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Weight, the Normal force and Newton's Third Law: dislodging a deeply embedded misconception

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Abstract

On entry to university, high achieving physics students from all across Australia struggle to identify Newton's Third Law force pairs. In particular, less than one in ten can correctly identify the Newton's Third Law reaction pair to the weight of (gravitational force acting on) an object. Most students incorrectly identify the normal force on the object as the Third Law force-pair to weight, rather than the gravitational force of the object on the Earth. This misconception may be constructed by students during instruction on Newton's Second Law, and hence forms a logical, connected part of their knowledge structures, making it highly resistant to both traditional and more interactive instruction. The use of operational definitions of weight may contribute to this problem. We have addressed this issue by using a consistent and explicit definition of weight, and having students work through a short hands-on group activity using a bathroom scale and drawing free body diagrams. As a result, the majority of students, post instruction, can correctly answer this question (and similar ones); and they retain this learning beyond the end of semester. This teaching strategy and activity could easily be used in high schools, so that students develop consistent knowledge frameworks when first introduced to Newton's laws.

Introduction

For years, as part of formal assessment in first-semester first-year Physics at UNSW Canberra, we have asked our students to identify the Newton's Third Law reaction force pair to the weight of a book which is sitting on a table (or equivalent). On entry to our courses, almost all of our students say that the normal force on an object is the Newton's Third Law force-pair to the weight of the object. After two weeks of study of forces and Newton's Laws, using language and examples consistent with both our textbook (Serway, Jewett, Wilson & Wilson, 2013) and our educational intent, over 60% of our students still gave the answer, “the normal force of the table on the book”. Only about 20% of our students gave what we consider to be the correct answer, “the gravitational force of the book on the Earth”. This is, to say the least, a disappointing learning gain.

Some would argue that the normal force *can* be the Newton’s Third Law reaction to weight, if an operational definition of weight (essentially “what a scale reads”, or what might be called load in engineering) is being used instead of the gravitational definition ($W = F_g = mg$). Taibu, Rudge & Schuster (2015) suggest that the operational definition is not only acceptable, but even preferable. However, we teach the gravitational definition exclusively to our students, and use it in applications such as free-body diagrams. In this language, “the weight of the book” means “the gravitational force of the Earth on the book”. When we treat Newton’s Third Law, we emphasise that it describes an *interaction* between two objects where the two forces involved are of the *same type*.

Clearly, we are not getting the answer we want: our teaching is not working. This is despite increasing the emphasis on the concept in lectures and tutorials, including it in multiple assessment tasks, and providing increasingly vehement feedback to students.

While the prevalence of a conceptualisation inconsistent with our teaching is dismaying, it is not particularly surprising. Difficulties with Newton’s Third Law in general have been described many times in the literature, over at least three generations (Lindsay, 1943; Brown & Clement, 1987; Brown, 1989; Hellingman, 1992; Wilson & Low, 2015). Gunstone and White (1981) described inconsistent mathematical and conceptual understandings of gravity, gravitational field strength and weight amongst a group of Australian university students. Issues with identifying the reaction force to weight have also been previously described (Terry & Jones, 1986; Yeo & Zadnik, 2000), and they are experienced not only by students, but also by teachers of physics (Hughes, 2002; Stocklmayer, Rayner & Gore, 2012). In a more sophisticated problem, final-year Australian high-school students were seen to exhibit confusion in the relationship between weight and the normal force during the collision of a bouncing ball with a table (Gunstone 1987; section III-D). Various interventions including hands-on activities (Stocklmayer et al., 2012), computer simulations (Graesser, Franceschetti, Gholson & Craig, 2013; Shute, Ventura & Kim, 2013), and dialogue (Savinainen, Scott & Viiri, 2005; Savinainen, Mäkynen, Nieminen & Viiri, 2012) have been proposed and tested, and found to have varied effectiveness.

The big disappointment is that, in spite of all the research and development on this topic, our students continue to find it deeply problematic. The fact that we often see the same response amongst our academic colleagues and graduate students, particularly when they are put on the spot and asked to give a quick answer, indicates that a university education in physics or engineering does little to address this misconception. The idea that the normal force is the Newton’s Third Law force-pair to weight is highly resistant to instruction. As with many strong alternative conceptions, once it is embedded, it is very, very difficult to get it out again.

In this paper we aim to first demonstrate the scope of the problem, and suggest some probable causes for it. Second, we present a simple, cheap and quick learning intervention that we have found to successfully move students away from their inconsistent world view, and towards a more consistent understanding of Newton's Second and Third laws and the concept of weight.

