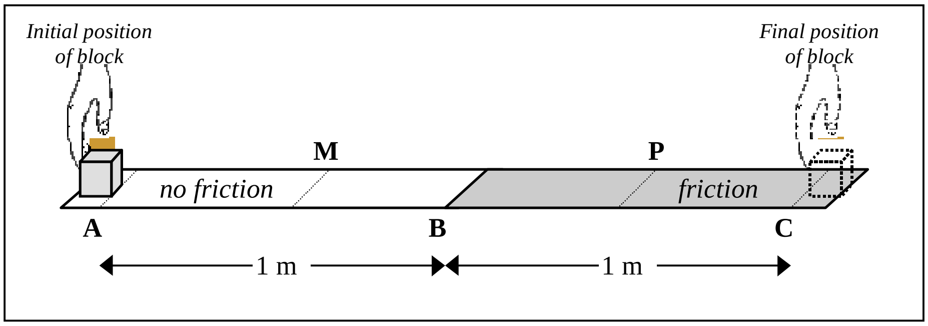
Appendix C: Full Interview Transcripts of the Interviews Used in the Dissertation: Advanced Students

Picture from the problem shown in Figure 5 – 1.



"Peter" (11/12/98)

(reads question)

a) (Draw a free body diagram)

P: So this point represents a block — this is the normal force — weight and [pause — looks back at question] [draws in a force to the right and a force to the left labeled friction] … *this is 2 N* [writes 2N on the force to the right] — *do I have to draw it to scale? I guess this is — it probably travels at a constant velocity — right? F equals F. F big equals F small amplitude.*

I: How did you know it travels at constant velocity?

P: Umm — actually I don't — there is no indication that it travels — it might be having some acceleration — there is not enough information so — it is not necessarily —

I: You are told that the block starts at rest at point A and the force of the hand remains constant — and it comes to rest at point C.

P: Okay.

I: And the hand applies that force throughout the whole time.

P: … what is the question?

I: Calculate the coefficient of kinetic friction.

P: So — … So we have to write out in components the NII law which would be — x component is — F minus F of kinetic friction equals the acceleration which is going to be negative because my x axis is to the right — so [draws an axis labeled +x to the right] — *since the object comes to rest moving from B to C the acceleration is in the negative x direction although the sign of the acceleration will — eventually determined at the end —*

I: … Before you were saying the acceleration was zero —

P: No — you're right — because since … you pointed out that the force was acting throughout the motion. So since there is no motion in y component the normal force … is balanced by weight which is N equals mg — so we can write F minus μ_k *N equals minus ma — so we have to find a now and — we are going to do it in the following way — I guess — So we are going to find the velocity at point B — this will be* $v_o + v$ *squared will be equal to* v_o *squared plus 2a′ times the distance of AB times 1 meter where a′ is force over mass — since the force — since the only force acting on the segment of the distance from A to B is F equals to 2 Newtons — so we have 2 Newtons over 1 kilogram — so we have 2 Newtons per kilogram and we can find* v_o *— it's zero — it starts from rest. … So therefore* v_B *squared is 4 … So — and then find a … we have — we can use the same formula — it will be — if v is zero minus* v_B *squared over 2 times 1 meter — so it will be minus 4 over 2 — which is the same acceleration — but opposite sign … and now we can plug it back into this equation* [points to $F - \mu_k N = —ma$] *for the force and the coefficient of friction and so we have 2 Newtons — we are going to put numbers immediately — 2 minus* μ_k *will be equal to F plus ma over N —* μ_k *is 2 Newtons plus … I'm using here the absolute values of the acceleration over the 10 … so we are going to have 0.4.*

I: How does the net force at M compare to the net force at P?

P: Umm — the net force at P is smaller than at M — by the amount of the kinetic friction. The net force is smaller by this amount because — the y components of the two forces are canceled out. So the only difference — they will be cancelled out at point A too — and the only difference comes at point P because of the introduction of the force of friction, which is directed opposite to the applied force.

I: So can you draw me a vector for the net force at point P — how would that look?

