A Decoding Interview on the Bottleneck of Correctly Applying Newton's 2nd Law to Moving Systems

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Patricia - the Decodee

Diana: Denotes the voice of the interviewer (Diana)

Shantel: Denotes the voice of the second interviewer (Shantel)

Wendy: Denotes the voice of the third interviewer (Wendy)

Juan Carlos: Denotes the voice of the fourth interviewer (Juan Carlos)

Louisa: Denotes the voice of the fifth interviewer (Louisa)

Patricia: *Denotes the voice of the respondent (Patricia)*

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Understanding the bottleneck

Patricia: *So shall I start? So the bottleneck is something that happens in my Engineering Dynamics class because … a little bit of context: basically the students take Statics first where they learn how to analyze structures and things that don't move and figure out what are the forces acting within the structures, and then after that they take my class of Dynamics where they start analysing things that are moving. This requires them to apply Newton's Second Law, which says that the sum of the forces acting on a structure or a body cause an acceleration which is proportional – the amount of the acceleration – is proportional to the mass, or in other words, F = ma is the equation they are applying. So in Statics that is set to zero, and in Dynamics, of course, those don't add up to zero, it is the mass times the acceleration. And students generally seem to understand this concept and they can apply it in simple problems, but then when we get to more complex problems, or sometimes parts of the problem look like something they had done in Statics and they revert back to adding the forces up to be equal to zero and they kind of forget that they are not equal to zero. So that …*

Wendy: So they are having trouble bringing forward … they are sort of stuck on previous knowledge and they are having trouble understanding the new knowledge, or incorporating the new knowledge.

Patricia: *Yeah. Yeah, I think so, or they just revert back to habits, maybe? So the example I gave yesterday is if they have some kind of an object hanging off a rope – so I will just draw some kind of arbitrary object – and if this object isn't moving then the tension in the rope is going to be equal to the weight of the object, but if this object is accelerating up or down then the tension isn't equal to the* *weight anymore because of the effect of the acceleration. When they get to complex problems where there is a bunch of other objects moving around and they have to solve this system, then they get to analyzing this object and they say, 'Oh, but the tension is equal to the weight,' and they just forget to apply the Second Law., because again they are – I am not sure – but they are either just reverting back to a habit of saying, 'Oh, the tension is equal to the weight,' because they do that so much in their Statics class, or they haven't entirely made automatic, perhaps the process of analysing the forces and setting them equal to mass times acceleration, or they are not exactly sure.*

Shantel: So Patricia when you … when they are given problems are they given a diagram, or is it more like a word problem that they then have to draw?

Patricia: *There is almost always a diagram so they have to simplify … they take … if they are analysing a system of objects we generally draw a diagram of each object and analyze what is happening to … to each object and then relate them … relate them all back to each other to figure out what it is supposed to be.*

Shantel: So the other day when you drew the second – the one that was moving, how … how is it … how it is shown in the diagram that it is moving?

Patricia: *So it is not necessarily shown, so if you … if this was connect to – so it is on a pulley or something – if it is connected a whole bunch of pulleys over here, or something, with a whole bunch of weights attached the question might be, okay, if you want to design a system that is going to lift this weight with a certain acceleration how much weight would you have to hang on the other end of the system in order to lift this one up? Or what would be the tension in … like you might have to size the … size the rope, so how strong would the rope need to be to be able to make this system move at the required acceleration? How strong does the rope need to be? So what would be the maximum tension in the rope?*

Shantel: So the reason I know that it is moving is because that is the context?

Patricia: *Also because the name of the course is part of the question! Yeah, I mean it is implied in the question how … how much mass do you have to hang on here to move this side of the system up by a certain acceleration? It is a moving system, right? But it is not usually … there is no motion shown in the diagram, usually.*

Shantel: Yeah, so the diagram itself could look … what I was getting at is does it look to them, does it sort of trigger them to remind them of what they have done before?

Patricia: *Well actually the diagram could look exactly the same as a statics problem, so the statics problem could be, okay, here are some weights hanging on the system and what is the tension of the rope, or something like that. Or what kind of weight you have to hang on this side to balance the system so that it doesn't move, or something like that, so the diagram could be exactly the same.*

Shantel: So that is part of the problem, perhaps.

Patricia: *Clear? All clear as mud?*

Juan Carlos: Leaving aside the formula, what do you think is the concept here? How would you state the concept – the central concept?

Patricia: *Well, the basic concept is that in order for an object to be accelerated there has to be a net force acting on it, so forces can't add up to zero, they can't all balance each other out – the external forces – because if they did the object wouldn't move or accelerate. But because they do Statics first they always revert back to that habit.*

Juan Carlos: So does this involve the concept that an object at rest tends to remain at rest unless it …?

Patricia: *Yes, so that is actually Newton's First Law, which they do in Statics, so an object at rest tends to remain at rest if there is no net external force acting on it.*

Juan Carlos: And are they reminded of that concept before they approach a problem like this?

Patricia: *Are they reminded of …?*

Juan Carlos: Of Newton's First Law, and then of the Second Law which is mass times acceleration …?

Patricia: *Yeah, and I mean, I … the first is the free body diagram, I mean we require them … that is part of solving the equation, you have to draw a free body diagram of each object you are analysing because we know that that helps them remember, but then they still sometimes … they seem to skip that step.*

Shantel: Can you draw that again? That free body?