The problem: weight, the normal force, and Newton's Third Law

In 2016, we gave our incoming cohort of first-year Physics students (n = 167) a number of diagnostic tests, which included questions designed to probe their initial state of knowledge. The cohort was subsequently tested on their knowledge and understanding of weight and Newton's Third Law in quizzes and tests immediately following instruction, again at the end of first semester, and then again early in second semester. The data presented here (summarised in Table 1) are for the subgroup (n = 144) of that cohort who completed all of the pre- and post-instruction tests.

Figure 1 shows the test item used on the initial pre-instruction diagnostic test, and on later assessment tasks (often with variations, as described later). On entry, only 6% of students chose option E (gravitational force), while 86% chose option B (normal force). These students entered UNSW Canberra with relatively high UAI/ATAR scores (80 or greater), and the cohort was drawn from all across Australia, such that all states and territories were represented.

Furthermore, it is not just our students who display what we consider to be a flawed understanding of this concept. The 2015 Australian Science Olympiads Examination (ASOE) in Physics included the same question; and of over 1000 senior high-school students, selected by their teachers as being of high ability in physics, only 12% chose the gravitational option, while 71% choose the normal force option instead. Of the approximately 200 students who achieved 7/10 or greater in the multiple-choice section of the 2015 ASOE Physics paper, less than a third (29%) chose the gravitational option; and the increase was almost completely due to these high-achieving students choosing the gravitational option instead of a minor distractor. Over two-thirds (67%) of the high-achieving students still chose the normal force option.

Hence, this is a problem common across all Australian school systems: it is not confined to a particular State system, or to a handful of teachers, or to low-achieving students. The view that the Third Law force pair to weight is the normal force is endemic at the upper secondary level. The vast majority of students – including the highest achieving students – arrive at university with this picture firmly embedded in their heads. Traditional university instruction, even when incorporating best practice interactive and engaging activities, is ineffective in subsequently addressing this issue. In 2014 and 2015, the first year physics students were given a variation of the question shown in Figure 1, post-instruction on Newton's laws. As mentioned earlier, only 21% of students answered this question correctly, after several different passive and active learning experiences and a great deal of feedback. This is shown in the no-intervention data in Table 1.

The widespread nature of the problem in fact militates against the effectiveness of techniques such as Peer Instruction (Mazur, 1997), in which students describe their understanding to their peers. Since presenting a version of this item (Figure 1) as a Peer Instruction question in a lecture, and seeing the fraction of correct answers change from around 10% to (literally) zero, we no longer encourage students to help each other on this particular concept, even though it is very effective on other concepts.

There are really two problems being conflated here: the definition of weight, and understanding Newton's Third Law.

Weight and the Normal Force

Most physicists, and almost all high school and university level text books, advocate a gravitational definition of weight (Galili, 1993; Taibu et al., 2015). The gravitational definition identifies the weight force acting on an object (often referred to as "the weight of the object") as the object's mass multiplied by the local gravitational field, or $\mathbf{W} = m\mathbf{g}$. Unfortunately, students are often confused by the lay-term "weightless", which is usually dealt with at the secondary school level by the introduction of "apparent weight". This idea introduces students to the operational definition of weight as "what a scale would read", and hence invokes the normal force. This immediately introduces a confounding factor in students' minds, due to multiple conflicting definitions of weight.

To check if the problem was simply due to how students interpreted the word "weight", in another diagnostic (separated from the first by a week, but still before any tertiary instruction in Newton's laws or forces) we presented the question as, "What is the Newton's Third Law reaction force pair to the *gravitational force acting on* a book…". The results, shown in Table 1, were nearly identical: 7% of students chose the gravitational option E, while 87% chose the normal-force option B. The students drew no distinction between the two formulations of the question.

Between administering these two diagnostics, we also asked our students how they defined weight. We offered five options, of which the students could choose any, all, or none; and we asked them to define weight in their own words. The results were interesting: 32% defined weight purely gravitationally; 36% chose a definition which was purely operational, and did not include gravity; and 32% admitted to a mixed definition, accepting the gravitational definition as well as some form of operational definition. Hence we might expect that between approximately one-third and two-thirds of the students would apply the operational definition of weight, and, consistent with that definition, select the normal force as the Newton's Third Law reaction force to weight. However, what we see is that far more, almost 90% of students, select this option. This suggests that the fundamental problem is not with how students define weight, but rather with how they apply Newton's Third Law to the problem.