P: It would look — almost caught me there — yeah the force of friction is bigger than the force — this is net force — since the acceleration is negative — so negative y direction — net force — according to the famous Newton's *second Law should … I'll put it here to support my statement — the net force should be in the same direction as acceleration —*

I: Same direction as acceleration — so this is the net force at P — how about at M?

P: It would be to the right because this is the only force — we have no friction here so this is P and this is M — without scale — this is 2 Newtons — this is the difference between 2 Newtons and force of friction — .4 times N which is 4 — actually it is 2 Newtons also —

I: So how does the magnitude of this guy [points to the net force at P] compare to this [points to the net force at M]*?*

P: The same — … μ_k *is .4 — coefficient of friction is .4 and N is 10 and that is why we saw that the acceleration between A and B is positive 2 meters per second and the acceleration from B to C is negative 2. So far we did not find any discrepancies from Newton's second Law.*

I: Before you were saying that the net force at P was less because friction opposed —

P: It is not necessarily that — I had the impulse to say that the force was pointing to the right because I accidentally assumed 2 Newtons minus the frictional force would be still positive but I reversed the statement.

"Granola" (11/12/98)

(reads question)

a) Draw a free body diagram for the block when it is at "P."

G: Okay when it is a P — free-body diagram represented as a point mass — there will be a Normal force — no— a force of gravity acting down on the block — there will be a normal force acting up — there will be the force of the hand pushing it to the right — and there will be a force due to friction pushing the opposite direction — because it's in P which is the part with friction — I'm assuming — so four forces.

b) Calculate the coefficient of kinetic friction μ.

G: … Alright — 1 kilogram — what's it moving — okay 2 Newtons — okay — you start at B so it's moving at point B — there will be 2 Newtons, normal, gravity and then the final position — does it come to rest? Ok it comes to rest at point C. So at point C it comes to rest which means that at point C the force of the hand.

I: So this is a free body diagram [I point to the new free body diagram that has no friction force].

G: — at B — then that is what is between B and C and then over here — free body diagram here would be this and the hand and friction would be the same — because it is at rest — and these will be the same. So what is it?

I: If I compare the hand and the friction here— how do they compare?

G: At P? The hand should be greater because it is still moving because it goes from B to C and it comes to rest at C. Trying to think what friction is — friction is — the coefficient of friction is force equal to force gravity — I forget which one it is —

I: That is actually the normal.

G: — normal right — they are almost always the same — right? The normal and gravity?

I: It depends.

G: … so the force of the friction is equal to some coefficient of the normal force which will be 9.8 Newtons … —

I: What is 9.8 Newtons?

G: 1 kilogram block — The force Normal should be 9.8 down so that is going to be 9.8 up and force of friction would have to be 2 Newtons — that's 9.8 so 2 over 9.8 equals μ. I'm all confused — maybe I'm sicker than I thought. I feel retarded now — that happens often. … Something is not right —

I: … why don't you like it?

G: I don't know — there should be the force of the hand in there somewhere —

I: What is that 2 Newtons [points to 2 N in the equation Granola has just written]*?*

G: That is the force of the hand — oh when that equals — we want to find when this is equal — oh no — that's not right at all — this is the problem here — that is what it looks like over here [points to point C on the diagram] —

I: Right at point C?

G: Yeah. So wait maybe that should be right. [pause] *That's not right at all — … it doesn't seem right to me — just give me a second — I just started to solve it assuming it would be easy — then realized maybe it wasn't as easy as I thought. Could also do the work — the work from here* [points to point A] *to there* [points to point B] *— no that's got nothing to do with it — no — friction — 2 Newtons — the force of the hand remains constant — because according to this — this wouldn't be stopped there — it would stop there if this were the case — … if this were the case if it was 9.8 Newtons and 2 Newtons because that is the same circumstance that we have at B — so it would stop at B the way I have it set up — why would it stop at C? There is something about the 1 meter that I'm not getting — I'm not thinking very well. There has to be something to do with … the velocity — with the hand force I'm thinking — so I think — there is something to do with friction apparently — I've never done friction —* [pause] *I don't know — do you want to come back to this one.*

I: … [I give him the long version] *— This is the same thing but it has parts … — You did part A already so how about part B.*

b) Is the magnitude of the net force acting on the block at "M" greater than, less than, or equal to the magnitude of the net force acting at "P"? Explain your reasoning.

