Tutorial 4 – Blue group

1. In a moment we'll watch video of students working together on a mechanics tutorial. Boxed below are the questions they're discussing: work through them collaboratively with your partners before we watch the video.

The main point of this tutorial is helping you learn more strategies for learning physics concepts that seem to defy common sense.

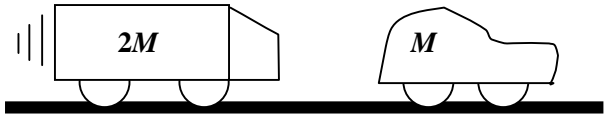
I. Newton's third law and common sense

According to Newton's third law, when two objects interact,

The force exerted by object A on object B is equal in strength (but opposite in direction) to the force exerted by object B on object A.

Often, this law makes perfect sense. But in some cases, it seems not to.

Consider a heavy truck ramming into a parked, unoccupied car.



A. (Work together) According to common sense, which force (if either) is larger during the collision: the force exerted by the truck on the car, or the force exerted by the car on the truck? Explain the intuitive reasoning.

2. Watch the video (about 2 min). The transcript is provided below. Student 1 (S1) is in the left foreground, S2 is on the left in the back, S3 is on the right in the back, and S4 is on the right in the front.

Transcript: Blue 4-1

S1: According to common...
S3: Yeah, I can (?) understand this.
S1: According to common sense, which force, if either is larger during the collision: the force exerted by the truck on the car, the force exerted by the car on the truck? Oh...
S3: I mean, the truck.
S1: The truck, yeah.
S1: OK, so...
S4: According to common sense, which force is larger in the collision? Tuh...
S1: What?
S4: Why are they asking that?
S1: Oh, OK, the car...
S4: question...
S1: Is your group's explanation in Part A similar or different? It's similar.
S4: Intuitively, the car reacts more, you'd rather be riding in the truck, so the car feels... is your group's explanation similar or different?
S1: It's the same. Right. OK, so, according to Newton's Third Law, which of the... which of those forces...
S3: It says they're equal, right?
S1: Yeah. Should be equal.
S3: I could never understand that, but... does this go against the law then, or is it that they are equal but we just think it's the truck? You understand what my question...
S1: We think it's the truck because the truck doesn't move backwards, I think. Right? Cause if there's equal and opposite forces, the truck... we would, if we actually saw it, we'd think the truck would hit the car and

go backwards because of the force, but since...
S4: Maybe they do exert the same force, but the truck doesn't move.
S1: The truck doesn't move cause I think it's got the momentum going, and... you know.
S3: So they, they are doing the same force, it just doesn't... it's just not common sense.
S1: Yeah, it just doesn't register because we see the truck (S3: It looks as being bigger) still moving forward, right, right.

3. Consider the following questions about the episode you just watched.
   A. Based on the evidence in this video, what are these students thinking about the physics of this problem?
   B. Student 3 asks, "Does this go against the law then, or is it that they are equal and we just think it's the truck?" Explain what you think she means by this question.
   C. How does student 1 respond to her question? Explain what you think he is saying.
   D. Some observers have suggested, at this point, that student 1 has quite a lot of the conceptual content of the tutorial figured out. Do you think so? Do you think there is any point in his working through the rest of the tutorial, or do you think he might as well leave and relax?
   E. We see students 1 and 3 as both making excellent contributions to the functioning of the tutorial in this clip. What is so good about what each one of them does?
   F. What is student 2 doing during this clip? If you were the instructor, would you do anything regarding student 2, or not? If so, what? What about student 4?

4. The students continue with the following tutorial exercises. Do them yourself before we watch the next video clip.

   B. (*Work together*) We've asked this question of many students, and a typical response goes like this:

      Intuitively, the car reacts more during the collision. (You'd rather be riding in the truck!) So the car feels the bigger force.

      Is your group's explanation in part A similar to or different from this? Explain.