Newton's Third Law and the Normal Force

In another variation of the question presented in Figure 1, which was also asked pre-instruction in the first week of the course, we asked students to identify, "the Newton's Third Law pair to the normal force of the table on the book". As shown in Table 1, while twice as many students (16%) gave the correct answer (the normal force of the book on the table) in this case, 68% of the class instead chose, "the gravitational force of the Earth on the book" (and another 10% chose, "the gravitational force of the book on the Earth"). The vast majority of students still identified a gravitational force as the Newton's Third Law pair to a normal force.

Newton's Third Law states that if object A exerts a force on object B, then object B exerts an equal and opposite force, of the same type, on object A. In symbols, $\mathbf{F}_{\text{A on B}} = -\mathbf{F}_{\text{B on A}}$, where $\mathbf{F}$ is a particular type of force (e.g. gravitational, or electrostatic/contact). Newton's Third Law deals with the *interaction* of *two objects* via *forces*. It suffers, however, from two difficulties in instruction: the well-known lay statement, "For every action, there is an equal and opposite reaction", does not convey the important details of the Third Law; and the Third Law is often seen (and taught) as a poor cousin to the Second Law, which commands more attention in students' minds due to its explicit use in problem-solving.

In fact, there is evidence that many students construct a flawed mental model of the Third Law by conflating it with the Second Law (Dedic, Rosenfield & Lasry, 2010; Wilson & Low, 2015). Unlike some misconceptions in physics, such as the Aristotelian idea that objects move until they run out of impetus, this is not a common sense alternative conception based on every day experience. Rather, it is something that is *learned* during the study of Newton's laws. We call this the "Newton's Second Law – Net Force" (N2-NF) misconception.

Consider an object in static equilibrium, under the influence of just two forces. In the N2-NF misconception, students note that the two forces must sum to zero (a correct application of the Second Law) and hence the two forces must be equal in magnitude and opposite in direction (also correct, as a direct mathematical result of the first statement), and thus are a Third Law force-pair (incorrect). This reasoning is similar to the (il)logical sequence, "All cats have four legs; my dog has four legs; therefore, my dog is a cat". While a Third Law force-pair are equal in magnitude and opposite in direction, not all forces which are equal in magnitude and opposite in direction are a Third Law pair. This subtlety is often lost on novice students; but the mental model which arises from the flawed sequence of reasoning is strong and resistant to instruction (Wilson & Low, 2015).

Applied to the case at hand, the reasoning is as follows: an object at rest on a surface in a gravitational field is in static equilibrium and is experiencing zero net force (correct); the two forces to which it is subject are the weight force (due to the local gravitational field) and the normal-contact force of the table (correct if the surface is horizontal and no other forces are acting); hence the weight force and the normal-contact force are equal in magnitude and opposite in direction (correct); and therefore the normal force and weight force are a Newton's Third Law pair (incorrect on two fundamental grounds: these forces both act on the same object, and they are different types of force).

Having arrived at this result for an example which is commonly used to introduce problem-solving with Newton's Second Law, a student operating under the N2-NF model expands it to the (incorrect) general result that the normal force is ***always*** equal and opposite to the weight force ("because they are a Third Law pair"). The N2-NF model, and the consequential flawed understanding of the Third Law, is resistant to corrective instruction because it has been formed internally as a "logical" consequence, with strong (but flawed) derived links between knowledge structures. It is much harder to break down a belief structure, than it is to simply replace incorrect information.

The N2-NF model leads to some nonsensical ideas, particularly when situations other than an object at rest on a surface are considered. For example, when a first year engineering class (post-instruction on Newton's laws) was asked, "What is the Third Law reaction force to the gravitational force of the Earth on the moon?", more than a third of the class chose the answer, "The normal force of the Earth on the moon"!

The solution: some simple questions, and a bathroom scale

To begin with, we needed to address the definition of the term, "weight". Firstly, we clearly defined weight as the gravitational force, via $\mathbf{W} = \mathbf{F}_g = m\mathbf{g}$. From that point on, we avoided using the word weight in isolation: we would either not use it at all, using "gravitational force" instead; or we would refer to it as "the weight (gravitational force)". Similarly, in diagrams or equations we avoided labelling "the weight force, $\mathbf{W}$", preferring either "$\mathbf{F}_g$" in isolation, or "$\mathbf{W} = \mathbf{F}_g$". The term "apparent weight" was not used, but the "scale force" was discussed via the normal force and Newton's Second Law. For example, "a scale displays the normal force it exerts in order to satisfy Newton's Second Law". This allowed free-body diagrams to be consistently labelled with "weight" as "the gravitational force", regardless of acceleration or any other forces which may have been involved. The term "weightlessness" was given as an example of a lay term, that a physicist might prefer to call "normal-forcelessness", as it referred to a situation where no normal force would be exerted on or by a scale.

