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Students' Understanding on Newton's Third Law in Identifying the Reaction Force in Gravity Interactions

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In the past three decades, previous researches showed that students had various misconceptions of Newton's Third Law. The present study focused on students' difficulties in identifying the third-law force pair in gravity interaction situations. An instrument involving contexts with gravity and non-gravity associated interactions was designed and conducted among students in junior secondary school, senior high school and university. The finding revealed that students in all grades did statistically worse in gravity interaction contexts and had general difficulties in distinguishing interaction forces and balanced forces. However, students improved their reasoning on third-law force pair with the increase of grade level irrespective of contexts. Special difficulties for junior secondary school students in understanding gravity interaction were also addressed. It is important to emphasize that the educational contexts of gravity interactions should be paid more attention to.

Keywords: Balanced forces, Gravity interaction, Interaction forces, Misconceptions, Newton's third law.

INTRODUCTION

Scientifically, Newton's Third Law (NTL), which is related to the fundamental concept of interaction between two entities, is one of the most significant laws in physics. Generally, varieties of contexts related to NTL contain gravitational, electrostatic, and magnetic interactions. In particular, NTL gives as a quantitative description that the concept of force is considered as the result of the relation between two entities. Therefore, it is necessary for science teachers and students to comprehend explicitly the intimate relation of action and reaction, as well as the relation of the concepts of interaction and force.

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Newton's Third Law (NTL) has been addressed in introductory mechanics: "when two bodies interact, the forces on the bodies from each other are always equal in magnitude and opposite in direction" (Halliday, Resnick, & Walker, 2005). It should be noted that this statement explicitly addresses the notion of interaction. The conceptual aspect specifies that, interaction between two objects implies that they exert forces on each other: forces always come in pairs; these two forces are always called a third-law force pair. Previous research has revealed that understanding NTL is quite a complicate work. It suggests that just "telling" students that forces arise due to interactions is not very effective (Savinainen & Scott, 2002).

To better comprehend NTL and the concept of force interaction, five aspects of the specification of conceptual content are suggested: existential, ontological, coarse quantitative, compositional and causal (diSessa, Gillespie, & Esterly, 2004; Spyrtou, Hatzikraniotis, & Kariotoglou, 2009). For the existential aspect, the notion of symmetrical interaction between two objects is generally applicable to all situations,

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State of the literature

- Newton's Third Law (NTL) is one of the most significant laws in physics and previous researches have revealed that understanding NTL is quite a complicate work for students.
- Many frequently-used assessments are conducted and suggest that students have various misconceptions on NTL. However, most researches are limited to concerning students' difficulties in comprehending the coarse quantitative aspect of NTL that the interaction forces are always equal in magnitude.
- Current studies referring to student behavior in gravity interactions are considerably few, and most of these studies are restricted to focus on distance force interactions.

Contribution of this paper to the literature

- An instrument has been designed and conducted to evaluate students' difficulties in identifying the Newton's Third Law force pair in gravity interaction contexts in the present study.
- Analyses reveal that students improve their reasoning on third-law force pair with the increase of grade level irrespective of the given contexts.
- Gains in students' inappropriate reasoning suggest that there are general difficulties with the failure to distinguish interaction forces and balanced forces for students at different grade levels, especially in gravity interaction situations. The result has also addressed two special difficulties for junior secondary school students.

regardless of different contextual features of the situation (Savinainen, Scott, & Viiri, 2005). For example, inanimate bodies (Finegold & Gorksy, 1988; Hestenes, Wells, & Swackhamer, 1992), stationary bodies (Terry et al., 1985; Tao & Gunstone, 1999a), and distant bodies (Kolokotronis & Solomonidou, 2003) can exert and be exerted a force. The ontological aspect concerns the nature of the force (Spyrtou, Hatzikraniotis, & Kariotoglou, 2009). The forces between two interacting bodies are of the same nature, and they appear and disappear simultaneously. The coarse quantitative aspect specifies that the forces the two bodies exerted on each other are always equal in magnitude. However, the compositional aspect reveals that two forces do not act on the same body as two bodies exert forces on each other. Therefore, the interaction effect could not be the vector sum of two forces between two interacting bodies. While, the causal aspect underlines a scientific view that interaction is a mutual relation between two objects, rather than that reaction is caused by action. Action force could be also called reaction force, which depends on the object of reference.

Over the past three decades, findings from many related studies have shown that students have various misconceptions of Newton's Third Law and the interaction forces. In the following sections, the literature review focuses on two aspects: (1) How do the previous studies investigate student misconceptions on the Newton's Third Law? (2) What misconceptions do students have on the Newton's Third Law in the past researches?