G: … well these cancel at M so it would just be like that so the net force would be like that at M [draws vector to the right] *— at P there should be the same normal and gravitational force should be the same because it is not moving up or down. But this should be less* [draws smaller net force vector to the right] *because it will be decreased by the … frictional force.*

c. i. Draw a vector representing the acceleration of the block at "P." If the acceleration is zero state that explicitly.

G: There is a force on it — there is a net force on it so it should be accelerating — I'm guessing …

I: How did you know it was to the right?

G: The greatest friction could be — friction can't push something backwards so friction can keep something at rest but it can't push something backwards — less than or equal to — it is a less than or equal to force — yeah — I don't know — … I've never known something to move backwards because of friction.

c. ii. Does the magnitude of the acceleration increase, decrease, or remain the same as the block moves from "B" to "C"? Explain.

G: It decreases — the acceleration — because the force decreases —

I: Which force decreases?

G: The net force … — it should — at some point the net force has to be equal to zero — the net force has to be equal to zero.

I: Why is that?

G: Because the hand and the frictional force will cancel out because it says it is at rest at point C … So decreases — cause …

d. Calculate the coefficient of kinetic friction μ.

G: I think it is the same problem — I'm drawing a complete blank here.

I: What is Newton's Second Law … ?

G: The second law?

I: The sum of the forces —

G: The sum of the forces is equal to zero for a body at rest. — I don't know the second law.

I: What is happening to the velocity as the block goes from B to C?

G: It is decreasing — wait — oh no — the velocity here [points to point A] *is going to be — whatever — 2 N over 1 meter —*

I: … Why is that the velocity?

G: No — you can get the velocity — what is it v squared over … d —

I: Equals 2 a.

G: Yeah so v squared will be 2 a d so 2 Newtons over the mass which is 1 kilogram — … something like that — … velocity at B — the velocity at C — at C the velocity is zero because it is not moving. What is the question?

I: Calculate μ_k.

G: Okay — it goes from root 2 meters per second to 0 meters per second — … so if there was a constant acceleration from B to C it would look like . . . so it would have the same acceleration here [points in region between B and A] *as it did before — that's not the case —*

I: How do you know that is not the case?

G: Because it has the frictional force acting backwards so can't use that.

I: Newton's second law is sum of the forces equals mass times acceleration.

G: Ok —

I: … Does that come into play here?

G: … Sum of the forces equals mass times acceleration — so the acceleration — oh — … this acceleration would be [pause] *this acceleration has to be the same as this one — if it goes from 0 to 2 — 0 to whatever here* [points to region from A to B] *and then goes from here to there* [points in region from B to C] *in the same distance — same force —*

I: … that's different then what you said before — right?

G: Before I said it couldn't be the same.

I: Now you are saying the same force?

G: No — I guess — I guess it has to have the same net acceleration — if it goes from 0 to root 2 — or 0 to v here and then goes from v to zero that way — it should have the same acceleration going this direction — except the acceleration would be in the opposite direction — so —

I: So you're saying the acceleration would be this way now [gestures to the left] *in this region* [points at BC region]*?*

G: Yes — in this region — … It is different then what I said over here — I said this coefficient of friction would be less than since it was still moving to the right — I'm really confused — I'm confusing myself — that was over here actually.

I: — and here for part C when you were drawing the acceleration.

G: Yeah — it's not accelerating at all in that direction —

I: How do you know it is not accelerating in that direction?

G: It would still be moving at this point [points to point C] *if it were accelerating in that direction — it would be moving faster in here then it was before — that was dumb — not dumb but … so now we got it going backwards because it goes from v to 0 — the change in velocity is acceleration — all that — so sum of the forces — mass times acceleration — I guess this acceleration* [points to region BC] *has to be equal to the acceleration here* [points to region AB] *which is 2 Newtons —*

I: How did you know that?

G: It goes from zero to velocity and then from the same velocity to zero — this force — this acceleration has to be the same as it is up there — it's the same mass — same mass — same acceleration — it should be the same force as it is up here — which is the same as —

I: … Is it always true that if I go from 0 to a certain velocity — I'll have a certain acceleration — and maybe I'm driving my car the next day and I go again from 0 to that same velocity — is my acceleration always the same?