It was only after this treatment of weight that Newton's Third Law was introduced, in order to uncouple weight (and the Second Law, and the normal force, and scales) from the Third Law. In 2016, the lecture-class treatment of the Third Law was the same as in previous years, concentrating on the use of subscript notation to identify Third Law force-pairs by swapping the order of subscripts (e.g. $\mathbf{F}_{g,AB} = -\mathbf{F}_{g,BA}$). The main difference between 2016 and previous years was that tutorial classes were run as interactive workshops (see Wilson et al., 2002). These two-hour meetings allowed for a far greater degree of hands-on exploration of concepts than had been possible in the theory-driven, one-hour duration problem-solving tutorial classes that were offered in previous years.

The intervention activity relevant to this paper is shown in Figure 2, and the associated post-tutorial discussion notes are given in the Appendix. Working in self-directed groups of 4-6 students at a whiteboard, the class explored a series of scenarios involving scales, forces, and external loads by constructing free-body diagrams and identifying Third Law force-pairs. During the workshop, students rotated through six activities; the time spent on any individual task (allowing for settling, introduction, packing up, etc.) was only around 15 minutes. The class size was approximately 50 students, and three academic tutors moved around the room, helping students with the activities. Hence the time spent on task by the students was not large, nor was much resourcing in terms of staff time required. The physical resources required were a whiteboard, markers, activity sheet and a set of bathroom scales.

In addition to being popular with the students, this workshop activity also resulted in clearly effective learning, as demonstrated by a significant improvement in performance over previous years on the assessment later in semester.

In the summative test at the end of the "Motion, Force, and Energy" section of first-semester Physics, when presented with the question shown in Figure 1, 63% of the cohort gave the gravitational answer, while 23% chose the normal-force answer (see Table 1). This is a pleasing result, as the proportions are reversed from the results obtained in previous years' equivalent summative tests. Almost all of the rest of the cohort (13%) gave answer A; this option is gravitational, but with the wrong "what acts on what" order. That is, these students probably understood the relevant concept, but require some additional instruction in the nature of force interactions.

Even more pleasing are the results achieved three months later, in a second-semester pre-instruction diagnostic quiz where we once again asked the "What is the Third Law pair to weight?" question. Despite the intervening time, where other topics in physics were studied, the cohort returned practically the same distribution of answers (59% gravitational, 23% normal) as they did in the first-semester Class Test. The shift in mental model that these students experienced has proved to be robust. In addition, another second-semester diagnostic posed the gravitational force version of the question: here, 88% of the cohort gave the gravitational answer, compared to just 7% on entry. Finally, a third second-semester diagnostic asked the students to identify the Third Law force pair to the normal force of the table on the book: once again, 88% of students gave the correct answer (which in this case was the normal force of the book on the table), with just 8% giving the incorrect (in this case) gravitational force answer. These results are summarised in Table 1.

These three second-semester diagnostic results indicate that, while there is still room for improvement when the word "weight" is involved, our students are now much better at applying Newton's Third Law in these situations.

Conclusion: implications for teaching

By combining a consistent theoretical framework with a series of interactive activities that participants were required to explain using free-body diagrams, we appear to have helped students develop a robust general model of the relationships between weight, the normal force, and Newton's Laws.

Our pre-instruction data demonstrates that senior secondary students are arriving at university with a mixed model of weight, and an inconsistent understanding of Newton's Third Law. While their model might be able to get them through the secondary curriculum, it fails when they are required to apply it to more complicated situations (involving additional forces, or accelerating frames) in a tertiary environment. However, the strength of the flawed N2-NF model makes it resistant to traditional teaching. It would be better for students if they learned a self-consistent model in the first place, so that they could deal with the tertiary physics curriculum without significant corrective action.

We suspect that the flawed N2-NF model arises when students take two correct statements from their teachers, and infer for themselves a third, incorrect implication. If teachers of physics are aware of this issue, they will be able to address it at the time when the concepts of weight, the normal force, and Newton's Laws are first introduced to students, and prevent the flawed model from taking hold in the first place. As far as possible, teaching should be forwards compatible: the ideas presented at the secondary level should be transferable to the tertiary level, just as those presented at the primary level should be transferable to the secondary level.