   C. (*Work together*) According to Newton's third law, which of those forces (if either) is bigger?
   D. *Experiment.* Is this a case where Newton's third law doesn't apply? At the front of the room, the TA has set up an experiment that simulates a truck ramming a car. Go do the experiment and record the results here. You can also test whether Newton's third law holds for other collisions.

II. What to do with the contradiction between common sense and Newton's third law?

Before moving on to the next part of our Newton's third law lesson, let's consider the contradiction we just found between physics and common sense.

A. (*Work individually*) In summary, for most people, Newton's third law contradicts the common-sense intuition that the car reacts more during the collision. Which one of the following best expresses your attitude toward this contradiction?

i. We shouldn't dwell on these kinds of contradictions and should instead focus on learning exactly when Newton's third law does and doesn't apply.

ii. There's probably some way to reconcile common sense with Newton's third law, though I don't see how.

iii. Although physics usually can be reconciled with common sense, here the contradiction between physics and common sense is so blatant that we have to accept it.

Briefly explain why you chose the answer you chose.

B. Discuss your answer with your group. Is there a consensus or do people disagree?

5. Watch the next video clip (about 5 minutes).

Transcript: Blue 4-3

S4: In summary, for most people (?) blah blah blah blah...
S4: We shouldn't dwell on this kind of question and instead focus on learning exactly when...
S4: This is like one of the questions.
S2: Yeah, this was question 6 on the homework.
S1: Really?
S4: Mmmhmm.
S1: I haven't gotten that far.
(pause)
S3: Why? Six is just an explanation question?
S2: Mmmhmm.
S3: Oh really?
S2: That's why I said that was good.
S1: What'd you put? Two? Three?
S2: Huh?
S1: Three?
S2: What do you mean?
S1: You put three? A?
S2: Oh yeah.
S1: You put three too?
S3: Hell yeah.
S4: I put two.
S3: I'm mad, so I would have picked three.
S2: Oh, you picked two?
S1: Yeah, because, I mean...
S4: That's what he even said in class, there's always some way to like...
S1: There's always some way to explain
S3: You think so?
S4 and S1: Yeah.
S3: I don't think there's any way that you can explain to me how a massive truck is going to have the same forces on it...
S4: I mean, I think they do feel the same force... (S3: I just have to accept it), it's just one is like...
S3: I don't see it!
S4: Just... it just looks like that one got the push.
S1: Yeah, it always looks like the one gets pushed...
S3: No, like...
S1: I'm sure the truck gets like...
S3: Think of a Porsche versus a humongous truck, (S2: I know, that doesn't make sense) how do you explain to me...?
S1: OK, the Porsche would get totaled, right? But then I'm sure the truck's...
S4: Felt the same.
S1: The fender probably got like, you know, messed up.
S3: Scratched?