Patricia: *Yeah, so the idea of free body is in physics or engineering we would take the object that we are analysing and separate it out from all of its contexts so we can just look at the one object. But to make that free body an equivalent body to what it is in context we replace everything with forces. So if we were to just look at this object then we would say, okay, if we draw the object by itself, in order for this to be equivalent to this, then the physical effects of the things touching this object need to be drawn in here. So there is a rope touching the object which is causing a tension force and pulling it up, so we would replace that with drawing the force. And then there is nothing else touching this object, so the only other force would be the weight of the object, so we would draw that and the weight is tending to pull the object down. So in Statics this would be all you would need to draw, and if you add those forces up it is clear that the tension has to be equal to the weight for those forces to add up to zero. Again, in Dynamics they don't usually add up to zero and so we require the students to draw the other half of that equation and draw the mass acceleration vector on the right hand side. So depending on whether this system is moving up or down we would draw that going up or down. The idea is making them draw this is supposed to help them remember that, no, the tension isn't equal to the weight anymore because we have this thing on the other side that is affecting the forces, but they always seem to just revert back. So they will analyze this complicated system over here, and then they will just look at this and go, 'Oh yeah, the tension is equal to the weight,' and then they will continue on, on this part. The more complex problem they just skip over that step and just don't seem to remember to do it.*

Shantel: Okay, so can I ask, just so I am understanding this in my kind of … so in an everyday kind of context what this is really about is like if I want to move something that is heavy, like this TV, I have to pull on it hard.

Patricia: *You have to apply force.*

Shantel: And the heavier it is the more I have to … the more … the harder I have to pull on it, right?

Patricia: *Um hum.*

Shantel: In order to actually move it - or how quickly? So the harder I pull it, the faster it is going to move, right?

Patricia: *Right.*

Decoding the bottleneck

Shantel: Okay. So there … so there is kind of a … because you talked about the other day, you said you had - when we asked you about what you do in your line – you said you had a kinesthetic feeling, you had a feeling of this process?

Patricia: *Um hum.*

Wendy: So could you describe that or talk about that a bit more?

Patricia: *So in the example of a weight hanging off a rope – and I keep going back to this one because it is a nice, simple example, but there are other cases where this would be applied - but if you were holding a weight on the end of a rope and just holding it, the amount of weight you would feel pulling down on your hand would be the weight essentially, but if you tried to pull it up really fast you would feel more force pulling down on your hand because you are trying to accelerate it up, so the tension … the tension here has to be higher than this to cause that acceleration up. And then the same thing in an elevator, actually, when you first start moving up in an elevator you feel heavier because there is that total force underneath you has to be higher than your weight to start moving you and accelerating you upwards. When you start going down in the elevator you feel light for a second when it is accelerating down because that force underneath you is actually lighter than your weight while the elevator is accelerating. So in the case of the weight on the end of a rope if you suddenly just let it drop the force on your hand would feel less.*

Wendy: So when you thought about those concepts in your head do you typically think of the elevator yourself as a way of visualizing it or feeling it? Or is there something else?

Patricia: *Not consciously, I guess. I guess somehow I just … I don't know if it is a combination of … this is just what I was saying the other day, I don't actually know if I could ever actually decode this because it is so innate I don't know what I do, but I just have this innate understanding that the forces are not necessarily balanced anymore because the object is moving and there has to be some unbalanced force working on them to cause that movement.*

Shantel: And do you see this … so back to what you see in your mind, you don't necessarily see it in your mind? Do you see - when you look at this diagram - do you see it moving? Is it moving? Or do you just know… you know that is moving? Do you know what I am saying? Do you just picture it, or …?

Patricia: *No, I don't think I do.*

Shantel: Like that cartoon kind of idea, like …?

Patricia: *No, I don't think I do, but that just may be from years of working with textbook examples, you know, 2D static pictures.*

Juan Carlos: This really mystifies me because they seem to be to be two very simple concepts, and how people can confuse them is a mystery to me.

Patricia: *Well, I was thinking about this too; so I think somehow they have just … they have internalized this simple example of when they see a picture that looks like this they see, 'Oh, the tension is equal to the weight,' because they have done that so many times in Statics, and then they are just … it is just so automatic, it is like a step, a recipe sort of thing, and they memorize this and then they just can't get past it when they get to doing the dynamics example.*

Wendy: So what helped you yourself get past it when you were learning it years ago?

Patricia: *I think, and again this … I mean it was so long ago it is hard to say, right? I think it is … it is drawing … remember to draw the free body diagram and not just make that initial assumption. I remember back to whatever it was, grade four or five math when you learn order of operations – I don't know, I am talking math again – but I remember our teacher doing something like, you know. $x + 3 = 5$ and he would make us write '-3' and '-3' on each side of the equation and then you get $x = 2$ and I was just annoyed because it was so stupid because it was so obvious that $x + 3 = 5$ and it is just that x is equal to 2! So why do I have to write '-3' on each side? Because you are training those steps so that when you get to a more complicated problem you know how to apply the steps, right? So I guess they are learning to apply this simplified version first, and then they are not applying the full … the full step.*

Diana: Patricia, you said something interesting a minute ago. You said when you approach it you don't make the initial assumption, you draw the diagram. So is there some kind of … you have to stop yourself from making an immediate judgement?

Patricia: *I think so. I think because, again, the more and more complex these system get the more valuable drawing this out becomes so … so maybe that is what it is, I recognize the fact that this is going to be valuable as the questions become more and more complicated and they just haven't realized that yet.*

Shantel: So do you … is it that the students that do draw that, do they get it right, and the students that don't draw it get it wrong? Is it really that step of drawing it that will solve it for them, or if they draw it, do they draw it wrong? Do you know what I mean?