The key approach in presentation that we recommend is decoupling Newton's Second and Third Laws from each other. The Second Law is used to analyse the relationship between the sum of forces acting on a single object, and that object's acceleration. The Third Law, on the other hand, helps us understand how two objects interact via forces. Writing out Third Law force-pairs with subscripts is one way of emphasising this.

Linking interactive, hands-on activities with a requirement to express the observed results using words, pictures and equations, helps students consolidate their understanding of physical principles.

References

Brown, D. E. (1989). Students' concept of force: the importance of understanding Newton's third law. *Physics Education*, *24* (6), 353-358. doi:10.1088/0031-9120/24/6/007

Brown, D. E., & Clement, J. (1987). Misconceptions concerning Newton's law of action and reaction: The underestimated importance of the third law. In J. Novak (ed.), *Proceedings of the Second International Seminar: Misconceptions and Educational Strategies in Science and Mathematics*, volume III, pp. 39-53. Cornell University Press: Ithaca, New York.

Dedic, H., Rosenfield, S., & Lasry, N. (2010). Are all wrong FCI answers equivalent? *AIP Conference Proceedings*, *1289* (1), 125–128. doi:10.1063/1.3515177

Galili, I. (1993). Weight and gravity: teachers' ambiguity and students' confusion about the concepts. *International Journal of Science Education*, *15*, 149-162. doi:10.1080/0950069930150204

Graesser, A.C., Franceschetti, D., Gholson, B., & Craig, S. (2013). Learning Newtonian physics with conversational agents and interactive simulations. In Stein, N. L. & Raudenbush, S. (Eds) *Developmental Cognitive Science Goes to School* (Chapter 11, pp 157-172).

Gunstone, R.F. (1987). Student understanding in mechanics: A large population survey. *American Journal of Physics*, *55* (8), 691-696. doi:10.1119/1.15058

Gunstone, R.F., & White, R.T. (1981). Understanding of gravity. *Science Education*, *65* (3), 291-299. doi:10.1002/sce.3730650308

Hellingman, C. (1992). Newton's third law revisited. *Physics Education*, *27* (2), 112-115. doi:10.1088/0031-9120/27/2/011

Hughes, M. J. (2002). How I Misunderstood Newton's Third Law. *The Physics Teacher*, *40* (6), 381-382, doi:10.1119/1.1511603

Lindsay, G. A. (1943). Newton's third law of motion as presented in textbooks of physics. *American Journal of Physics*, *11* (6), 319-323. doi:10.1119/1.1990512

Mazur, E. (1997). *Peer Instruction*. New Jersey: Prentice-Hall

Savinainen, A., Scott, P., & Viiri, J. (2005). Using a bridging representation and social interactions to foster conceptual change: Designing and evaluating an instructional sequence for Newton's Third Law. *Science Education*, *89* (2), 175-195. doi:10.1002/sce.20037

Savinainen, A., Mäkynen, A., Nieminen, P., & Viiri, J. (2012). An intervention using an interaction diagram for teaching Newton’s Third Law in upper secondary school. In *Physics Alive: Proceedings of the GIREP-EPEC 2011 Conference*, pp. 123-128. ISBN 978-951-39-4801-6

Serway, R., Jewett, J., Wilson, K., & Wilson, A. (2013). *Physics, Volume 1*, *Asia-Pacific edition*. Melbourne, Australia: Cengage Learning.

Shute, V. J., Ventura, M., & Kim, Y. J. (2013). Assessment and learning of qualitative physics in Newton's Playground. *The Journal of Educational Research*, *106* (6), 423-430. doi:10.1080/00220671.2013.832970

Stocklmayer, S., Rayner, J. P., & Gore, M. M. (2012). Changing the Order of Newton's Laws – Why & How the Third Law Should be First. *The Physics Teacher*, *50* (7), 406-409. doi:10.1119/1.4752043

Taibu, R., Rudge, D., & Schuster, D. (2015). Textbook presentations of weight: Conceptual difficulties and language ambiguities. *Physical Review Special Topics – Physics Education Research*, *11*, 010117. doi:10.1103/PhysRevSTPER.11.010117

Terry, C., & Jones, G. (1986). Alternative frameworks: Newton's third law and conceptual change. *European Journal of Science Education*, *8* (3), 291-298, doi:10.1080/0140528860080305

Wilson, K., Sharma, M., Millar, R., Moroney, C., Newbury, R., Logan, P., Cathers, I., Vella, G., & Emeleus, G. (2002). *Workshop tutorials for physics*. The University of Sydney, NSW: UniServe Science.