S1: But you know, it still did get some damage, so, I mean, there's still some...
S3: No.
S1: No?
S3: No.
S1: It's not working?
S3: I just have to accept it.
TA: So, this is cool. I just heard that you're having trouble getting, like, you're saying no, I can't believe that.
S3: Yes.
TA: I can accept it, but I can't believe it. And it's cool that you can realize that, you know, if that's how it is, but I don't get that. That's what we're gonna work on later through this tutorial. We're gonna try to understand how...
S4: Yeah, why that happened.
TA: Yeah.
S3: OK.
TA: But it's cool that you could realize that "I don't get that."
S4: It's cool.
S3: So, what, you agreed with his explanation, right?
S1: His ex... like, if you crashed like a... like a little... like a sedan type car...
S2: I just think it's one of those things that it is cause it is. I dunno.
S3: Yeah.
S3: (whispered) suppose the truck's mass is 2000 kilograms...
S3: How much does the car speed?
S4: No, there's not a consensus.
S3: No.
S1: Nope.
S4: We disagree.
S1: Yeah, well...
S4: I mean, it doesn't seem right. I get it, I totally understand what you're saying.
S1: Yeah, yeah yeah.
S3: Would you just say that there must be some type of plausible explanation about it?
S4: No, I think that they are exerting the same force on each other, but it just looks like, when we look at it...
S1: When you look at it, you see the other car running over the smaller car.
S3: Maybe if you were blind, you wouldn't... it's just cause your eyes and common sense (S1: right, rightright) plays a role in it, that's why.
S1: But then again, like sometimes you see, like...
S4: I wonder if that truck felt the same... the person in the truck feels the same thing?
S1: Feels the same push... Like, sometimes when you... I know if you get in an accident or something with a truck... a really big truck with a smallish-type car, right? The car's gonna be completely totaled, pretty much, right? But the truck's gonna have maybe like, some minimal dents or whatever, but then again sometimes, like, I know for insurance companies, they also check the frame of the vehicle. Cause usually the frame gets kind of bent out of shape, and it's not really superficial type damage, but it's actually like major damage, because inside it's like, the frame's weakened. So there's actually the same kind of force on the same thing, there's just more mass.
S3: Did you say the frame of the truck gets messed up the same?
S1: Yeah, the actual interior frame of the truck
S3: Really?
S1: it's like all, the metal's like really stressed, and sometimes it like, bends. And it's really expensive to, uh...
S3: Even though you don't like, it's like...
S1: Yeah, even though you look at it, the bumper might have been taken off
S3: Right, but the frame is all internal
S1: Yeah, it's like internal damage that you don't see.
S3: OK, I see what you're sayin'.
S1: That's why I think it'll be explainable, but...
S4: They'll explain why.
S1: Yeah, they'll explain why later.

6. Consider the following questions about the episode you just watched.

   A. We love how honest student 3 is being in response to the epistemological question, and we love that the TA overheard them and cheered her on. How do you think student 3 is doing at this point? Is she stuck and angry, productively challenged, or something else?

   B. What does student 1 say just after the TA leaves? What do you make of that?

C. What do you think is student 4's point about what the driver would feel?

D. What do you think student 1 is trying to say regarding damage to the frame of the truck?

E. Now that you have watched several minutes of this group in action, you may be getting a sense of their dynamic. Is it healthy or unhealthy? What about the way they work together do you like or dislike?

7. Here is the last bit of tutorial worksheet that we will see the students talk about.

I. A new strategy: Refining intuition

Before accepting that there's an irreconcilable contradiction between Newton's third law and the intuition that the car reacts more during the collision, let's try a reconciliation strategy called *refining your intuitions.*

A. (*Work together*) We'll start with a new question. Suppose the truck's mass is 2000 kg while the car's mass is 1000 kg. And suppose the truck slows down by 5 m/s during the collision. Intuitively, how much speed does the car gain during the collision? (Apply the intuition that the car reacts more during the collision, keeping in mind that the truck is twice as heavy.) Explain your intuitive reasoning.

B. Does your answer to part A agree with Newton's third law? To find out, we'll lead you through some quick calculations.

i. Suppose the car and truck remain in contact for 0.50 seconds before bouncing off each other. Calculate:

- the truck's acceleration during the collision.
- the car's acceleration during the collision (assuming your guess about its change in speed is correct).

ii. To good approximation, the forces that the car and truck exert on each other are the *net* horizontal forces they feel during the collision. Starting with the accelerations you just calculated, use Newton's second law (the one relating net force to acceleration) to find:

- the force felt by the truck during the collision.
- the force felt by the car during the collision.

iii. The accelerations and forces you just calculated were all based on your guess about the car's gain in speed – a guess based on the intuition that the car reacts more during the collision. Does that intuitive guess agree or disagree with Newton's third law? How do you know?

8. This next video clip is about 8 minutes long.

Transcript: Blue 4-5

S4: Suppose the car and truck remain in contact for point five...
S3: OK. Remain in contact for
S4: Calculate the truck's acceleration (S3: bouncing off each other) during the collision.
S3: Truck's acceleration during the collision, how you gonna figure out that?