Patricia: *That is a good question. I would say a little bit of both; so I have, you know, students are required … they are supposed to draw a free body diagram first for every mass in the system they are supposed to analyse, and in a dynamics problem they are supposed to draw both sides of the equation. The idea is if you can draw this properly the equation and the rest of it is easy, it is just math, it is figuring out the forces acting on it, and drawing this diagram properly and the equation is supposed to come out of the diagram. Now I forget where I was going with that – would you repeat the question?*

Shantel: Oh, it is a question of them drawing the diagram, or actually drawing the diagram incorrectly.

Patricia: *Okay, right, so I guess I have seen students who just don't bother to draw a diagram for the case of an object hanging on a rope – again, going back to this example we just did – they would write all their equations for the other parts and then just say, 'Oh, the tension is equal to the weight,' and do their equations. And then there is the occasional person who will just skip over it and say, 'Well, tension is equal to the weight,' and continue on. But for the most part I think if they draw this usually they don' t make that mistake, so they haven't internalized the value of this step maybe? Again, this is a real … this is a simple example I chose to try and demonstrate, but as we go through the course and the examples we get … the objects we are analysing, you know, have forces in multiple directions and many forces acting on them, like there could be five forces in different directions acting on one object, and then it becomes … like you really do need to have this diagram in order to … to solve the problem because you can't just automatically make those jumps anymore.*

Shantel: Do they get marks for that step?

Patricia: *Um hum. Yep, and in fact if they got the question right and they didn't draw the diagram I will still take marks off because we are trying to emphasize that this is important. This is the engineering part, and after that it is really just math. Just math!*

Juan Carlos: I know that you sort of skip over the visualization and go directly to the solution in your mind, but let me ask this one, do you visualize the system in motion first and then isolate the case of the system not being in motion in order to figure it out, or do you visualize the system not in motion and then put it into motion?

Patricia: *I don't think I visualize the system. I might think about, well, if the weight on this side is heavier then it will go down and therefore that is going to move that up, but it is more … it is more just working it out in my head, and I don't think I actually visualize it moving.*

Diana: What do you mean by 'working it out'?

Patricia: *Well, so let's say, for example, you were given this system and then you were saying, okay, to hang a weight of a certain amount on the end and find out what the acceleration of the system is, so it doesn't actually tell you whether this part is moving up or down, or if this part is moving up or down, you would have to … you don't even have to know that to solve the problem, but generally my first step would be to get a sense of well, this one is heavier so it is probably going to move down, but it also depends on a lot of complicated things that are happening over here, so I don't usually try to figure that out in advance, I try to, you know, break it down into the simple parts and look at each simple part by itself and then put it back together. When these systems get more complicated you can't actually tell just from looking at it which way it is moving and that is part of the problem.*

Shantel: So you can't … so can you, at sort of the start of a problem, can you … do you have a sense when you get an answer whether it is right or not? Like do you have a feel for when you look at a diagram what the answer is probably going to be? You know, sometimes, like I remember doing word problems and you had to think back to, 'This is a really improbable answer that I got. I must have made a mistake somewhere.' Do you have a feel for that?

Patricia: *I think … I think I have a feel, but again, the more complex a problem is you might know what seems to be reasonable, but you would also know when it would be reasonable not to know, if that* *makes sense? So yeah, depending on how the pulleys are set up, and depending on what the weight is it could move either way. I guess I have … what I am trying to say is I guess I have a sense of when it is not possible to know which way it is going to move.*

Diana: I was just going to say it sounds like you are bringing a lot of your knowledge of more complex systems backwards to this. It seems like because you know what could happen when it gets more complex and you had experience with all those complexities you are kind of bringing that in to making your judgements about what is happening when it is simple –is that true?

Juan Carlos: That was kind of the thrust of my question about whether you visualize the system in motion, or pick out all the static parts and put them together, and that was the same kind of thing I was trying to get at.

Patricia: *Yeah, I guess I don't try to visualize the system first because I know the more complex it is you can't just actually look at it and necessarily figure it out, and that is why it is important to look at all the pieces.*

Shantel: So can I go back? I am really interested in the kinesthetic element of this because it almost … I would have assumed, based on what I know about engineering, that this is a totally visual process for you, but you made that comment about feeling it more than seeing it, and so are you bringing, like your field experience of seeing these kinds of things in operation so you know that it… there is this embodied feeling of some of these kinds of forces …

Patricia: *Like the elevator example? Yeah.*

Shantel: So do the students … do you have labs with this kind of thing? Do they have … do they get experience with actual objects to support these kinds of processes or physical … processes?

Patricia: *That is a good question. Yes, they do have labs but I know if it really… I mean we obviously y haven't sat down and decoded some of these bottlenecks really intentionally and tried to think of what kinds of activities can we do to address this particular issue.*

Juan Carlos: So they don't … they do not go into a lab where there is a pulley system with weights?

Patricia: *We don't actually have a pulley system in our lab.*

Shantel: I know with teaching math – math concepts – to young children, and I am much more familiar with that, and there is a process that has been really well developed of starting them with manipulatives first, and then going to visual representations, and then symbolic, and that seems to work best for many kids. There is such a concern that some kids, over many years memorizing things, like times tables, or whatever …

Patricia: *Yeah, like tension is equal to the weight? They think they can just memorize that.*

Shantel: Yes, and some kids just intuitively understand the concept underneath, and some children never really understand, like the relationship between addition and multiplication, for example, right? So they don't really conceptualize it, or base ten, what that actually means. So if students are working at that level – the symbolic level – and using a visualization but they don't have that kinesthetic feel for what is actually going on they can just not … they just don't really conceptualize it, and I wonder if that is what is happening for some of the students. You have that feeling of what this means in the world - the real world.

