Gesture with Interactive Computer Simulations

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Abstract

This paper explores student gesture while using interactive, animated computer simulations. First I will carefully analyze the rate and type of gesture used with the Nuclear Physics simulation created by the Physics Education Technology Project. This analysis can be viewed with two lenses. The first being simulation use as an extension of gesture. The other is to evaluate through gesture, how the simulations are used to support student understanding. This paper is simply a taste of what can be understood through analysis of gesture. Future work is identified.

I. Introduction

The use of gesture has been carefully studied with student's scientific talk. Researchers have found that the students' gestures change in several ways while explaining a topic they "understand" versus talking while constructing meaning. Gestures differ with the two types of talk temporally, in rate of gesture and in types of gesture used. More broadly, research, including the above, supports the claim that gesture is *necessary* for meaning construction.

Crowder (1996) found students' gesture less often and that their gestures coincide with the words they use while 'explaining their ideas'. In fact she goes as far as to describe this type of gesture as redundant. In contrast she describes the type of gesture used while students are constructing meaning as preceding verbalization or even providing information their words do

not convey. Additionally, the rate of this type of gesture is also higher. Another difference Crowder found with the two types of talk are what she describes as inside and outside gestures. The students, who are constructing understanding, step inside of the gesture space indicating they are using the gestures for their own understanding rather than as a communication tool. This can be observed by watching a student's eyes. When explaining a topic they understand, students look at the audience and not at their hands.

Roth and Welzel (2001) observed similar behaviors with their German students during scientific talk. There studies were slightly different in that they studied the students while doing hands on activities. They classified manipulation of the objects as part of gesture. Their observations brought them to three conclusions: (1) Students use gesture to take the place of words that they are unfamiliar with. (2) Gesture provides the necessary glue for students to construct complete conceptual understanding. (3) They found changes in type, rate and timing of gesture as students became more comfortable with their explanations. Both (1) and (3) are consistent with Crowder's work described above. The second conclusion adds an additional dimension in part due to the use of objects. Roth and Welzel found that gesture and the objects were necessary items for the students to construct understanding. In order to understand the scientific topics at hand students are required to layer conceptual understanding onto the phenomena they observed in lab. Roth and Welzel state that there are more representational layers possible when objects or gesture can be used during speech. Without the use of gesture or objects the demands on memory capacity would be tremendous.

In support of Roth and Welzel's hypothesis that gesture and objects allow the students to construct meaning are studies done such as those by Glenberg and Robertson (1999), Rime, Schiaratura, Hupet and Ghysselinckx (1984) and Alibali, Kita, Bigelow, Wolfman and Klein

(2001). Rime et al and Alibali et al both did studies with gesture and spatial information. Rime et al found adults' descriptions contained a greater degree of imagery when they were allowed to gesture than when their appendages were restricted. Alibali et al studied children's descriptions and found more perceptual-based explanation when they were allowed to gesture than when they weren't. Even closer related to Roth and Welzel's claims, Glenberg and Robertson argue indexing, that is, linking words and phrases to real-world objects , is required for comprehension. They studied adults attempting to follow directions. Some were given directions while seeing a compass and watching an actor's hand point to the compass's arrows and turn its dial at the appropriate moments. Others simply heard the directions. The adults who were given the visual cues had a much deeper and more usable understanding of the directions than those who simply heard the verbal transcript.

In order to understand students' sense making while using simulations, it is necessary to study students' gesture while using the simulations. In this paper I study two roles of gesture with simulations. First I will look at the rate and type of gesture used while exploring simulations and second I will observe students' gestures while describing a phenomena related to the simulations and evaluate, through gesture, how the simulation can be used in their descriptions.

To answer the above questions think-aloud style interviews were conducted with students while using simulations that are part of the Physics Education Technology Project (PhET)[1]. These simulations are of a highly interactive, animated nature. Thirteen different students were interviewed about various simulations. The students consisted of volunteers from introductory physics courses at the University of Colorado, Boulder. There were six students from a first

[1] http://www.colorado.edu/physics/phet

semester non-science majors course, four from the second semester of the non-science majors course and three student's who were taking the second semester of algebra based introductory physics. All students exhibited the same general trends in gesture while playing with the simulations.