LITERATURE REVIEW

In the previous researches, various situations related to Newton's Third Law (NTL) could be classified into two groups: the static group and the dynamic group (Kariotoglou, Spyrtou, & Tselfes, 2009). In the static group, the cases with bodies in contact include: a book on the tabletop (Terry et al., 1985; Hestenes, Wells, & Swackhamer, 1992; Trumper, 1996; Palmer, 2001; Bryce & MacMillan, 2005), a man trying to push a box (Brown, 1989; Thijs & Bosch, 1995), a stone resting on another (Palmer, 2001), an object connected to a spring which is placed on a frictionless plane (Park & Han, 2002). On the other hand, the dynamic group focuses on students' understanding about the cases in which bodies are moving. For example, cases in contact include the collision situation between a car and a small truck, or between a bomb and a missile, or between two identical marbles, as well as the pushing situation in which a small car pushes a large one or a student on rollers pushes another student (Watts & Zylberszajn, 1981; Brown, 1989; Gamble, 1989; Kruger, Summers & Palacio, 1990a, 1990b; Summers, 1992; Thijs, 1992; Montanero, Perez & Suero, 1995; Trumper, 1996; Heywood & Parker, 2001; Bao, Hogg, & Zollman, 2002; Savinainen, & Scott, 2002; Savinainen, Scott, & Viiri, 2005). While, there are some studies referring to interaction objects at distant, e.g. the interaction between the Earth and a ball dropped from a height (Suzuki, 2005), or between the Earth and a golf ball travelling through the air (Kruger et al., 1990a; Hestenes, Wells, & Swackhamer, 1992), or between two masses, magnets or charged bars at a distance (Kariotoglou et al., 2009; Jiménez-Valladares & Perales-Palcios, 2001). Although cases in the dynamic group may involve the Newton's second law of motion and the concept of impulse, NTL motion is of the main concern in the above researches.

Based on the above contexts, different investigations are carried out to study student understanding on NTL and reaction force. Palmer (2001) carried out individual interviews among 53 10th graders to study the concept of action and reaction in simple instances of static equilibrium in nine concrete items, including a book resting on a table or an object floating on water. Heywood & Parker (2001) described in their study how students and in-service primary teachers applied key ideas about forces from floating and sinking situation to different contexts. Montanero et al. (2002) designed a test to explore how students understood the interaction between two static bodies in contact. The test consists of a set of identical situations, e.g., a stone resting on another stone or a person resting on another person. Savinainen et al. (2005) focused on the question whether students could transfer a concept or a physical principle to a variety of familiar and novel situations according to NTL.

From the previous researches, the popular research issue related to NTL concerns students' difficulties in comprehending the coarse quantitative aspect that the interaction forces are always equal in magnitude. Several frequently-used assessments support researchers to carry out the above research issue. Take Force Concept Inventory (FCI) (Hestenes, Wells, & Swackhamer, 1992) as an example, four questions presenting different situations are related to NTL in the test with questions in the similar form. Students are asked to choose a reasonable description about the forces two bodies exerting on each other when they are in contact and interact from five possibilities. There are: (a) one object exerts the same amount of force with another one; (b) one object exerts a greater amount of force than another one; (c) one object exerts a smaller amount of force than another one; (d) one object exerts a force but another one does not; and (e) neither exerts a force on the other. Likewise, Force and Motion Conceptual Evaluation (FMCE), which is also an assessment on students' conceptual understanding of Newton's Law of Motion, includes ten questions related to NTL (Thornton & Sokoloff, 1998). Each question has six or seven choices. Five of the choices are designed based on the format equivalent in NTL of FCI, and the other choices state that not enough information is given to pick one of the answer above, and/or none of the answers above describes the situation correctly. All of these questions are designed for evaluating student understanding about the magnitude of the action and reaction forces. More directly, students are required to pick from five possibilities about the magnitude of the reaction force based on the given magnitude of action force in a Mechanics Baseline Test (MBT), an assessment of students' ability in comprehending the most basic conception in mechanics (Hestenes & Wells, 1992).