Juan Carlos: If it is a really, really complicated system do you still have that feel?

Patricia: *No, not necessarily, I think you really have to take it apart to figure it out.*

Juan Carlos: So if you take it apart and have a feel for each of those parts, and then sort of sum them in a way, or how does that work?

Patricia: *Well, I guess I just … I have the sense that … for example, the tension in this rope is going to depend on so many factors; the way it is wrapped around these pulleys, the different masses that are attached and how fast they are accelerating, so … I just … I just know that there is no way to figure it out unless you look at each one separately and don't try to jump to figuring out the tension before you have looked at … because you are going to get an equation out of this free body diagram and you are going to get an equation out of every other free body diagram, and then you have a system of equations you have to solve for the unknown, and the tension in this case might be the unknown, and you just … you can't jump to that conclusion, you have to go through it including every object in the system and putting that into a system of equations to figure out tension and there is no other way to do it.*

Shantel: I am really fascinated with this idea which I feel has come up in multiple disciplines of how experts withhold judgement until they have all the information or until they have fully explored. So that is what you are talking about, not rushing through the problem and making sure you know all the components before you try and solve it. It feels to me like maybe experts have a way of withholding judgement or, you know, holding back? Knowing what they don't know.

Louisa: Or thinking about all the possibilities.

Patricia: *That is the same, and there are actually articles about engineering design that say the same thing, that the expert designers spend more time on the brainstorming stage thinking of lots of possibilities and evaluating those possibilities before they start developing an actual solution, whereas the novice ones, you get one idea and they go with it and are done sort of thing. So … yeah, that is a good point.*

Wendy: So Patricia, if I could just go back again and how do you know … how do you … I know you said it was innate and you probably have different skills set than I have for figuring this out quickly like when you were in grade four, but how … how did you learn that yourself?

Patricia: *How did I learn what?*

Wendy: This process, this concept.

Patricia: *Well perhaps I didn't really … maybe when I first started doing this I felt that feeling of annoyance, like this seems like so much extra work just to draw something that seems obvious, but over time with the practice and experience of solving more and more complicated problems I realized the value of that stuff. And also seeing the mistake that students make and telling them, 'You have to draw a free body diagram to get full marks,' you know, 'You don't write your equation until you have done this* *part,' and again, if you do this part that is solving the problem right there. So it is the experience of knowing how valuable that stuff is.*

Wendy: And did you get that experience once you graduated from your undergrad, or your graduate studies, or did you know that before you went into university?

Patricia: *I think … I mean I am a mechanical engineer so this was one of my best subjects, right? So even in this course by the time we get to the end we are solving these complex problems with the students. I think they have realized by that point they need to do this because there is no other way to figure it out, the system is so complex, but I guess they haven't really internalized it because then I see a weight hanging off a rope and they say the tension is equal to the weight again! So maybe it is just it looks the same, you know, but it is not the right cue for them, 'Oh, it looks like a problem we did in Statics,' and they are off again and they just forget to do that step.*

Shantel: I think those visual kind of triggers can be very powerful for people.

Diana: What are the cues for you that it is different?

Patricia: *It is Dynamics!*

Diana: So is it the context of the problem, or is there something in the problem instructions that you look for?

[pause]

Patricia: *I mean … I mean the whole course we are analysing moving systems, right? So we are always … we are always drawing both sides of this equation. So it is not like something within the course, like that is always the process, it seems to be the jump from Statics where they are treating static objects, and then they see something familiar and they just go back to their previous way of understanding that.*

Wendy: Can I just chime in? What cues you that they are different?

Diana: So it is like a context, right? You are thinking …

Patricia: *Yeah.*

Diana: … 'This is moving,' so you have a different set of assumptions when you look at … so you said the diagram could look exactly the same as the other course, but in your mind you know it is totally different because it is moving, and because you are told it is moving.

Patricia: *Well it is not totally different, you would still solve the statics situation by looking at each object and drawing a free body diagram, but you would only have to draw this part because this would just be a big zero on this side, there is no effect, so you just draw this diagram and add everything up and figure out whatever you need to figure out.*

Louisa: So it looks like you are able… when you look at that equation you are able to substitute weight, as opposed to someone where it looks like weight equals mass times acceleration? So are you substituting breaking down the elements into its components when you think about what weight is? I don't know.

Patricia: *I guess it is just … I mean the … I don't even know how explain it. The internalization is that this has an effect, basically, and so that is why we have to draw it, because once you have this acceleration term there it changes the balance of the forces on the other side – or actually it is the balance of the forces that cause acceleration, but this just changes the way the forces balance. I just … just … I know that this has an effect, as soon as something is moving it has an effect on the resultant, so the tension would change as soon as you started accelerating that weight.*

Shantel: So what sort of experiences do the students have in the lab? What kinds of things do they do?

Patricia: *Well there is … there is lot of other … we have friction kinds of problems and so we look at an object sliding on a slope and that kind of stuff, they look at projectiles moving through the air, and so we have lots of … we just don't actually have a pulley set up in the lab to demonstrate this particular concept. I mean, like Newton's Second Law can be applied in all those other examples as well, but it seems to be this particular thing is one of the … one of the types of problems where I see students always reverting back to that previous knowledge.*

Juan Carlos: If they are dealing with an object sliding down a plane do they also have to draw a diagram similar to this because it is just another case of this?