II. Rate of Gesture during simulation interviews

While using these simulations students predominantly use the mouse, watch the simulation and gesture sparingly. The mouse becomes an extension of their hand and is continuously used to change parameters or move objects on the screen. It's also used to point or show motion on the screen in conjunction with student's verbalization. In the extreme cases students do not gesture at all while using the simulation or others may gesture with an average rate of one gesture every 15 seconds. The highest rate observed is still much lower than during typical speech or science talk and was punctuated with intervals up to two minutes where the student relied solely on mouse movements to supplement her speech.

The following examples were taken from a set of interviews with a simulation called Nuclear Physics[2]. This simulation has three panels that can be explored demonstrating alpha decay, nuclear fission and chain reactions. Some of the students had already seen the simulation used in class, others had never seen it before nor had any instruction on the topic. The use of gesture by these two categories of students was comparable once the students stopped trying to explain what they remembered and began playing with the simulation in earnest.

Gordon, a rather talented second semester non-science major, used three gestures during a 30 minute interview (Figure 1). When words were not adequate, he reached for the mouse.

[2] http://www.colorado.edu/physics/phet/simulations/nuclearphysics/nukes.jnlp

This is a student who's gestures are never grand; however, while explaining his major and employment he gestured 23 times in two minutes. Granted this is not the same type of science talk; however, it was in the same setting with the same interviewer in an interview that occurred before the above mentioned interview with simulations.

Time	Gesture	Statement	Commentary
0:10			Began Nukes
3:15	right hand flitters (darts) up and out	"they're not just standing still, they have to be moving. Then when they get shot out, they just go"	On the Alpha Decay Page
23:55	Hands sitting on legs. Right hand lifted slightly off leg on 'looks', 'amount' and barely on 'random'.	"it could could easily just explain this. It looks to me like there's no actual like set amount you need to have to get like a certain percentage or whatever it's just kinda random"	While on the Chain Reaction Page
24:19:00	hand poised above mouse, rolls wrist to the right on probability and a little further on half.	"for there to be like a good enough probability to get like half or more of them hit"	While on the Chain Reaction Page
32:30:00			Switched to Semi Conductors

Figure 1: Complete transcript of Gordon's use of gesture while spending 30 minutes using the Nuclear Physics simulation.

Serena, a B- student from the algebra based physics course, happily had no instruction on nuclear physics. She spent more time with the simulation than the other students, approximately 40 minutes, while constructing her understanding of what the simulation was demonstrating[3], she gestured at a higher rate than the other students studied. During an eleven minute segment,

[3] Serena did construct a nearly complete understanding of the Nuclear Physics simulation during the interview by simply playing with the simulation, talking and being asked only a couple of probing questions by the interviewer. No instruction was given and Serena's questions were not answered by the interviewer.

Serena gestured 40 times while using the simulation (Figure 2). This included briefs periods of time where she answered related questions by the interviewer that could not be answered directly by the simulation. During these episodes, Serena gestured continuously without any discernable break until she'd finished answering the question.

Time	Gesture	Statement	Commentary
17:10			Starts talking about Nukes While Serena thinks about things she asks herself questions and then answers with "I don't know" "I can't figure out this computer program" "I don't really know!". While doing these things she does not move the mouse or gesture. Maybe plays with her hair or shirt. Once she gets a piece of information she pionts with the mouse or gestures.
17:33	points at legend on screen touches side of computer	"That's a proton"	
17:45	Left hand open up moves to the left.	"Biology perspective"	
18:08	Right hand opens towards screen fingers straight. Bounces again on farther away it gets	"Energy is decreasing the farther away it gets."	
18:24	Fingers open up fingers close together then open both hands	"Break atom? Release energy"	
18:39	Right hand waves to right	"That's fine just thinking outloud"	
19:16	points at nucleus as neutron enters then at potential energy curve and then at daughter as it moves off the screen	"So when a neutron enters it the potential energy increases and it splits"	
20:06	Right hand barely open beats twice as moves right (indicating two words)	"It says chain reaction"	