Based on the above assessments, there are similarities in many research findings concerning students' learning difficulties in comprehending NTL and the interaction forces. It appears that the scientific view that action and reaction have equal magnitude is too difficult for students to understand, and an incorrect reasoning about the dominant principle of NTL is common in most of the students. For example, there is a frequent alternative conception that the body with greater mass exerts a greater force (Hestenes, Wells, & Swackhamer, 1992; Bao et al., 2002; Kariotoglou et al., 2009). Another common misconception is that the upper body exerts a force on the lower one, while the lower body does not exert a force on the upper one (Montanero et al., 2002). Some research results indicate that students always hold naïve perspectives that a larger force is exerted by an object which has larger velocity, or is speeding up, or is an active initiator, e.g. the one pushing another one, or the one winning in the tug-of-war game (Watts & Zylbersztajn, 1981). Besides, the point of view that action always overcomes reaction is a common reason for the failure of accepting the principle that the third-law force pair has the same magnitude (Grimellini-Tomasini, Pecori-Balandi, Pacca, & Villani, 1993). Finding in some other studies reveals that students have problem in comprehending that objects have the same magnitude of force as the opponent in the following situation: inanimate bodies (Finegold & Gorksy, 1988; Hestenes, Wells, & Swackhamer, 1992), stationary bodies (Terry et al., 1985; Tao & Gunstone 1999a), distant bodies (Kolokotronis & Solomonidou, 2003), and so on.

Considering the above studies, evidence supports that most students have a poor understanding of the scientific view that two bodies exert action and interaction forces with magnitude in equal when they interact. Most of the researches carry out investigations by following the questions with multiple choices which are similar in structure, as we mentioned above in the FCI question related to NTL. The structure of these questions is restricted to focus on the magnitude of the action and reaction forces. Therefore, there is no need for students to determine the third-law force pair involving the given situation. Although students could pick a correct choice from several possibilities and offer a correct reasoning that action and reaction forces are always equal in magnitude from the principle of NTL, they may have no idea about what is the reaction force of the action force. Some findings in the previous studies show that students are ambivalent in recognizing the reaction force (Trumper, 1996; Finegold & Gorsky, 1988). It is noticed that current studies referring to student behavior in gravity interactions are considerably few and most of these studies are restricted to focus on distance force interactions, e.g. interaction between the Earth and the Moon (Kariotoglou, Spyrtou, & Tselfes, 2009). In the finding of Bryce & MacMillan's work (2005), a common alternative conception describes that the reaction force of a table on a resting book and the weight of the book form a Newton's third-law force pair. Another research result shows that students have difficulties in identifying the reaction force in gravity interaction situations, whereas they could reason correctly in the case of non-gravitational force interactions (Savinainen, Scott, & Viiri, 2005). Based on these facts, further analysis is required for evaluating students' performances in identifying the third-law force pair in gravity interactions. From this perspective, three research questions are framed in this paper:

A. How do students perform in identifying the reaction force in gravity interactions?

B. What are students' incorrect reasoning patterns against the Newton's Third Law in gravity interactions?

C. How are students' performances in gravity interactions influenced by grade level?

RESEARCH BACKGROUND

In China, students go through a special curriculum in science and mathematics during their kindergarten through 12th grade (K–12) school years. Take physics course for example, it starts in grade 8 and continues every semester through grade 10 for every student and through grade 12 especially for those who will major in science, engineering, technology and other related fields in university. Newton's Third Law (NTL) covers physics course both in grade 8 and grade 10 in secondary school, as well as introductory physics course for freshmen in university. Grade 8 and grade 10 are two different instructional stages in China, where grade 8 belongs to junior secondary school and the 10th grade is part of senior high school. The instructional requirements related to NTL vary a lot for these two stages, including content knowledge in the textbooks and the instructional methods. The details of the differences are outlined in table 1.

From table 1, we could find different requirements related to NTL for the 8th and 10th grade students. In grade 8, NTL is not regarded as the essential law to teach. Students are only required to know that two interacting bodies exert forces on each other. There is no need for students in this period to know the magnitude and direction of interaction forces. They even have no idea about what NTL is. In contrast, NTL is taken as the essential content in the textbook for the 10th graders. Students should understand not only the magnitude and direction of the interaction forces, but also the extension of NTL. The extension content states that the interaction forces have the same nature, act on two different bodies, appear and disappear simultaneously. Therefore, students in grade 8 and grade 10 learn and master different levels of content knowledge related to NTL. For freshmen in university, learning the content of NTL in introductory physics course is considered as a repetitive work. The difference from the 10th graders lies in the higher demand of problem-solving skill for them. From this perspective, students, who achieve different understanding levels of NTL, consisting of the 8th and 10th grade students and freshmen in university, would constitute our research samples.