Patricia: *Yes.*

Juan Carlos: So do they do that in every case where it is that kind of problem?

Patricia: *Every single problem.*

Juan Carlos: But you are saying that they don't draw the diagram here, but when they are doing that kind of problem do they draw the diagram pretty consistently and pretty automatically?

Patricia: *More consistently, I guess, yeah.*

Juan Carlos: So for you, what creates the difference in the way you think of this kind of problem, versus the way you think when an object is sliding down a plane? Is the latter simpler, like is there just two forces - no, three?

Patricia: *Well, you could have this object sitting on a plane and sliding down, so …*

Shantel: Do they make the same mistake?

Patricia: *I would have to think about that. I think occasionally, but I mean I just picked this particular example because that is the time I see it happen the most often. So yeah, I would have to pay attention to that as I am not sure. Like I could think of a few other examples where they kind of forget that right hand side.*

Juan Carlos: What would those be?

[pause]

Patricia: *Like, say if you have an object … and object on top of a … sitting on top of – again, I am just going with boxes because we tend to – so if you have a cart moving around, or, you know, a crate sitting on the back of a pickup truck or something like that, you know, how fast can the truck accelerate without the box sliding backwards, or something like that? They might have to draw a free body diagram of the object on top to figure out what kind of acceleration would cause it to slide, but then they forget, again, because this is sitting on something that is moving it is also moving, and so they don't draw the mass acceleration of that one either. I don't know – does that help?*

Juan Carlos: Well it … I think we are actually going somewhere here, because that is pretty complicated and a complex case, whereas this one is a very simple case, I think.

Patricia: *I am glad you think we are going somewhere!*

Shantel: Can you draw the plane one as well? The box on one?

Patricia: *You could; you could make this one more complicated by saying you have a crate sitting on some kind of conveyor belt on a slope, or something like that, and pulling the whole system. Now figure out what this weight has to be to move that one, or something.*

Shantel: And just really curious whether this has to do with that assumption, or basic context of motion, that you seem to … that you have as an expert, that this is all moving, but to the students if it is not … if it is not apparent to them in that diagram easily they don't make that same assumption that you … they forget as they are working through, but you don't forget that it is moving. Like that car – that truck – doesn't look like it is moving, to me. That … the box on the plane looks like it is moving to me, and I can see that is moving because it is sloped, right? That could be a parked car and how do I … I have to remind myself that it is moving when I am working through the problem and I could forget that. I don't know.

Juan Carlos: You need some little streaks on the truck.

Shantel: [laughs] Exactly! So now it is different. I wonder if it is really … it sounds silly, but I wonder if it is that simple in a way?

Wendy: You have certain cues, like Diana is asking you, about the context, so for me that would be a cue for movement, and maybe the students aren't … like you go there because you have years of experience and you just do that in their head, but maybe they need more of the visual cues.

Diana: Patricia, are there cues you use in the way the problem is framed? Presumably there are words associated with these, right, because there is a question, so when you look at the question are there cues you see in the question that you then use to remind you it is in motion?

[pause]

Patricia: *Yeah, I mean the question will always be 'what is the weight required to accelerate it by a certain amount?' or, 'How fast can this go without the crate slipping or tipping over?' or, so the movement is talked about in the word part of the problem.*

Diana: So you look for words just…

Patricia: *And then sometimes there might be, you know, you might be told the system is moving and it would have an arrow, and okay the velocity is this way, but you still have to figure out the acceleration or something, so sometimes there is a bit of a cue about … nothing earthshattering though.*

Diana: But there are little subtle cues that you identify, like the word 'fast', the arrow, the velocity, there are little thing you are picking up that are signals to you that this is in motion.

Shantel: Yeah, I think for me what was always, and the little bit of reading I have done about physics and the SoTL work that has been done in physics is that you are competing with people's everyday understanding of their world, right? So I have been in an elevator a million times and I have never thought about that, that you feel … of course it makes sense, you feel it more when it starts moving and then it seems to go easier, but I have never thought about why that is, or what it means in terms of the physics of it, and because it is not … right? But … so I think the connection to … now I don't know where I am going.

Patricia: *So this is – and now I am kind of getting off topic – but this is the question I have about decoding, and I mean we are speculating about some of the things students may be stuck on decoding, but shouldn't we be asking students too?*

Diana: So can I just make kind of an editorial comment? Originally one of our general strategies, and the strategy that David and John suggested to us is 'always bring the interview back to what the expert does, and interrupt or redirect if the topic goes to teaching or what students do,' so I think if we are asking about students, if we can reflect it back to, 'In comparison what do you do?' so that we are kind of redirecting what the students do to what you do, so I think … just a brief editorial comment.

Louisa: I … I would like to go to where Shantel - I don't know where you were going with that - but, you know, so Shantel's comment around everyday life and do you find that when you … that you are thinking about … like when you are sitting in the elevator do you think about all the … does your brain work that way? Like yesterday we were talking to Sally about journalism and some of the thinking processes her students go through, and she was talking about how observant she is and how she just asks questions about everything, and whenever she sees something it is just like … you know? It is natural for her. So when you are in an elevator, for instance, using that as an example, it is a natural process for you to think, 'I wonder how fast this elevator is going? I wonder what …?' do you think about that in everything you do?