20:08	holds right hand spread out to screen and pulls back and brings fingers in a fist Three times spaced apart by a second or so as she asks	"so what was that burst of light right there? Was that energy? Was that energy…"	
20:16	hands move apart with index fingers pointing	"when the two particles separated"	
21:00	Right hand lifts off the mouse and waves over shoulder to right with arm resting on table.	"maybe this is a chain reaction when…"	Sense making
21:05	points at screen three times puts hand down then up and points again beats twice	"Can't remember what these stand for because I haven't had chemistry in awhile I think this is one of the elements"	
21:29	folds hands together then beats down	" I don't remember for sure Maybe it's a half life.."	Asked what makes it radioactive
21:38	Hands open facing each other and apart as talk move in and back out. Then on half slaps together and apart and almost together and sweeps right hand towards her across palm of left without touching them.	"It just means that umm as time goes on it's going to decrease by half and then keep decaying but it'll never be gone"	These gestures were in response to interviewers questions and she's drawing on previous knowledge
21:55	puts middle fingers to thumbs like holding something and brings them together and apart and then just the right hand this way and then sets them down.	"it's always going to be there. I think that's still radioactive it's usually what they're talking about right?"	
22:03	points at the screen	"It is like this element. This chemical they have here like, what is that ura uranium?"	
22:30-23:02	hand, plam up, fingers out, in front of her Whole serious of hand waving as she explains rockey flats. Never stops moving them.	"like Rocky flats"	
24:55:00	Hand is poised above the mouse then rotates up and to the right.	"releases energy" (pause opens hand) "potential energy I guess."	
25:30:00	Points at nucleus and then follows daughter	"Nuetron is fired at it it breaks apart and releases energy"	

25:40:00	rotates open right hand up and out to right	"it looks like"
25:50:00	points again at potential energy curve and then to right along curve.	"And it looks like looks like that particle that is split apart goes away from the nucleuses center."
26:08:00	points at PE curve and moves finger along and to the right	"So, so that should I think that should show you that the potentail energy is decreasing the further away it gets from the nucleuses center."
26:50:00	points vaguely at the screen and beats on that, maybe and neutron	"So I'm thinking that maybe when the nuetron hit the uh.."
26:53:00	points at legend on right beats with a little circle on uranium	"that particle uh uranium"
27:00:00	points at a spot on the screen and then back to the mouse	"it causes a chain reaction it says"
27:05:00	points at neutron and follows off the screen	"Maybe these two particles that split off"
27:08:00	hands loosely open facing up moving in and out together.	"Hit other particles and keep releasing more and more energy"
27:12:00	hands flow out and around down	"or the radiation"
27:15:00	hands in and out. Left out then fold	"maybe that's what causes what causes decay"
27:41:00	points at each U238	"1, 2, 3, 4 5, 6 six on the screen"
27:04:00	lift hand off leg and rolls out to left	"then they split"
27;50	points loosely at the nuetron coming in.	"I think that … the neutron I keep firing"
28:01:00	open curved right hand pointing towards the screen and beat on 'something'	"always going to hit something"
28:10:00	open hands waving together and apart	"because all these particles are gonna be really close together and there's gonna be a lot more of them so it'll cause more a a bigger chain reaction than I'm seeing here."
28:01:00	hands together	"particles really close together"

28:06:00	hands come together then pull apart	"bigger chain reaction than what I'm seeing here"	
28:25:00	points at a daughter that moves off the screen	"passed right by it"	
28:29:00	points at one particle and then another	"when this particle broke off it didn't hit this one and cause it to break off as well"	
37:18:00	hands fly around indicating activity	"maybe that's what causes the decay, all that radioactivity"	
41:29:00	hands forming ball	one whole nucleus	
51:15:00			Finishes with Nukes

Figure 2: Transcript of an eleven minute excerpt from Serena's use of gesture while using the Nuclear Physics simulation for 40 minutes.

Sally and Larissa were both from the same second semester non-science majors course as Gordon. They gestured in a similar fashion to one another. Larissa is a stronger student than Sally in many ways. Sally gestured eight times during the first ten minute interval of the 28 minutes that she explored the Nuclear Physics simulation (Figure 3). Similarly Larissa gestured ten times during the first 13 minutes of the 17 that she needed to thoroughly explore the same simulation (Figure 4).