METHODS

Research Design

Taking into account a strong finding in a previous research (Bao et. al., 2009), it emphasizes that senior high school graduates at medium level in China achieved almost 85% accuracy (ceiling effect) in the FCI test. Therefore, it implies that questions in FCI test,

Table 1. Description about the Content Knowledge in the Textbooks and the Iinstructional Methods Related to NTL in Grade 8 and Grade 10

	Grade 8	Grade 10
Instructional strategies	Questions-based exploration teaching: *Supplying examples with questions and making explanations to students.*	Experimental-inquiry instruction: *Self-inquiry with hand-on experiments or demonstration experiments*
Contexts of teaching cases	Two examples: *A person sitting on one boat pushes another boat; a girl on rolls pushes the wall and slide backward*	Two experiments: *Two soft foams contact each other ; two springs pull on each other*
Conclusion related to NTL in the textbooks	When one object exerts a force to the second, it is exerted a force by the second too. They are interaction forces.	The action and reaction forces are always equal in magnitude, opposite in direction, and in a straight line. It is called Newton's Third Law. The interaction forces have the same nature, act on two different bodies, appear and disappear simultaneously.
Supplementary notes	Interaction is emphasized as the dominant content knowledge of NTL for students in grade 8 in China. Other aspects of NTL are not required, e.g. magnitude, direction or nature of interaction forces.	It covers almost all elements of NTL, including the existential, ontological, coarse quantitative, compositional and causal aspects.

which address Newton's Third Law (NTL) with the structure we mentioned above, are not suitable to be applied in this study. The methodology in this study aims at the research issue about student understanding on NTL in gravity interaction situations. A targeted instrument is designed to investigate the proposed three main research questions.

The instrument includes 8 multiple-choice questions, in which five are associated with gravity interaction and three are not. For each question, students are required to identify the NTL force pair or some related information. Since evidences show that students' reasoning about interaction seems to be highly affected by context, we believe that the present instrument should carefully consider the contextual coherence regarding force and interaction in contexts. The instrument is comprised of eight different contexts with each for one question, including a table with a book on it, a ceiling lamp suspended from a string, a raindrop falling in the air, a box on a slope, a floating wood pressed by hand, two collisions between cars (one between a small car and a big one, the other between two identical cars), the magnetic attraction between two magnets, and a person rowing a boat with oars. These contexts are similar to, but not all identical with, those in previous researches (Terry et al., 1985; Hestenes, Wells, & Swackhamer, 1992; Trumper, 1996; Palmer, 2001; Bryce and MacMillan, 2005; Jiménez-Valladares & Perales-Palcios, 2001; Kariotoglou et al., 2009; Heywood & Parker, 2001; Savinainen, Scott, & Viiri, 2005; Bao, Hogg, & Zollman, 2002; Montanero, Perez, & Suero, 1995; Trumper, 1996), for the sake of a good validity of the questions. All contexts in the present instrument have been classified as two categories in table 2. One category is associated with gravity interaction, while the other is associated with non-gravity interaction. Each context is labeled with the number of forces to balance the targeted object. Further, the way of raising a question for each context is given in the table as well.

As described in table 2, we can obtain two main results in our research design. The first is a comparison of student understanding between one category of contexts concerning gravity interaction and the other category of contexts with non-gravity interaction. There are five questions in the first category and three questions in the second. In gravity interactions, the Earth, as one object in the interaction system, which is a hidden and latent variable, is easily overlooked by students. Therefore, we hypothesize that the task of

Table 2. Description about the Classification of the Contexts in the Instrument

	Contexts	The number of forces to balance an object	Ways of raising a question
Gravity associated interactions	A raindrop falling in the air (raindrop)	Two	What is the reaction force of the gravitational force acting on the raindrop?
	A table with a book on it (book- table)	Two	What is the reaction force of the gravitational force acting on the table?
	A ceiling lamp suspended from a string (ceiling lamp-string)	Two	What is the reaction force of the gravitational force acting on the ceiling lamp?
	A box on a slope (box-slope)	Three	What is the reaction force of the gravitational force acting on the box?
	A floating wood pressed by hand (wood-water-hand)	Three	Which is the pair of NTL forces among the gravitational force acting on the wood, the buoyant force on the wood, and the tension force from the hand to the wood?
Non-gravity associated interactions	A collision between a small car and a big one, the other collision between two identical cars (car-car)		Which of the following statements is correct? (There are four statements about the NTL force pairs and the comparison of the magnitude of each force pair.)
	The magnetic attraction between two magnets (magnet-magnet)		Which of the following statements is correct? (Each statement describes whether there is NTL force pair between two magnets and the comparison of the displacement of each magnet.)
	A person rowing a boat with oars (boat-oars-water-hand)		Which of the following statements is correct? (The statements describe about the NTL force pairs and the ontological aspect of NTL about whether the forces appears simultaneously).

questions involving gravity interaction will increase its difficulty. The research result in this study will provide evidence to evaluate the proposed hypothesis and develop deeper understanding on students' performances on the task with gravity interaction. For the second result, we want to learn more about whether the number of forces, which balance the targeted object in gravity interaction situations, would influence student reasoning. In our instrument, there are different numbers of forces to balance an object in gravity interaction contexts. By contrasting students' performances on different contexts, we can study if the number of forces balancing an object reveals the difficulty levels of determining the third-law force pair. Further, since the samples in our study is constituted of the 8th and 10th grade students and freshmen in university, we could explore whether student performance is influenced by grade level and how their reasoning changes by grade level in the above two research issues.