Patricia: *No, not consciously, but I mean if I was in an elevator where I suddenly didn't feel heavier when I was moving up I would pay attention, I guess, and wonder what was going on!*

Wendy: Oh, that would be the elevator over here!

[laughter]

Patricia: *Well, it is just in that instant when you are still accelerating, and then you reach a constant velocity and you are not accelerating anymore and you don't feel it; it is just at the moment you start moving or stop moving. And yeah, the more the acceleration the more you feel it, so …*

Louisa: I know I walked around … I walk down the street and I see people with large abdomens and I am thinking, 'You have heart failure or liver failure,' right? 'You are a heart attack waiting to happen. You are going to have a stroke,' right? These are things … I see people with grey skin and I am thinking, 'You need to stop drinking. You need to stop smoking,' right? Like these are things that … that …

Wendy: We are always assessing.

Louisa: You are always assessing, right? So I am just wondering if this something you do in your life, like if you are always looking at, 'I wonder …?' so I don't know if that is why you are getting it.

Patricia: *I don't know, and not that I am really aware of, but like I said, if I felt something or saw something that seemed unusual I would notice that.*

Diana: It is interesting though that you have these conceptions of what seem usual and what seems unusual, like that requires a lot of implicit knowledge there.

Juan Carlos: Did you play with Lego when you were young?

Patricia: *I had two brothers, so yeah, I don't remember playing with it a whole lot, but definitely.*

Juan Carlos: And then do you think there were other - after that – other experiences that gave you this sense of a dynamic world, and a world of forces? I don't think most people walk through the world thinking it is a world of forces, but I am getting the notion that maybe you do?

Patricia: *I mean I guess, like when people ask me why I went into mechanical engineering I say, well, because we are analysing things that we can see, and things that are moving so you can visualize them and so it all makes sense to me. Electrical engineering with little electrons moving through, you know, current moving through wires is not as visual and I didn't enjoy it as much, so … so I guess yes, but I couldn't explicitly say the things I think about, it just seems more natural to me for some reason.*

Juan Carlos: Which means, I think, on some level – correct me if I am wrong – you have actually embodied these concepts if you are feeling them, and in your past conceptualizing them, and then you are actually embodying them.

Shantel: Yeah, I think that kinesthetic element is quite interesting to me.

Patricia: *Well, I am into biomechanics too, right? Like to analyse the movement of human bodies, and sports, and recovering from injury and it was all … all forces and accelerations.*

Juan Carlos: So you are getting cues from the … your physical relationship to the world you are moving in.

Patricia: *Yeah, I guess, without thinking about it, probably. When I talk to students about the case of … we analyse vehicles and their wheels and things like that, like as a car is accelerating forward we talk about what are the forces between the wheels and the ground, and usually we compare it to walking. If you are trying to accelerate forwards then you have to push backwards on the ground to move, and it is the ground that is pushing back and pushing you forwards, so it is the same thing. If the car is* *accelerating forwards and we are analysing the force under the wheel, the force under the wheel is forwards and that always confuses them too, but that is because the car has to push backwards on the ground and then the ground pushes it forward, so the force on the car has to be forwards if it is going to accelerate forwards.*

Shantel: And you, I mean you use different … the way you use language, it is very interesting to me in physics, because it is not our everyday way of thinking about it. So for me to think about the ground pushing, it is not an everyday concept, right? It does feel to me, it doesn't seem to me the ground is doing anything, right? So that … but it actually is, right?

Patricia: *For every force there is an equal and opposite reaction, right?*

Shantel: So I am thinking about the conversation – I think I raised it before –with a biologist who was explaining how food moving through your digestive tract is outside your body, and he was really determined about it, and everyone else was saying, 'Yeah, but … actually, not really, like we can't see it so it is inside,' so there is the everyday way and then there is the way that the discipline understands what is happening. So there is a socialization into that kind of way of understanding that the ground is pushing you, pushing back, or pushing you forwards, so …

Louisa: I am also thinking of your use of different examples because, like, I am wondering when you are looking at inanimate objects and then your biomechanics, do you find the students understand more when, like, you give them a biomechanics answer, or situation, as opposed to a crate on an inclined plane, versus someone walking? Or pushing against an object.

Patricia: *I don't know necessarily, like if we are talking about some concept I try and give as many examples as possible and I don't know if there are any particular ones that work better, I just try to give a range, and hope that they, you know, can at least relate to one or two of them. Yeah, you are asking what the students do and I don't know that!*

Louisa: Yeah, so let's bring it back to the …

Patricia: *It seems to work!*

Louisa: Sorry, that seems to be getting at the bottleneck. We say students have difficulty and I was just wondering which situation they have more difficulty with, and then to bring it back to you, which do you find easier to think about? Biomechanics or to think about it as an inanimate object?

Patricia: *Well biomechanics is way more complicated because we are actually … you would analyse a body as a system of connected objects, right? The foot might be three objects, and your shin might be one, and your thigh would be one, so you would have to draw a free body diagram of each part because you do have forces between them. Yeah, so … it is like this, almost a system of connected bodies and you have to analyse each one separately to figure out what is happening – depending on what you want to know. So you could … in gait analysis, for example, you could measure the force on the floor, and then if you know where your body is in three dimensional space you could figure out approximately y what are the forces acting inside the knee joint, and then look at … link that to orthotics and how that changes the loading.*

Louisa: Oh, so it is more complicated?

Patricia: *Yeah, way more complicated.*

Wendy: Patricia, how do you know when you have thought through this correctly? How do you know when your thinking has got you to the place where you want to be, where you understand, and where you have added that piece that the students are forgetting? How do you know you have thought of it correctly?