Time	**Gesture**	**Statement**	**Commentary**
0:00:00			Sally actually began nukes a few minutes before the video started.
1:00	left hand opens and moves to right at the same time	"pushed away"	Sally is trying to explain what the graph is representing
1:08	hand forms hitch hike emblem and moves to left with thumb leading	"so increase"	HAND PRECEEDED VERBAL

1:11	hand forms hitch hike emblem and moves to left with thumb leading on sucked away then sits stationary	"but if it's an electron it's being sucked there. So it'll decrease as it gets closer"	
7:00	hands together and then apart	"splitting things apart whereas fusion was crushing them together"	
7:27	hands around making a circle held until statement complete	"whole containing all the same amount of protons and neutrons"	
8:25	right hand barley off mouse fingers curled together and open up as wrist rolls out to right	"broken apart"	
10:10-10:30	Small beat gestures	explaining what radiation is trying to remember	
10:50	rigth wrist rolls hand out to right then fingers seem to grasp and pick out particles.	"waves coming off the explosion. The actual air moving around it the particles"	
29:00:00			Switched to Semi Conductors

Figure 3: Transcript of a ten minute excerpt from Sally's use of gesture while using the Nuclear Physics simulation for 28 minutes.

Time	**Gesture**	**Statement**	**Commentary**
1:30			Starts sim on Alpha Decay panel Larissa confidently explains what will happen using the mouse to show it while waiting but nothing is happening. Eyes on sim.
5:07	hands start together and then move out she begins her comment hands clasp on 'fuse together' then pull apart on 'fiss' clap then pull apart and back on 'fissioned'	"Wait, fusion is fusing together fiss fissioned" chuckles "apart" chuckles	
5:20	right hand curves up	potential energy curve starts	

6:14	hands together, folded at knuckles, then hands spray out 4 times to denote energy	Because it's fissi fissioning together part of the energy is going to have to be set out to once it tunnels out.	either mismatch with fission or showing energy going out before she describes it.
8:40			Moves to Fission Panel
9:30	hands start together loosely curved, they move out quickly and then back together. Repeats this 5 times.	"creates two daughter nuclei that and other neutrons that go out and then they split and if it was the chain reaction one then it hits another one and another one and"	
14:46-15:10	Hands spray out twice with energy comes out of it. Then clasp together (fingers intertwine) on 'fuse' then fist into flat hand for neutron fuses. Flat hands facing and move forward and back opposite each others motion on 'get those two confused' Hands pause in mid air until gets to 'energy goes out' simultaneously hands start together and spray out twice. Then arms stretch out in front in circle on 'big huge' then swoops up 'comes back up'	"Just like the energy that comes out of it…" Like once the fuse once the neutron fuses to the I still get those two confused" chuckle "to the U235 it just um shows all the energy that comes out of it so it's kinda like when the nuclear bomb goes off there's like all that stuff that goes out and it comes back up from like the big huge all the energy that comes back up."	In answer to question "what is the yellow circle when a U235 fissions?"
16:10	points at bottom and then curved up like potential and then fingers intertwine on nuclear force	"The proton has to travel up here It has kinetic and then it becomes Electrostatic potential and then it starts to become internuclear force "	Did this because asked her to explain the graph
16:30	hands togther and then apart and then right hand curves up	"To get in there because there's a repelling force from the protons and it has to go and it has to has to have enough potential energy to get to where the nuclues is."	
17:15	fingers together then two hands start intertwined and then move up.	"this short little divit it won't take that much energy for it to get in there but if it has it has a bigger well it takes more energy to get in there."	

17:25	Hand flat up and down beats on overcome and repelling force	"over come that repelling force to get to the nuclear force"	
18:00	lifts slightly off mouse and beats twice	"anyways"	
18:33			Quit Nukes and Started Semi Conductors

Figure 4: Transcript of a thirteen minute excerpt from Larissa's use of gesture while using the Nuclear Physics simulation for 17 minutes.