Data Collection

In this study, the subjects are constituted as three groups of students in accordance with the profundity and scope of content knowledge about NTL they have been taught. The first group has 80 8th grade students who have not been taught what NTL is, but they have been introduced that two interacting bodies exert forces on each other. The second group consists of 73 10th graders, who have learned NTL and interaction forces. Students with the number of 64 in the first year of the university compose the third group, in which they are taught NTL for the second time in the introductory physics course. All three groups of students study in a local junior secondary school, a senior high school, a university, all at medium level separately in Guangzhou, which is located in south part of China.

FINDINGS AND DISCUSSIONS

Students' performances in identifying the reaction force in both gravity and non-gravity associated interactions

Table 3 presents the mean scores of students' performances among different grade levels in both gravity associated interaction contexts and non-gravity associated interaction contexts.

To determine the significance of difference on students' performances among junior level, senior level and university level in both gravity associated and non-gravity associated contexts, we conducted a 3×2 (grade level × context) measures ANOVA. The dependent variable was students' mean scores, whereas the independent variables were grade levels (junior secondary school students, senior high school students and university students), and contexts (gravity associated interaction contexts and non-gravity associated interaction contexts). The analyses of measures ANOVA yielded no statistically significant interaction between grade level and context, F(1, 433)=1.65, p=0.19. However, the result suggested a main effect for context, F (1, 214) =41.36, p<0.001, indicating that students outperformed in the non-gravity associated contexts (M=0.60, SD=0.25) than in the gravity associated contexts (M=0.41, SD=0.29). As well, the analyses proved an effect for grade level, F(2, 214)=174.56, p<0.001, indicating significant differences among three group levels. Analysis of Poc Hoc Multiple comparisons revealed significant differences between the junior level and both the other two groups (p<0.001), and students at university level outperformed senior high school students (p=0.001).

Although the interaction between grade level and context was not significant, we further study the grade difference in each context group. Two simple main effect analyses were performed with Separate one-way analyses of variance (ANOVAs). For the gravity associated contexts, the results of ANVOAs showed a significant difference among grade levels, F(2, 214)=86.35, p<0.001. Analysis of Poc Hoc Multiple comparisons indicated that there were significant differences between the junior level and both the other two groups (p<0.001). However, the difference between senior high school students and university students was marginally significant (p=0.06). Similarly, analysis of ANVOAs for non-gravity associated contexts indicated a significant difference for grade level, F(2, 214)=90.50, p<0.001. Analysis of Poc Hoc Multiple comparisons also revealed statistically significant differences between the junior level and both the other two groups (p<0.001). Further, students' performances at university level far exceeded those at senior high school level (p<0.001).

Table 3. Students' performances in the Instrument among Different Grades

		Gravity associated interaction contexts		Non-gravity associated interaction contexts		T test	
Groups	*N*	*Mean*	*Std.Err.*	*Mean*	*Std.Err.*	*p*	*Effect Size*
Junior	80	.040	.020	.288	.032	*p*<0.001	1.04
High	73	.553	.048	.676	.039	*p*<0.05	.33
University	64	.706	.044	.896	.022	*p*<0.001	.68
All	217	.409	.029	.598	.025		

The difference of student performance between two contexts for each grade level was assessed and reflected in Figure 1. At junior secondary school level, the difference of students' mean scores between gravity associated contexts and non-gravity associated contexts was significant, t(151.5)=5.14, p<0.001, ES=1.04, indicating that students at this grade level identified the reaction force better in non-gravity associated contexts than in gravity associated contexts. The mean score in gravity associated contexts (M=0.04, SD=0.18) showed that students at junior secondary school level universally kept misconceptions about the reaction force of the gravitational force. To examine the difference of performance in both contexts for senior high school students, their mean scores also were compared (M=0.55, SD=0.41, and M=0.68, SD=0.33). A t-test for independent groups revealed that the difference between the gravity associated contexts and the non-gravity associated contexts was significant, t(138.2)=1.98, p<0.05, ES=0.33. From the mean scores, we could find that, students at senior high school level achieved considerably better in identifying the reaction