Patricia: *Well, I guess part of it is knowing where … where to break the system up into the different pieces that have to be analyzed separately. So to me it seems pretty obvious in an example like this because everything has a mass, so usually we assume the pulleys are small and the rope is not very heavy compared to the objects and so we are just analysing the big masses in the system, and so that … that is actually one step that I think it is fairly automatic. It becomes automatic for the students, but I don't know if they really internalize why, or they just get in the habit of knowing that if they see this bigger mass they have to draw a free body diagram of it.*

Wendy: When you incorporated it correctly what does that look like to do, and how do you know you didn't forget that step?

Patricia: *Well I would draw a diagram like that for every single object in the system that needs to be analysed, so I guess, again, it becomes, 'How do I need to know which objects need to be analyzed, right?' Usually the question will say, 'You can assume the mass of the pulleys are negligible,' but then we do, later on in the course get to, 'Well what if the pulley is big and heavy?' and then we do have to analyze it as well. So that's … that comes from experience too, I suppose, knowing which parts to … but the question is supposed to cue, even if something … if it says the mass of one of the objects is such and such many kilograms then that is a cue that you should probably drawing a right angle under that – does that answer your question?*

Wendy: Yeah, I was just trying to …

Patricia: *So I know that everything is connected in the system, and a mass needs a free body diagram, because if it has a mass and it is accelerating in a system it is going to affect the forces in the system.*

Louisa: So let's say you have done all your free body … all your … what you think are all your equations and … and you come up with an answer; how do you know that answer is appropriate for this system?

Patricia: *Well, I mean there is kind of order of magnitude, and if … if the weights are on the order of a hundred Newtons or something like that, then depending on how high the acceleration is you would expect the tension in the rope to be at least the same order of magnitude, probably, unless the acceleration was extremely high and we don't usually, you know, deal with supersonic objects or anything like that in this course! So generally, same order of magnitude might … I mean there are also other cues, like tension for example; if you were solving for tension and you got a negative answer you would know that you did something wrong because tension can't be negative – negative actually means the force is the other way and they always say in engineering, 'You can't push a rope,' you know, it just buckles and you can't push anything, so if the force on the rope is the other way you know something is wrong. So there is [sic] cues like that too. But yeah, order of magnitude and sign I would say would be two … two big things.*

Louisa: So would you say there are some rules? You mentioned some laws and stuff, but you mentioned that the tension can't be [negative] and, I mean would that be something that you learned, or is that something that …

Patricia: *Yeah, that is something we talk about and I always model that too, and you get to your final answer – whatever it is that you are trying to figure out – and you go back to the question and look at it, 'Does that actually make sense?'*

Louisa: I know we do that in nursing a lot, and especially math problems, like does that make sense? Are you really going to give somebody twenty five pills? Or can you measure a quarter of a drop.

Juan Carlos: When you were learning this stuff where did you learn it? In a lab?

Patricia: *No, I didn't have a lab for this course when I took it.*

Juan Carlos: So this was basically mathematics and …

Patricia: *Diagrams.*

Juan Carlos: … diagrams for you?

Patricia: *Yeah, but I think … I mean I was attracted to the mechanical, I think, because of the … I don't know, maybe the kinesthetic and the visual aspect of it, of knowing how things move and being able to visualize and have an understanding of how that happens.*

Juan Carlos: Right. And have you had experience with having to do this kind of thing with actual machines and objects?

Patricia: *Not …not really, actually. Like I said, in biomechanics you do it, but there are no pulleys and things like that. It is the same idea, drawing the free body diagrams and including the fact of the acceleration, but it looks completely different. It is always … it is always this; it is always drawing the diagram.*

Juan Carlos: So you have experience with moving from an actual biomechanics system to these kinds of diagrams and an outcome?

Patricia: *Yep. Yes.*

Juan Carlos: And how important do you think that is in your ability to think about these pretty quickly, pick up all the cues pretty quickly and see how it makes sense or doesn't make sense?

Patricia: *Yeah, I think it is important to be able to, I guess, have that initial sense, but again, it comes back to that experience thing and realizing the more and more complicated the problems get the more important this part is to try and make the students … make them! Just do it!*

Diana: That is important because …

Patricia: *Just do the diagram!*

Diana: You know the value of it. You see the value and you know why that is valuable and that seems to be a crucial part of what you are doing.

Patricia: *And when you are analysing data analysis you have to do that with every single object in the system that is moving with respect to another object you have to include that in the diagram and figure out how they are all interacting.*

Juan Carlos: Would you do that even if you were faced with a very simple problem? Or would you just go right to the formula and …?

Patricia: *Yeah, because, like, this example is a simple one and I would still go and do it. Yep.*

Juan Carlos: Because I was … I have an interesting thought to throw on the table: I wonder if the examples are too simple?

Patricia: *But they are not too simple because they are not getting it, and they are still saying the tension is equal to the weight, right?*

Juan Carlos: But they are making that mistake …

Patricia: *… because it looks simple, yeah. So you are saying I should give them harder problems?*

Shantel: I think there is a kind of forgetting – like a remembering and a forgetting that is happening.

Patricia: *Well, yeah, because the overall problem gets more and more complex, and so they in general are doing things right but they forget the little things.*

Shantel: These little things that can make it all wrong.