S1: How the hell are we supposed to do that?
S2: Isn't it, um...
S4: Acceleration equals change in velocity over
S2: Yeah, velocity over time.
S1: Yeah, yeah.
S4: Is force...?
S1: So that means the change in velocity would be, um, five meters per second, right? Divided by the time which is point five seconds, equals... I dunno... oh, that's ten.
S3: You said... it's... the change was five, right?
S1: Ten meters per second. Right, five.
S3: Oh, five divided by point five.
S1: So it should be ten meters per second, right? If you divide by point five, you divide by half, it's times two.
S3: So it's times ten?
S1: No, divided by...
S4: Point five.
S1: Point five seconds.
S3: I can see that.
S1: Yeah, because you have change in velocity over time, which is ten meters per second.
S3: Car's acceleration... assuming your guess about its change in speed
S1: Is correct...
S4: So ten meters per second?
S3: Squared. Hold up. The car's...
S4: Ten meters per second divided by point five
S3: So we think it's...
S1: So yeah, ten meters. Ten meters.
S3: Ten divided by point five, right?
S1: Right.
S3: Oh.
S1: Which is...
S3: Who knows?
S1: Twenty?
S3: Twenty, yeah. Because a hundred divided by five.
S1: It's basically ten times two, right?
S4: Yeah.
S3: OK.
S4: To good approximation, the forces on the car are the net horizontal forces they're feeling. Start with the accelerations you just calculated, use Newton's Law, second law to find the force felt by the truck during the collision.
S3: So, OK...
S4: Force equals m a.
S1: Yep. Force of the truck equals the mass of the truck which is (with S3: 2000 kilograms), times the acceleration of the truck, (S4: equals ten) which is ten meters per second squared.
S4: It would be twenty thousand. Oh, wow, look how cool that is!
S3: What?
S4: Cause if you do the same thing the next one, I think it comes out equal, doesn't it?
S1: Oh yeah, it does!
S4: (S3: Stop, are you serious?) That's so neat!
S1: Yeah, that makes sense. That's really cool.
S3: Oh my goodness. (S4: Look at that!) Get the hell out of here, that's scary to me!
S1: Yeah, it's pretty cool.
S4: Yeah.
S2: Yeah, that's...
S3: That's scary to me, I don't like this scary stuff.
S1: So the acceleration and the forces are based on the car's gain in speed...
S3: This is scary. (S4: It's soo cool!) I'm not... (? - laughs)
S1: So mathematically you just proved (S4: It agrees) why, yeah.
S4: So that our intuition does agree. It agrees with Newton's Third Law.
S1: Yes. OK. Sweet.
(pause)
S4: That's neat.
S1: So this, this guy...
S3: Oh, let me go back to the first one. We said that because the truck was twice the size, the car would feel twice...
S1: Twice as much.
S3: OK.
S1: Yeah.
S4: See, you gotta think about how much it weighs, and then acceleration (S1: Right) and blahblahblah.
S2: Yeah.
S4: cause then velocity... then it does have to do with... you do have to take into account velocity
S1: The velocity of things. Because it factors into acceleration, which does eventually...
S4: Yeah.
S3: (?) It's interesting...
S1: See... it just goes back to what I was trying to say...
S4: I never even... See, I like the reasons that they did this because then you figure out why.