Wilson, K. F., & Low, D. J. (2015). “On Second Thoughts": Changes of Mind as an Indication of Competing Knowledge Structures. *American Journal of Physics*, *83* (9), 802-808. doi:10.1119/1.4928131

Yeo, S., & Zadnik, M. (2000). “Newton, we have a problem...". *Australian Science Teachers Journal*, *46* (1), 9-18.

A book lies at rest on a table. The table is at rest on the surface of the Earth. By Newton's Third Law, the reaction force to the weight of the book is:

A. the gravitational force of the Earth on the book.
B. the normal force exerted by the table on the book.
C. the gravitational force of the table on the book.
D. the normal force exerted by the Earth on the table.
E. the gravitational force of the book on the Earth.

Figure 1: diagnostic item used to test students' understanding of Newton's Third Law applied to the weight force. Variations of this question included replacing "the weight of the book" with either "the gravitational force of the Earth on the book", or "the normal force of the table on the book".

(a) Have one student (hereinafter referred to as "the volunteer") stand on a scale. On the whiteboard, draw a free-body diagram for the volunteer, showing all forces acting on the volunteer. Include directions and magnitudes! Then, for each force you have included in your free-body diagram, identify its Third Law "reaction" force.

(b) Have another student (hereinafter referred to as "the Load") press down – **gently!** – on the volunteer's shoulders. Again, draw a free-body diagram for the volunteer. Which forces (if any) have changed from (a)?

(c) Give the volunteer some significant (but not ridiculous...) Mass to hold (treat multiple "things" as a single carried Mass). Once again, draw a free-body diagram for the volunteer. Compare with (b), and discuss any differences.

(d) Have two students (hereinafter referred to as "the supports") stand or kneel either side of the volunteer. The volunteer then presses down – **gently!** – on the supports. Draw another free-body diagram for the volunteer, and compare with (a).

(e) Finally, set up a situation with two volunteers, each standing on their own scale, facing each other at close range. Have one press down – **gently!** – on the other's shoulders. Draw free-body diagrams for each of the two volunteers, identify all Third-Law force-pairs, and explain what you observe on the scales!

Figure 2: activity for the exploration of weight, the normal force, and Newton's Third Law.

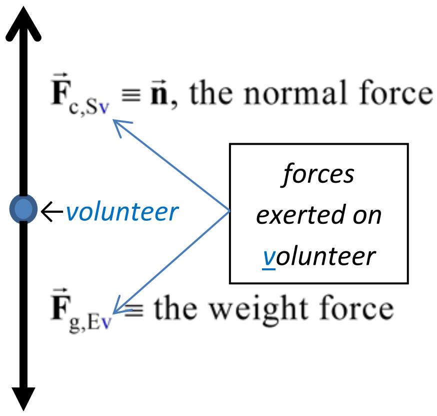
Test Item (*variation of question presented in Figure 1*)	Gravitational answer (%)	Normal Force answer (%)
NO INTERVENTION		
2016 First-Year Physics Entry Quiz (pre-instruction)		
Weight version	**6**	86
Gravitational Force version	**7**	86
Normal Force version	68	**16**
2014/2015 Class Test (average; post-instruction)	**21**	62
2015 Australian Science Olympiad Examination		
All students	**12**	71
Highest achievers (70%+)	**29**	67
FOLLOWING INTERVENTION		
2016 First-Year Physics Class Test (post-instruction)	**63**	23
2016 First-Year Physics Post Tests (Semester Two)		
Weight version	**59**	23
Gravitational Force version	**88**	10
Normal Force version	8	**88**

Table 1: a summary of the data referred to in this study. Figures are the percentage of the cohort who gave each answer choice to the question given in Figure 1 ("Weight version") or a variant (asking for the Newton's Third Law pair to either the gravitational force, or to the normal force). Numbers in **bold** are the correct answer; non-bold numbers are for the answer which matches the misconception that the normal and weight forces are a Newton's Third Law pair. The 2016 Entry Quizzes were conducted before any university instruction in Newton's Laws or weight. The 2016 Class Test was held a week after the conclusion of the instructional module "Motion, Force and Energy" (which involved 20 contact hours over 5 teaching weeks). The 2016 Post-Tests were conducted at the start of second semester, about three months after the 2016 Class Test, before any second-semester instruction, and immediately after the mid-year holiday period.