G: No — not necessarily — it could be — I guess it would be — something like the same average acceleration — not average — net acceleration — if you didn't know anything about in between rest point and going fifty miles an hour or whatever and you didn't know anything about those two and you did it in the same amount of time — … you could — if you didn't know anything else about in—between you could guess that it was constant acceleration — but you could speed up and slow down — and speed up and slow down — I don't know

— I'm trying to think if that has to do with anything here. This is actually one of the first times I've actually had to solve a problem with friction — if that helps at all. There is a story behind it.

I: … I'd like to hear it — maybe after —

G: … So now go back over here — this — the force friction is equal — to μ times the force normal and this force of friction we got was equal to — this acceleration is the same as the acceleration from A to B which was 2 Newtons over —… this force was equal to 2N and … meters per second squared is the acceleration and we got that multiplied by the kilograms so that is 1 Newton — I guess — I think — same kilogram — oh that's 2 — 2 meters per second — so the acceleration is 2 Newtons backwards — is the force normal — no — is the force friction —

I: The force of friction is 2N backwards?

G: 2 Newtons … — I said the acceleration has to be the same if it was constant — the acceleration had to be the same from here [points to point A] *to here* [points to point C] *— because the velocities — so we have 2 meters per second squared is the acceleration — it's the same mass so we have 2 Newtons is the force of friction — and the force normal is equal to 1 kilogram times gravitation, 9.8 meters per second squared so I got the same thing as I had before. Umm — … same as before which is 2 N divided by 9.8 N — but still it doesn't seem —*

I: You're not happy with it?

G: I don't know. I guess that's right.

I: So here you have a free body diagram at P — so you are saying the force of friction is — can you put numbers on all of these [points to the forces on free body diagram.]

G: Yeah — before I had it increasing because I was initially thinking of friction being velocity dependent because — it always shows up in differential equations as a velocity ... dependent thing — … here it's not really velocity dependent — it's just sort of a constant frictional force — so yeah — there should be — that's not right either — because — no — yeah — … there is an initial velocity at B so — but then again there is no force so it should just keep moving — so this has to be — 4 Newtons …

I: How did you know it had to be 4 Newtons?

G: Because it had to be 2 Newtons backwards.

I: What had to be 2 N backwards?

G: The force of friction in order to get it to stop ... the net force — the net force was 2 Newtons in order to get a net acceleration acting backwards to get the velocity to go from 0 to v and we want it to go from v to 0 so we had some acceleration here — make a backwards arrow and we had to have the same acceleration there in order to get that same acceleration — we had to have a greater net force in the opposite direction. So now I've got μ equals 4 N over 9.8 — … that sounds better.

"Erica" (11/12/98)

(reads problem)

a) Draw a free body diagram for the block when it is at "P."

E: … At P we have the friction and there's the hand so — this is the block and the hand is pushing it this way — and we have — this is the hand and this is mg and the friction is this way — …

b) Calculate the coefficient of kinetic friction μ.

E: Okay — so friction equals μN — friction equals μ kinetic N and this is the force of the hand — and we would like to sum the forces in the x direction — so the force of the hand is 2 Newtons — so 2 Newtons equals Normal μ kinetic …

I: How did you know that?

E: Because — You need to sum all the forces in the x direction — and if you sum them you just write 2 N minus F friction equals zero — sum of the forces in the x direction equals force of hand minus force of friction , equals — wait — is it moving? … no — but it's not accelerating … it's constant force so it's equal zero. Okay — so force normal is just — it's force normal that the table is providing so it's equal to mg — so that's mg — so μ_k *equals 2 divided by mg — and mass is 1 kilogram — that's 2 divided by 9.8 which is about 0.2 — Newtons divided by …*

I: How does this force [friction] *compare to that force* [hand]*?*

E: Well if it's still moving forward then this [points to force of hand] *is bigger then this* [points to friction force] *— it's not enough to stop it.*

I: … What can you tell me about the velocity as it goes from point B to C?

E: The velocity?