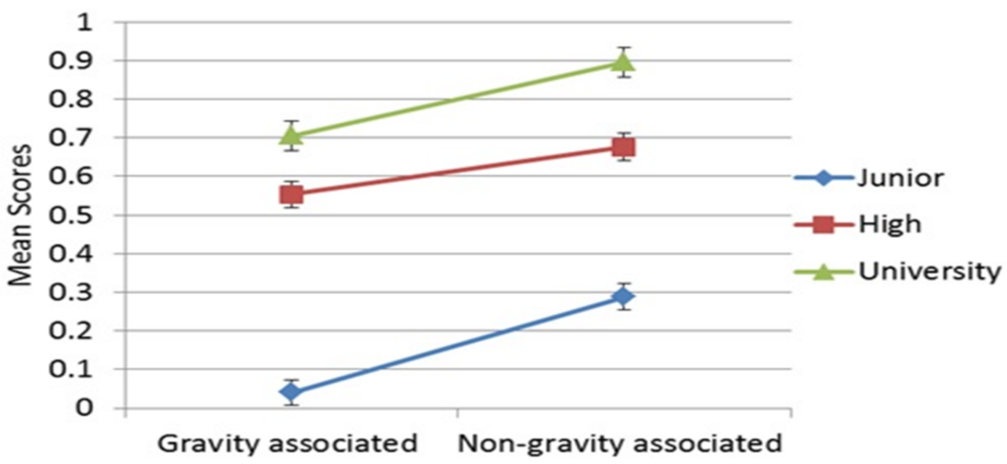

Figure 1. Students' performances between two contexts for each grade level

Table 4. Description about the Numbers of Forces Needed to Balance the Targeted Object in Different Contexts and the Result of Students' special Reasoning Patterns in Every Context for Three Grade Levels

	Contexts	The forces to balance it	Answer to the question about what is the reaction force of the gravitational force			
				Junior	High	University
Group 1	A raindrop falling in the air	Two forces:	Correct :	--*	53%	72%
		The gravitational force acting on the drop	Answer *(F)*:	10%	24%	--
		The air drag force (F)				
	A table with a book on it	Two forces:	Correct :	--	52%	67%
		The gravitational force acting on the table	Answer *(F)*:	74%	44%	31%
		The normal force acting on the table (F)				
	A ceiling lamp suspended from a string	Two forces:	Correct :	--	63%	70%
		The gravitational force acting on the lamp	Answer *(F)*:	75%	35%	26%
		The tension force acting on the lamp (F)				
	A box on a slope	Three forces:	Correct :	--	56%	70%
		The gravitational force acting on the box	Answer *(F1)*:	23%	--	--
		The normal force acting on the box (F1)	Answer *(F2)*:	43%	--	--
		The frictional force acting on the box by the slope surface (F2)	Answer *(F1)* and *(F2)*:	--	40%	23%
Group 2	A floating wood pressed by hand	Three forces:	Correct :	--	52%	73%
		The gravitational force acting on the wood	Answer *(F1)*:	12%	7%	--
		The buoyant force on the wood (F1)	Answer *(F2)*:	28%	--	--
		The tension force from the hand to the wood (F2)	Answer *(F1)* and *(F2)*:	42%	38%	12%

* -- stands that the percentage is less than 5%, which is quite a small number and is not important in the result.

force in non-gravity associated contexts than in gravity-associated contexts. For students at university level, the comparison of mean scores in gravity associated contexts (M=0.71, SD=0.35) against non-gravity associated contexts (M=0.90, SD=0.18) was also statistically significant, t(92.8)=3.84, p<0.001, ES=0.68. Although university students gained a very high score (M=0.71) in identifying the action and reaction force pair in gravity associated contexts, they acquired almost 90% accuracy in non-gravity associated contexts. From the effect size between contexts for each grade level, it could be found that the junior secondary school level has the highest effect size, while the senior high school level has the lowest one.

Considering the above results, we came to a conclusion that students improved their understanding on Newton's Third Law with the growth of grade, regardless of the given contexts with gravity associated or non-gravity associated. In both contexts, the best performance of the three groups was observed for students at university level, and then senior high school students outperformed junior secondary school students. The above analyses also suggested that students achieved considerably better in identifying the action and reaction force pair in non-gravity associated contexts than in gravity associated contexts, irrespective of the grade level of students in our study.

Students' incorrect reasoning patterns against the Newton's Third Law in gravity associated contexts

The instrument described in the part of research design was divided into two categories, which were contexts with gravity associated and non-gravity associated. In the category of gravity associated interaction, objects interact with each other and the gravitational force is considered as one of the forces to keep the targeted object balance. There are five contexts in this category. Students were allowed to identify the NTL force pairs and to find out the reaction force of the gravitational force acting on the object. Within these five contexts, the number of forces to balance the targeted object is regarded as a variable to divide all of the five contexts into two groups (see table 4). Group 1 is consist of three contexts where two forces are needed to balance the targeted object, while the other two contexts belonging to group 2 hold three forces to maintain the targeted object balance.