Patricia: *Or that they think is little, but are not at all little.*

Shantel: I mean it is really interesting in terms of - if we think of this in terms of – aptitude, right? And the discipline. So people have affinities for different things or different aptitudes, you know, so you seem to have – the way you talk about it – there is a kinesthetic sense of what is happening, and a visual sense, right? I know that I am very weak with visualizing things and I know for me what happens when I try and picture something like this in my mind I … it is … there is gaps. I can't hold it all in my visual mind; I can't hold it all. I focus on this part in my mind and I forget this piece and it is like it goes blind almost, is how I would describe it, so I have to have a way of remembering all of the components that I need, whereas you just seem to remember them all, like, it is obvious. So … yeah, I don't know.

Diana: I also wonder if there is a way that you visualize whether a problem is simple or difficult that is different from the way the students do. Like when you visualize a problem that is simple, you are not … you are not just automatically coming to a simple solution, like you are still going through all the steps and drawing it out regardless of how simple it is. Like you are approaching a simple problem, but not in a simplistic way, right, like you are still going through all the mechanism. So I wonder if there is a way you are approaching problems, like there is a way you are approaching the problem and I don't … I don't know what my question is! Sorry! I am just rambling.

Shantel: Well, there is a systematic … well that is back to that reserving judgement component, and like you are not jumping to conclusions just because something looks straightforward, you are still going through because you know there may be something you are still not … on your first glance you may miss something so you … you are still going through all the steps so you are not missing … you have to go through every … every possibility and you can't start discounting possibilities right off the … you know? Until, 'Okay, it is not this because of this. It is not this because of this.'

Patricia: *Yeah, and we talk about that a lot, and I don't assume. If you are not told something, or something isn't given in the question don't assume – don't assume the tension is equal to the weight, or don't assume anything. Draw the diagram, figure out what you know and then you have to be able to solve for whatever you don't know from the diagram and the equations that come out of the diagram. You can't … can't make that jump. So yeah, I don't … don't assume anything.*

Juan Carlos: Do you make that clear to them? This does feel like a procedural problem.

Patricia: *Yeah, I tried to, but I have to be a bit more attentive to that perhaps, but … every time we are working through a problem in class, you know, I ask the students to draw their diagram first or something, and then when they are all done we draw it together or … and if somebody suggests drawing something, or assuming something that isn't correct we will talk about what are the issues with that, and can we assume that? Usually, no, so I try to model that.*

Wendy: So how did you learn that was a part [inaudible].

Patricia: *Yeah, probably back to experience and maybe when in the similar problems when we first started doing this it seemed like an extra step that you didn't really know why you had to bother to do it - like writing '-3' on both sides of the equation! – but the experience of having done the more complicated problems …*

Wendy: Did you ever have the experience of not including it and then there was a consequence?

Louisa: The wardrobe fell off the truck onto Deerfoot Trail?

[laughter]

Shantel: What I am thinking about is if I did actually understand this in a better way it would really help me in my day to day life! The things that I do sometimes!

Patricia: *Like if you are into sailing, or something like that, there are always pulley systems to do the rigging for the sails. So they actually don't have a very …. we can try and talk about that too, but maybe we do need a pulley system in our lab and demonstrate what is the point of having a pulley system …*

Wendy: Well if they make errors and forget that part there is a consequence.

Shantel: Well and I think that kinesthetic component is very powerful, and so if students don't necessarily have … I mean at best they are remembering something like being in an elevator, but if they could actually have that play, of playing with the objects in the context of this if it would make a difference for them.

Patricia: *Or even, you know, lifting weights, that experience too … like when you start lifting weights that is the hardest part, right? Once it is moving it is not that hard anymore.*

Shantel: So lots of these things and the way we would approach it with young kids is to actually give the experience first and then talk about the principle so that they have to move from concrete to abstract. So, to me you can do that - I know we are talking about pedagogy, sorry! – to me it wouldn't even have to be in a lab, it could be while they are …

Diana: You could bring some weights in to the classroom.

Shantel: It would be very simple. Yeah, but teaching basic math concepts to young kids you can see the difference between the ones that just grasp it, and the ones that need an experience to build the concept onto, and that is just variations in people.

Patricia: *Yeah, it would be interesting to try and do that.*

Shantel: Although most of your students must be … must have a certain amount of aptitude.

Patricia: *Yeah, like to me, I guess, it just always seems so simple that I thought bringing some weights into class would be a waste of time.*

Diana: So Patricia, where do you feel like we are at in the decoding? Do you feel like we have sort of circled back to the beginning? Do you want us to decode further, or where do you feel you are at?

Patricia: *No, that is… I would say that feels … that is pretty good. I certainly have some things that I could try out in the class now to bring out some awareness that I hadn't thought of before. I don't know if I could go much further.*

Diana: Well, maybe like Juan Carlos says it is something that given another couple of days, or given a week things will emerge as you are thinking about them and coming back to them again a second time.

Juan Carlos: What would you say are the things that you now think you are thinking about?

Patricia: *Well I hadn't really thought about the kinesthetic part of it at all really, or … or the visualization and I still … I don't think I… because we are always solving these things for one point in time and I don't think I actually visualize them as moving at all, but I think I have a sense that they can move maybe? So I have to think about that a little more. Yeah, and then just the part about having the experience to know that this is such a valuable step is really important.*

Juan Carlos: It would seem to me to be pretty … a pretty central part.

Patricia: *Yes, it is very valuable.*

Juan Carlos: It is also part of the possible bottleneck.

Diana: It was good – thank you Patricia! I am going to shut the camera off and maybe we can just spend a couple of minutes debriefing…

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