I: Velocity of the block —

E: Well the force is constant so — acceleration is constant — yeah — velocity is increasing.

I: So the velocity is increasing from B to C?

E: I'm not sure. Let me think —I think it's the same —

I: You think the velocity is the same?

E: But then you won't have acceleration. Umm — acceleration is constant so velocity is increasing …

I: So what happens at point C?

E: It stops — zero — velocity equals zero — ... Oh — I see what your saying — but that is because the force is not acting anymore — the hand is not pushing anymore —

I: The hand acts all the way to point C.

E: Oh — so it just stops at point C — for no reason? — …

I: The force of the hand is remaining constant from point A to point C.

E: Then if there is no impediment there then friction is greater than the hand pushing it.

I: How did you know that? How did you know friction was greater?

E: How? Because the force of the hand is the same — so friction must have dominated that.

I: How did you know it dominated?

E: Because it came to a stop —

I: Before you said this force [points to force of hand] *was greater than the force of friction.*

E: Cause it was moving that way … — The coefficient must have been — No — Not the coefficient — I don't know — if the force of the hand is the same then the friction must have been different. No? (IA) maybe it's not zero — maybe it's not zero — I'm not sure. What if it's not — Hold on. (IA)

I: So why were you saying this was zero before?

E: It's not right. It's in equilibrium — this is — why was I saying zero? I don't know. — let me see if I can solve it. … — (IA) this velocity here [points to point C] *is zero. The velocity here* [points to A] *is zero — so v initial and v final are* *both zero.* [Pause] *(IA)* … [Pause] … *The velocity of the block from A to B is different from the velocity of the block from B to C? …*

I: What do you mean the velocity?

E: The speed?

I: So if I look from A to B — what's happening to the velocity?

E: It's the same.

I: What do you mean it's the same? It's the same throughout?

E: It's starting from zero and increasing —

I: And where does it start decreasing?

E: At B — so from v_o *to B it's a certain velocity and from B to C again it's zero — at C it's zero — right? So we are going from zero to some number then from that number to zero— right?*

I: Is that the way it would work out?

E: … Starts from rest and then moves on frictionless from A to B and then on friction from B to C — it has to be slower from B to C — then from A to B. Right? But — … if the force is constant — is this a simple problem or am I making it difficult? …

I: What if I asked you to compare the net force at point M to the net force at point P?

E: You mean the summation of forces?

I: Yeah.

E: It's equal to ma.

I: Okay.

E: And if they are equal to ma — is a the same? Is it the same or different?

I: Good question.

E: Umm — I have no idea — no but — here [points to point M] *you have just the hand — here* [points to point P] *you have the hand minus friction — so* *here the hand force equals ma and here force hand minus force of friction equals ma. Okay — we can't equal them because that would make no sense.*

I: How come …?

E: Because then friction would be zero. Right? If I equal this [F_h = ma] *and this* [F_h - F_f = ma] *then I would say F of friction equals zero. — It's not zero here* [points to point P]. *Therefore we can't say a is the same over here and here.*

I: What if I asked you about the change in kinetic energy from A to B compared to the change in kinetic energy from B to C?

E: This would be — it's the same — it would go from zero to something and this would go to zero. Give me a hint.

I: Does that help in any way?

E: … okay — … I already said that it is the same velocity here [points to B] *— I already said that.*

I: What if I asked you about the net work done on the block in going from A to B compared to the net work for going from B to C?

E: The work?

I: Yeah — the net work.

E: Work is equal to force times velocity

I: Distance.

E: Oh — right — … force times distance — it's the same.

I: How did you know?

E: Because the force is constant and the distance is the same.

I: So which force are you considering when you are thinking about the work?

E: Ooh — the summation of forces ... — you have to do that — so here it is just 2 Newtons times the distance, 1 meter, and here it is just this minus force times 1 meter but these two are not equal. And the work must be different.

I: Do you know how the work done on something relates to the change in kinetic energy?

E: I forgot — Wait — Oh god — Change in kinetic energy and the work — work … [silence] …

[Erica compares the dimensions of work and energy at this point.]

E: (IA) … There're the same — oh — they are the same dimensions — so — change in work must equal change in kinetic energy —

I: Yeah — work equals change in kinetic energy.