In this section, the aim is to study students' incorrect reasoning patterns against the Newton's Third Law in the gravity associated contexts, including group 1 and group 2. As well, the difference of students' performances influenced by grade level is an important topic in our study. Analysis revealed some general difficulties with the failure to distinguish interaction forces and balanced forces, and other difficulties specific for junior secondary school students.

A. General difficulties with the failure to distinguish interaction forces and balanced forces

If a student succeeds in answering the question about what is the reaction force of the gravitational force acting on the targeted object, he could identify the third-law force pair in the gravity interaction. He may recognize that action and reaction forces acting on each other should be equal in magnitude, opposite in direction, and always in a straight line. However, the previous study (Grimellini-Tomasini, Pecori-Balandi, Pacca, & Villani, 1993) mentions that students seem to have problems identifying the third-law force pair during an interaction and it is common for them to involve balanced forces. Although two balanced forces have the same magnitude and opposite directions in a straight line, they act on a single object instead of the interacting objects. Students may not recognize the difference between balanced forces and interaction forces.

From our research result, the tendency to find the balanced force rather than the reaction force of the gravitational force was popular for students at all three grade levels. Table 4 illustrated the percentage of students' special incorrect reasoning patterns in the contexts with gravity associated, including group 1 and group 2. For example, in group 1, senior high school and university students achieved 52% and 67% of correct responses respectively in the context of a table with a book on it. Nevertheless, a large number of students held a viewpoint that the normal force acting on the table was the reaction force of the gravitational force on the table: 44% and 31% of senior high school students and university students, respectively. For junior secondary school students, almost none of them could correctly recognize the third-law force pair in this context. It had a rather surprising result that 74% of them gave a response of balanced force—the normal force acting on the book by the table—as the reaction force of the gravitational force on the table. Likewise, in the context of ceiling lamp in group 1, students made correct reasons about the reaction force of the gravitational force on 63% and 70% at senior high school level and university level respectively. Whereas the percentages of students who were unable to distinguish balanced forces and third-law force pair were still high, with 35% of senior high school students and 26% of university students. Almost all students in junior secondary school provided inappropriate answers to this question, while among them 75% reasoned that the reaction force of the gravitational force on the lamp was the tension force acting on the lamp by the string. Considering students who failed to distinguish the third-law force pair and balanced forces in group 1, we could find that they occupied a large proportion of those who provided incorrect responses. Take the book context for example, the proportions of students confusing third-law force pair and balanced forces reached 74%, 44%, and 31%, compared to students with incorrect answers on 100%, 48%, and 33% of junior secondary school, senior high school and university students, respectively. It was obvious to gain an insight that the failure to distinguish the interaction forces and balanced forces was the general difficulty for students at all grade levels.

Analyses of students' incorrect reasoning patterns in group 2 showed a comparable trend at different grade levels. There is a similarity for two contexts in group 2 where the gravitational force acting on the targeted object is balanced by the vector sum of two other forces. For instance, the gravitational force of the box on the slope is balanced by the vector sum of the normal force and the frictional force acting on the box. Analogously, the gravitational force of the floating wood is balanced by the vector sum of the buoyant force on the wood and the tension force from hand to the wood. Therefore, if a student considers the vector sum of two other forces as the reaction force of the gravitational force of the targeted object in the above contexts, he/she is searching the pair of balanced forces instead of the action and reaction force pair. It reveals that the student confuses the concepts of balanced forces and third-law force pair. From the data in the second part of table 4, the proportions of correct answers in two contexts of group 2 were exactly corresponding to those in group 1: 0, 56%, and 70% in the box context, and 0, 52%, and 73% in the floating wood context at junior secondary school, senior high school, and university levels, respectively. Furthermore, the proportions of students who had the misconception of confusing balanced forces and interaction forces in senior high school and university were close to those of group 1: 40% and 38% of senior high school students in the box context and the floating wood context respectively; 23% and 12% of university students in these two contexts respectively. In addition, 40% of junior secondary school students held the same misconception in the floating wood context too.

The findings generally indicated that students' incorrect reasoning pattern of indenting the third-law pair in the context involving the gravitational force could be interpreted to recognize the balance forces rather than the reaction forces. The tendency was common that students failed to distinguish the difference between situation that forces balanced an object and the situation that forces interacted with each other. In the light of such findings, it appeared that this tendency had not been alleviated for students from middle school to university.