S1: It kind of forces you to figure out why.
S4: Because I've had this equation F = ma for like, forever.
S1: Yeah.
S4: I never understood, like...
S1: All right.
S4: That's pretty cool.
S1: Yeah, so both cars actually do feel 20,000. Just because the truck's so much... so massive, it doesn't look like it got hit by 20,000.
S3: But suppose they were going at the same speed, suppose the truck didn't slow down, would that still be the case then?
S1: Oh, both the car and the truck...
S3: were moving at the same speed (S1: going at the same speed)
S3: Yeah.
S1: And they hit each other?
S3: Yeah.
S1: Then they wouldn't feel anything. If the car and the truck were going at the same speed.
S3: You say they wouldn't feel anything?
S1: Yeah. If they're going at the same speed, they had to be connected anyway, cause you couldn't overtake one or the other.
S4: Aren't they coming in the same...
S2: Yeah, what if they're going like this at the same speed?
S1: Oh, what if they're going like THIS at the same speed?
S2: Yeah.
S3: And they collide. They're colliding. If... and the truck... a change in acceleration, but I'm saying suppose there isn't a change, suppose they're going at the same speed.
S1: Towards each other? Cause in this, they're going... the truck's rear-ending the car.
S4: Oh yeah.
S1: Acceleration's going in one direction.
S2: Oh.
S1: Only in one direction.
S2: I didn't get to that.
S3: But even if they are, OK, suppose they are rear-ending or whatever.
S1: OK.
S3: Suppose they're both going, say, fifty miles per hour.
S1: OK. They're going at the same speeds?
S3: Mmmhmm.
S1: Well, technically, if they're going at the same speeds, they'll never hit, you know what I mean?
S2: Yeah.
S4: Right. We're looking at (S1: if this is going at) going the same way right now. This is what Newton's...
S1: Right, if I'm running at five meters per second, and you're running behind me at five meters per second, (TA: all right) are you ever gonna catch me? I mean, that type of thing. You're not gonna be able to catch me.
TA: OK, what happened?
S4: They're equal.
S1: They're equal.
TA: They're equal, what do you mean they're equal?
S4: So cool...
S3: Mathematically.
TA: The forces turn out to be equal.
S1: Right.
TA: So, before you were saying, your intuition said the forces should be different. But then when you applied your intuitions to the velocity, what does that make the forces equal to? I mean, how... you say the forces are the same now.
S1: Right.
TA: What do you think about your intuition then?
S1: So the intuition was... it's partly correct. It's partly correct in that we saw the velocities are correct.
S3: Right.
S1: But I think the reason we said it does more force is because I think it's what we see in like, you know, maybe, superficial damage, or something like that on the car.
S3: I think our eyes make an assumption.
S1: Instead of actual force.
TA: So, does it make sense now? Before you were saying, "I can't see how that would work."
S4: Now it makes sense.
S1: It makes a lot of sense.
S2: It makes sense.
S3: I mean, it makes sense on paper (S1: It's right there in black and white!), but it's still not visually...
S1: I think the biggest problem was like for us seeing...
S3: Yeah
S1: Us imagining a big semi truck hit a small car.
S3: The small car.
S1: The small car is completely totaled, but the truck has maybe a dent.
TA: So they react differently?

S1: Right, they react differently.
TA: That's kind of how you use your intuition when you said the velocities were different. Right? You said the truck loses five meters per second, but the car... you use your intuition and said it would be ten meters per second that it would gain.
S3: Mmmhmm.
TA: So, I mean, you kinda had a feeling for that... for the reaction, the difference in reactions.
S1: Yeah.
TA: So it's kinda cool that, I mean, there's this difference. Sometimes your intuition... I don't know where it leads. Sometimes it leads you to the correct answer. So you have to be careful. But that's good.

9. Discuss the following questions.

   A. The students are pretty darned happy with the tutorial and with themselves in this clip. What pleases them so much?

   B. In the second half of the clip, student 3 starts a discussion about head-on collisions that is interrupted by the TA. Do you think that discussion is worth pursuing? Would it have been good if the TA had promoted that discussion?

   C. Notice the TA's body language. Do you think it affects the conversation? Why do you think he does that now, and not earlier? (It's probably subconscious, but it might still be meaningful.)

   D. We like to define the TA as "talking too much" if we (and the TA) don't get to hear what the students are thinking because of TA talk. Was the TA talking too much, or did the students have enough room to express themselves?

   E. In an earlier clip, student 3 said "I don't think there's any way that you can explain to me how a massive truck is going to have the same forces on it." How do you think she sees this issue now?