E: So — … Kinetic energy is — so for this — so it's like equaling these two together —

I: But you tried that before and you didn't like that.

E: It's saying that this [points to F_h = ma] *is equal to this* [points to F_h - F_f = ma] *— but — if I equal this to this then friction equals zero. What does that mean? Is it zero here* [points to M]*? It is zero here* [points to point M] *but not here* [points to point P]. *So — Okay what am I doing wrong?*

I: Can you draw me an acceleration vector at point M?

E: Acceleration?

I: Draw me an acceleration vector at point M and if it is equal to zero state that explicitly.

E: How can it be zero — if we start with v_o to v final? … Well v is increasing so acceleration is constant — if v is increasing then acceleration is constant. Right? Or — it doesn't have to be. Like that [draws vector to the right labeled a] —

I: Okay — how about at point P?

E: Oh it has two components — it has this one and this one [draws two vectors pointing in opposite directions on x axis] *— and this one* [pointing right] *is bigger.*

I: How did you know the right one as bigger?

E: Because it's moving. — Still moving forward … — but it's decelerating. ... It's slowing down — velocity is zero here [points to point C]. *But velocity is decreasing — velocity is decreasing — if velocity is increasing can a be constant?*

I: … What is the definition of acceleration?

E: delta v over delta t — so t is increasing and v is increasing — can a be constant?

I: What do you think?

E: Yeah? — Can it? It can or it can't?

I: If I go at a constant acceleration what happens?

E: … You're increasing velocity … — If you are constantly accelerating you are constantly increasing velocity. No? Right?

I: What do these deltas mean?

E: Change in —

I: So when you say dv over dt what does that mean?

E: v final minus v initial over t final minus t initial —

[At this point we stray from the problem and talk about the concept of acceleration for the remainder of the interview. The remainder of the interview is not included in this thesis.]

"Eagle" (11/18/98)

(reads question)

a) Draw a free body diagram for the block when it is at "P."

E: So — I see there is no given friction force — so … I'm drawing the block or something that looks like it. So these are the 2 Newtons coming from the hand — Now — of course — I suppose it is useless but this is the weight and the normal force and the resulting friction force — since we are on the part of the surface with friction —

b) Calculate the coefficient of kinetic friction μ.

E: Let's see— the block travels an equal distance (IA) with the force remaining constant — Let's see — (IA) — let me think — does it say anything about the speed — it doesn't — oh okay I see — I suppose the forces being applied until the end of the trajectory and the block stops due to the friction and not that the hand stops.

I: The hand keeps applying from A to C.

E: Okay — So I'm going to calculate the kinetic energy that the block has until point B —

I: How come you're doing that?

E: To find out what the total — what the energy it loses on the friction surface is — which should tell me —yes of course — what the force acting against it was. So that is going to be 2 Newtons times 1 meter, which is 1 Joule and that is equal to ½ m v squared — … v being the velocity of the block — and that is exactly what it is going to lose which means the force — the friction force should be equal to 4 Newtons in the other direction — meaning … in the direction C to A, or to the left — So that the net force being applied on the block is 2 Newtons in the other direction so that the loss of energy is equal to the gain of energy in the first half of the trajectory.

I: How did you know the loss in energy was the same as the gain in energy?

E: Because it started at rest and it ends at rest — I suppose. I assume that is what it means when it travels an equal distance — … [Rereads part of the question.] So the force is 4 Newtons, which is equal to the magnitude of the normal force times μ — the kinetic friction coefficient— … so the normal force *is equal to the weight of the block which is 1 kilogram times 9.8 so — μ is equal to 4 over 9.8 which is about .4.*

I: … Can you compare the magnitude of the net force at M to the net for at P — how would they compare?

E: The magnitude of the net forces? — well they should be equal and opposite —

I: And how did you know that?

E: By the same argument — because I assume that the force due to friction — which is constant along the whole surface since the weight of the block doesn't change — I assumed that it was equal and opposite to the force — I'm sorry — I mean the sum of the force being applied by the hand and the friction should be totally equal and opposite to just the force applied by the hand on the block so that the loss of energy is equal along the same distance traveled — so they will be equal and opposite.