity as a force, Independence, and threshold. The test was given to students twice (pre and post-test), a total of 684 students took the pre-test and different number took the post-test. Some students participated in the pre-test and didn't take the post-test, while others did it the other way around. For this paper, we included the results of only 511 students, accounting for those who participated in both tests. This will make it easier to compare pre and post-results in future reports and allow us to calculate the gain and record students' different performances in the pre-test compared to the post-test.

The class we teach is an introductory physics class, being the first one about physics for our students in college, and therefore, the knowledge they have about gravity coming to this class is only that they acquired from pre-college sources. Since this is a general physics course, what we teach them about gravity is only the basics covered in one or two lectures. By examining the content of the NGCI, we found that what we teach students about gravity is enough to enable them to answer the test. This point is crucial because we know that students should have the necessary knowledge about gravity if they attend classes and grasp the presented concepts.

In their paper, the authors of the NGCI presented a table including the four domains and a range of misconceptions uncovered throughout the development process along with the right ideas for each question on the test. In Table 1 and Table 2, we present a rearrangement of these misconceptions listed as codes (Table 1) and the places they appear on the test marked by question numbers and answer choices. These two tables should serve as a reference to quickly and easily recognize misconceptions by just looking at the answer choice chosen by students for each question.

Table 2

Full list of codes of all misconceptions probed by each answer choice for each question on the NGCI.

	A	B	C	D	E
1	AP	R	M	AP, R, M	
2		MO1		DT1, MO1	
3		ROM3	RD5	RD5	ROM3, RD5
4	RD4	RD3	RD4		
5	RM			RM	
6	DT1		DT2		
7		RD5	RD5, ROM3		
8	AP	M		R	AP, M, R
9	M, R	M, R	M, R		
10	MO1	RD4, ROM2	RD4, ROM2		MO2
11	ED1		ED1		
12			SO1		
13				OT	
14	ED1	ED1, RD1			
15	M		M		
16	ROM2, RD4		ROM2, RD4		
17	RD1		ED1		
18	DT1	ROM3	ROM2		
19	ROM2, RD4	ROM2, RD4		ROM2, RD4	
20		ROM2	ROM3	ROM3	
21	DT1	DT1	DT1		
22	AP		M	R	
23	AT	DT2	DT1		
24	AT		DT1	DT1	AT
25	AP	RD1	R		
26		RM			

To identify misconceptions held by students based on their answer for a certain question, one should look at Table 2 and get the code/s under their answer choice for that question and extract the misconception from Table 1. For example, if one student chose answer (A) for question one, one can easily see from Table 2 that the code associated with this particular answer choice for question one is (AP). Looking at Table 1, one quickly realizes that the student must have the misconception that "Gravity is affected by air pressure."

As noted in Table 2, some answer choices have more than one code next to them, like answer choice (D) for question one with three codes (AP, M, R). In this particular case, it means that by choosing this answer, the student might have any of these three misconceptions: Gravity is affected by air pressure, Gravity is affected by magnetism, or Gravity is affected by rotation. The possibility of having any of these misconceptions here is equally divided among the three, so the percentage would be 33% each. If the answer choice has two codes listed next to it (answer E question 3, for example), then the possibility of either one of the two misconceptions listed would be 50%.

Result and Discussions

In previous work (H. N. Bani-Salameh, 2017a), we used the method of dominant incorrect answers to identify misconceptions related to motion held by students. This report will use the same method to diagnose gravity-related misconceptions. The idea is to examine all incorrect answers for each question on the NGCI and compare it to codes in Table 2 and their meanings in Table 1. Each incorrect answer reflects a specific misconception held by the student, and therefore, one can calculate the percentage of each misconception relative to other misconceptions for each question. This will reveal if there is a dominant misconception over the others based on specific criteria defined below.

We start by eliminating from the calculation the percentage of students who got the question under consideration correct. For each possible wrong answer, we find the number of students who picked that answer and then divide it by the total number of students who answered that question incorrectly. The result is the percentage of students with a particular misconception based on Table 2. Some misconceptions show up in more than one answer choice for the same question; in that case, to calculate students' percentage with that misconception, one has to add the number of students choosing all the possible choices for that misconception in that question (or a certain percentage of the number as explained in the example below) and then divide by the total number of students with the wrong answer.

One thing to keep in mind is that if one answer choice is driven by more than one misconception, it is possible for the student to have any of the possible misconceptions represented by that choice. Therefore, we take only a percentage of the number depending on how many misconceptions are possible for that choice (as discussed in the example below). For a specific misconception to be considered dominant for a particular question, the percentage described above must be more than 50%.