B. Specific difficulties for junior secondary school students

Analyses above identify students' reasoning difficulties of a general nature elicited by our research instrument with the contexts of the gravitational force associated for all three grade levels. The following section will describe difficulties specific for junior secondary school students. In junior secondary school, interaction is emphasized as the dominant content knowledge related to Newton's Third Law (NTL) for students in China. Other aspects of NTL are not required, e.g. magnitude, direction or nature of interaction forces. Besides, it is not a necessary demand for students to understand what NTL is. Thus, junior secondary school students might possess some spontaneous misunderstanding, that we are concerned, on the principle of action and reaction.

Students' responses provided further insight into two special difficulties, which were consistent with the instruction at junior secondary school level. First, some students did not recognize that the reaction force of the gravitational force on the object was a "force". Instead, they considered that the reaction force was an "object". For instance, 10% of junior secondary school students comprehended "the ceiling" as the reaction force of the gravitational force acting on the ceiling lamp attached from the ceiling by a string. As well, 7.5% of students at this grade level took "the book" as the reaction force of the gravitational force on the table with a book on it. It seemed that the error junior secondary students made was primarily due to students' confusion of the relation between interaction and force. Since the concept of interaction is central to comprehending the force concept, students who have problems in understanding the concept of force may fail to identify the third-law force pair.

Second, another important result in the contexts of group 2 revealed that many junior secondary school students only concerned the direction of the forces when identifying the third-law force pair. Student performance was inconsistent between group 1 where only two forces were sufficient to balance an object and group 2 in which three forces were needed to keep an object balance. In the context of the box on a slope, 23% and 43% of junior secondary school students responded the normal force and the frictional force on the box respectively as the reaction force of the gravitational force on the box. Although both the normal force and the frictional force had the directions against but not exactly opposite to the direction of the gravitational force on the box, the magnitude of those two forces were not equal to the gravitational force. Students seemed to be inclined to consider the direction of the force as an only key component and completely disregarded the magnitude of the force when identifying the third-law force pair. Likewise, in the context of the floating wood in group 2, the proportions of students who considered the buoyant force and the tension force from hand to the wood as the reaction force of the gravitational force on the wood were 12% and 28% respectively. Note that such behavior was rare for the senior high school and university students, but was special to junior secondary school students.

CONCLUSIONS AND TEACHING IMPLIMENTS

A main aim of the present study was to investigate students' performances in identifying the reaction force in gravity interactions. An instrument involving contexts with gravity associated and non-gravity associated interactions was designed. It was conducted among students in grade 8 of junior secondary school, students in grade 10 of senior high school and freshmen in university. The findings suggested that there was statistically significant difference for students at every grade level when identifying the reaction force between gravity associated interactions and non-gravity associated interactions. Based on results obtained with t-test for independent groups, it indicated that students had more difficulties in recognizing the reaction force of the gravitational force acting on an object than other action and reaction force pairs without the gravitational force ($p<0.001$, $p<0.05$, and $p<0.001$ for junior secondary school, senior high school and university students respectively). Analyses with ANOVA data also revealed that students improved their reasoning on third-law force pair with the increase of grade level irrespective of contexts.

Another main goal of this study was to examine students' incorrect reasoning patterns against the Newton's Third Law in gravity interactions. Gains in students' inappropriate reasoning were obtained and indicated students' general difficulties with the failure to distinguish interaction forces and balanced forces in all grade levels. Students usually involved the forces which balanced a single object as the third-law force pair. In the light of such findings, the tendency for students to find the balanced force instead of the reaction force of the gravitational force was common. The current study had also addressed two difficulties special for junior secondary school students when searching the action and reaction forces in gravity interactions. On one hand, some students at this grade level considered an "object" rather than a "force" as the reaction force of the gravitational force on a targeted object. They have problems in differentiating between the concept of interaction and the concept of force. On the other, many junior secondary school students seemed to be inclined to concern the direction of the force as an only key component and completely disregarded the magnitude of the force when identifying the third-law force pair.

The findings of this study have strong implications for instruction on Newton's Third Law. Although students could make a good reasoning that action and reaction forces are equal in magnitude via the principle of Newton's Third Law, they may have difficulties in determining the third-law force pair, especially in situations involving gravity interactions. Students should be encouraged to identify the third-law pair and to find the reaction force on their individual basis, for the sake of a better understanding of Newton's Third Law. Besides, the present study has addressed students' learning difficulties on gravity interactions. It is important to emphasize that the educational contexts of gravity interactions should be paid more attention to. Furthermore, students' low performances on concepts between interaction and force in junior secondary school must be taken seriously. Since the concept of interaction is central to comprehending the force concept, it is necessary to improve student understanding of the concept of force, as the ground for future grasping the conception of action and interaction.

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