Appendix: Discussion notes for the intervention activity presented in Figure 2

[For ease of calculation, use g = 10 m s^{-2} in this question to convert between the scale reading in kilograms, and the weight force in newtons]

(a) Have one student (hereinafter referred to as "the volunteer") stand on a scale. On the whiteboard, draw a free-body diagram for the volunteer, showing all forces acting on the volunteer. Include directions and magnitudes! Then, for each force you have included in your free-body diagram, identify its Third Law "reaction" force.



The Newton's Third Law reaction force to the contact force $\vec{\mathbf{F}}_{c,Sv}$ that the Scale exerts on the volunteer (also called the normal force, $\vec{\mathbf{n}}$) is the contact force that the volunteer exerts on the Scale, $\vec{\mathbf{F}}_{c,vS}$.

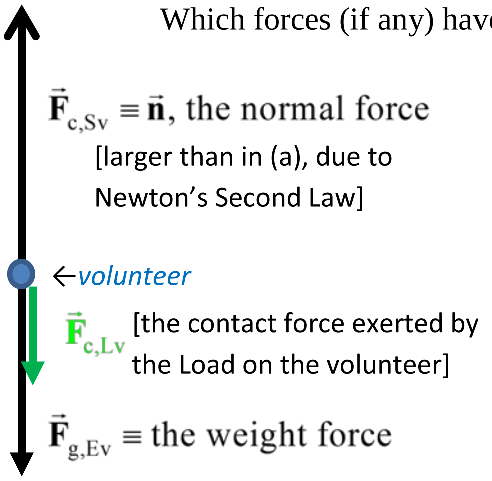
The Newton's Third Law reaction force to the gravitational force $\vec{\mathbf{F}}_{g,Ev}$ that the Earth exerts on the volunteer (also called the weight force) is the gravitational force that the volunteer exerts on the Earth, $\vec{\mathbf{F}}_{g,vE}$.

Because the volunteer is not accelerating, Newton's Second Law tells us that the net force acting on the volunteer must be zero, and hence these two forces acting on the volunteer are of equal magnitude. They also act in opposite directions. However, this does **NOT** make them a Newton's Third Law pair! In fact, you can **never** show a Newton's Third Law force-pair on a free-body diagram!

This is because a free-body diagram shows all the forces acting **on** a **single** ("free") body, while the forces of a Newton's Third Law pair must act on **different** bodies! Draw for yourself the Newton's Third Law force-pairs: the best way to do this here would be two separate sketches: one showing the contact-force pair (involving the volunteer and the scale, and the contact forces that they exert on each other), and the other showing the gravitational-force pair (involving the volunteer and the Earth, and the gravitational forces that they exert on each other).

Important point: Newton's Third Law force-pairs are "equal and opposite". But just because two forces are "equal and opposite" does not make them a Newton's Third Law force-pair! To think that all equal-and-opposite forces are a Newton's Third Law pair would be the physics equivalent of the argument, "All cats have four legs; my dog has four legs; therefore, my dog is a cat". Not a marks-gathering argument, that one ☺

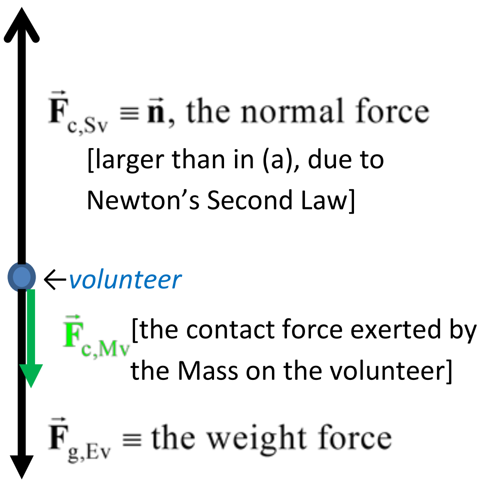
(b) Have another student (hereinafter referred to as "the Load") press down – **gently!** – on the volunteer's shoulders. Again, draw a free-body diagram for the volunteer. Which forces (if any) have changed from (a)?



When the Load presses down on the volunteer, they exert a contact force $\vec{\mathbf{F}}_{c,Lv}$ on the volunteer. The weight force does not change because neither the volunteer's mass nor the Earth's gravity have changed. If the volunteer is still in equilibrium (i.e. not accelerating), then Newton's Second Law tells us that the normal force (the contact force exerted by the scale on the volunteer) must increase, so that the net force on the volunteer is zero! The reading on the scale therefore **increases**, as the scale shows the normal force.