Let's take question one as an example to demonstrate how we calculated the reported percentages in Table 3. There are five answer choices, with choice E being correct and four wrong answers, known as distracters. A specific misconception drives each one of these distracters (sometimes more than one; see Table 2) and is supposed to distract students from the correct answer if they have that particular misconception. If the student picks choice A as an answer for question one, that means he/she has the misconception that "Gravity is affected by air pressure" (see Table 2). If the student picks answer choice D, he/she might also have that same misconception along with the possibility of two others ("gravity is affected by magnetism" or "gravity is affected by rotation," see Table 2). By picking choice D, there is a 33% chance that the student has any of the three possible misconceptions (AP, M, or R). For this reason, if one wishes to calculate the percentage of students having the misconception AP for Q1, one should add the number of students picking choice A and 33% of the number of students picking choice D and then divide by the total number of student with a wrong answer for Q1. If the answer choice for a specific question is driven by only two possible misconceptions (question 3 answer choice E), then the percentage of the number of students to add is 50%.

Table 3 includes all misconceptions found from our results with dominant ones bolded and italicized. One of the things that will catch the eyes of anyone studying Table 3 is the percentage reported as 100 for three different misconceptions in three different questions (Q11: ED1, Q15: M, and Q21: DT1). The percentage tells us that all students who didn't answer these questions correctly had one specific misconception for each question and nothing else. A close examination of these questions reveals the possibility of this happening. Take Q11 as an example; the question asks about the effect of objects' increase in density on the force of gravity. There are only three possible answer choices: the correct one that says there is no effect, one that says the force increases, and one that says the force decreases. Any student not picking the correct answer thinks that the density of objects involved will always affect the force of gravity. Therefore, all of them carry the misconception ED1: "Changing the density does change the gravitational force experienced by an object in space" (see Table 2). This is why the percentage of this misconception for this question was 100%. The same story is found in questions 15 and 21 with the difference in Q21 having four possible answers.

Table 3
Codes for Misconceptions Found from Students' Incorrect Answers Along with Percentages of Students Having Each Misconception For Each Item on The NGCI. Dominant Misconceptions are Bolded and Italicized

Item	Misconception Code (Percentage)			
1	AP(34)	M(39)	R(28)	
2	MO1(44)	DT1(33)		
3	ROM3(44)	*RD5(56)*		
4	*RD3(54)*	RD4(46)		
5	RM(47)			
6	DT1(46)	*DT2(54)*		
7	*RD5(64)*	ROM3(36)		
8	AP(26)	*M(50)*	R(24)	
9	*M(50)*	*R(50)*		
10	MO1(21)	MO2(11)	RD4(34)	ROM2(34)
11	*ED1(100)*			
12	SO1(44)			
13	OT(27)			
14	*ED1(70)*	RD1(30)		
15	*M(100)*			
16	*RD4(50)*	*ROM2(50)*		
17	*ED1(64)*	RD1(36)		
18	DT1(30)	ROM2(25)	ROM3(46)	
19	*RD4(50)*	*ROM2(50)*		
20	ROM2(16)	*ROM3(84)*		
21	*DT1(100)*			
22	AP(17)	*M(55)*	R(12)	
23	DT1(40)	DT2(21)	AT(39)	
24	DT1(45)	*AT(55)*		
25	AP(23)	R(15)	*RD1(62)*	
26	RM(29)			

Full scan of Table 3 reveals a total of 11 dominant misconceptions ranging in percentages from 50% all the way to 100% in some questions. Some of these misconceptions were dominant in more than one question like M, "gravity is affected by magnetism," which was found to be dominant in four questions (Q8, Q9, Q15, and Q21). The complete list of dominant misconceptions found with our students is summarized in Table 4.

Table 4
Summary of All Dominant Misconceptions Found With Our Students in the Pre-Test

Misconception	Question Number (%)			
AT	24(55)			
DT1	21(100)			
DT2	6(54)			
ED1	11(100)	14(70)	17(68)	
M	8(50)	9(50)	15(100)	22(55)
R	9(50)			
RD1	25(62)			
RD3	4(54)			
RD5	3(56)	7(64)		
ROM2	16(50)	19(50)		
ROM3	20(84)			

Conclusions

The main purpose of this article is to report our results on the study of our students' misconceptions related to gravity using the Newtonian Gravity Concept Inventory (NGCI). In the methodology section, we presented a brief description of the NGCI and two tables listing all misconceptions probed by this test and their codes to be used as a quick reference to identify misconceptions. The overall performance of our students is weak, with an average score of 39.9% and a standard deviation of 3.811. We conclude that our students still need improvement when it comes to gravity-related concepts, and what we teach them in class does not seem to be enough to correct their misconceptions. Regarding misconceptions found using the NGCI, the idea is straightforward. We just studied students' incorrect answers for each question and calculated the percentages of students picking each wrong answer choice. We followed a specific percentage criterion of 50% or more to consider a specific misconception dominant. Elaborate details about the calculations can be found in the results section. Some of the most dominant misconceptions (higher percentages and higher number of questions it showed up in) include: Gravity is affected by magnetism, changing density does change the gravitational force experienced by an object in space, and there is a distance for which the force of gravity suddenly stops. We found a total of 11 dominant misconceptions. Careful future planning for our teaching instructions related to these misconceptions is needed. It's not in the scope of this article to suggest an exact solution for it. This particular objective is part of a future planned project that will hopefully end up helping students replace these misconceptions with the right ideas related to gravity.

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