From the difference in the scale reading between (a) and (b), you can measure the magnitude of $\vec{\mathbf{F}}_{c,Lv}$, and hence determine how much force the Load is applying to the volunteer.

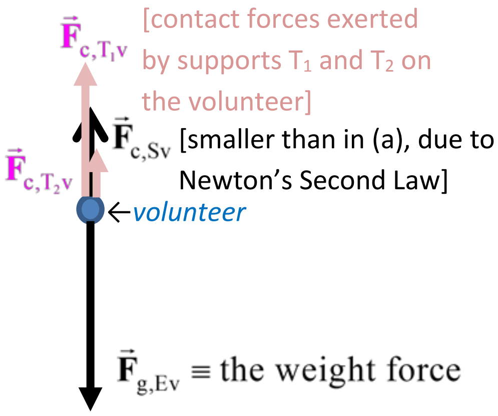
(c) Give the volunteer some significant (but not ridiculous...) Mass to hold (treat multiple "things" as a single carried Mass). Once again, draw a free-body diagram for the volunteer. Compare with (b), and discuss any differences.



This picture is almost identical to that in (b), although the magnitudes are likely to be different. The Mass exerts a downwards contact force on the volunteer. Be careful: while technically there is also a gravitational force between the Mass and the volunteer, this is very small compared to all the other forces involved in the problem! More will be said about that in Chapter 11.

Note that there is a Newton's Third Law reaction contact force $\vec{\mathbf{F}}_{c,vM}$, exerted by the volunteer on the Mass. If the Mass is not accelerating, Newton's Second Law tells us that this force must be equal in magnitude (and opposite in direction) to the weight of the Mass…and hence $\vec{\mathbf{F}}_{c,Mv}$ must be equal to the weight of the Mass!

(d) Have two students (hereinafter referred to as “the supports”) stand or kneel either side of the volunteer. The volunteer then presses down – **gently!** – on the supports. Draw another free-body diagram for the volunteer, and compare with (a).



My picture shows the general case, where the volunteer exerts different (contact) forces on the supports (T_1 and T_2), and hence the supports exert different (contact) forces back on the volunteer. The force that the volunteer exerts on a support is a Newton’s Third Law force-pair with the force which that support exerts back on the volunteer.

If the volunteer is not accelerating, then Newton’s Second Law tells us that the sum of the three upwards-directed contact forces must balance the downwards-directed gravitational (weight) force.

Hence, the scale reading (equal to the magnitude of $\vec{\mathbf{F}}_{c,Sv}$) must be **less** than the volunteer’s weight! Again: the volunteer’s weight has not changed, because neither their mass nor the Earth’s gravity have changed. But the scale does not show “weight”: it shows the normal force that it is exerting, due to Newton’s Second Law.

(e) Finally, set up a situation with two volunteers, standing on their own scale, facing each other at close range. Have one press down – **gently!** – on the other's shoulders. Draw free-body diagrams for each of the two volunteers, identify all Third-Law force-pairs, and explain what you observe on the scales!

You can draw your own diagrams here, because the details are very situational: who is heavier, who presses, etc. ☺ The key point, however, is that if A presses down on B, then there is an equal and opposite Newton's Third Law reaction (contact) force that B exerts upwards on A. The force that A exerts on B is ***NOT*** drawn on A's free-body diagram: it appears on B's free-body diagram. The force that B exerts on A is drawn on A's free-body diagram, not B's.

Similarly, the gravitational force that the Earth exerts on A (i.e. A's weight) is drawn on A's free-body diagram; the Newton's Third Law force-pair to this, which is the gravitational force that A exerts on the Earth, would be drawn on the *Earth's* free-body diagram!

The contact force that the scale exerts on A (the normal force) is drawn on A's free-body diagram; the Newton's Third Law force-pair to this, the contact force that A exerts on the scale, is drawn on the *scale's* free-body diagram. In fact, the reading on the scale (which is the normal force it exerts on A) will be equal to the difference between the (downwards) force of gravity acting on A (A's weight), and the (upwards) contact force that B exerts back on A. The scale reads less than the weight of A.

Similarly, B's scale will read a value greater than the weight of B, due to the downwards "press" exerted by A on B.

Neither A's weight nor B's weight changes. But the scale readings **do** change, because the normal force required to give a net force of zero (by Newton's Second Law, since neither A nor B are accelerating) **does** change when other, external forces are applied.

What can you say about the *sum* of the two scale readings? What can you say about the *difference* between the two scale readings?