As with the Nuclear Physics simulation, all of the interviews show a very low rate of gesture while students are using simulations. In fact, Nuclear Physics actually has a higher rate of gesture than most of the other simulations. One may argue that the mouse is inhibiting the students ability to gesture; however, I do not believe this is the case. Evidence for this opinion comes from a quick look at the transcripts which shows that the students are not gesturing with their left hand, which is free to move. Additionally, the students are extensively using the mouse to animate the simulation or point to objects or motions on the screen.

III. Type of Gesture during simulation interviews

In addition to the rate of gesture during simulation use being dramatically lower than in typical science talk settings, the type of gesture was also affected by the simulations. I have classified types of gesture using three categories as defined by Krauss, Chen and Gottesman (2000). Lexical, deictic and motor are as follows: Lexical is a broad category that includes objects or people in space, shapes of objects or people and smooth, continuous motions or a set of discrete movements that represent change over a series of steps. Deictic gestures always indicate objects or people such as pointing to where an object or person is or was. Finally motor gestures beat with the rhythmical pulsation of speech.

Gestures used by students while playing with the simulations are predominantly deictic in nature and are directed at the screen. I have identified three reasons for gesture that is not deictic in nature during the interviews with the simulations. First, when students are answering a question from the interviewer to clarify a term or concept that they had used, they look away from the simulation and use more traditional gesticulation. Second, when the student's metaphor for understanding differs from the visualization provided by the simulation. Finally when the student is unable to quickly cause the simulation to provide the visualization they need to support their speech. In this section I will look at both Larissa and Serena's type of gesture; however, the other students also fit into the scheme indicated above.

Larissa gestures very little. Near the beginning of the interview, 5:07, she uses a lexical gesture to help her describe what she thinks will happen. She is on the alpha decay page and at that moment the simulation has not yet emitted an alpha particle. She is trying to remember what she saw the simulation do during class and incorrectly defines alpha decay as fission. At 5:20 she follows the curve of the graph on the screen (Graphing addressed shortly). At 6:14 she gestures while describing fission again, even after watching the alpha decay occur on the screen[4]. The next time she gestures is over three minutes later at 9:30. Here she is describing chain reactions, again remembering what she's seen in class, while looking at the fission panel. Up to this point her gesture has been very limited and used when she's thinking about something the simulation is not showing her. During the next episode of gesticulation, 14:46-15:10, she is answering a question by the interviewer about the yellow circle that appears briefly around the nucleus at the instant it undergoes fission. This requires her to visualize a phenomena which the simulation merely represents as a yellow circle.

[4] Larissa, after watching fission in the fission panel around ten minutes into the interview, smoothly transitions into the correct descriptions of alpha decay and fission as if she'd been explaining them correctly the entire time.

The last series of gestures, 16:30-18:00, occur while she is describing the potential energy curve shown in the bottom half of the play area. There was also a gesture early on, 5:20, where she indicated the shape of the curve. Every student using the Nuclear Physics simulation, except Gordon, gestures in this way when describing the curve. During the interviews several students did not construct sufficient descriptions of the potential energy curve. After coding the interviews for gesture, I saw that all students, except Gordon, used many lexical gestures while answering the question, "what does the potential energy curve mean?". I interpret this as an indication that the simulation is not providing the animation necessary to convey understanding of the curve. In any case, it was clear that the potential energy graph is something the simulation did not adequately address for the students.

A course look at Serena, my high rate gesturer reveals that she predominantly points at the screen either indicating an object or motion that is occurring or has recently occurred on the screen. On occasion she uses a lexical type gesture to indicate an event that recently occurred such as fission of the nucleus. The only time she averts her gaze from the simulation and makes use of gestures that do not refer to or mimic the simulation, she is answering a question posed by the interviewer. For example at the time stamp 21:38 she has recently used the term radioactive and the interviewer asks her to define radioactive. In this case she looks away from the screen and for a little over 30 seconds does her best to define radioactive while gesturing continuously. She then looks to the simulation to help her with her definition, points to the screen and then takes up playing again.

By looking closely at lexical gesture I have stumbled across a very valuable aspect of coding gesture use with simulations. When students' gestures are not deictic in nature or mimicking the simulation, it's an indication that either the simulation cannot keep up with their

description or, more importantly, the students are drawing on other resources to understand or describe the concept at hand. This can be a very useful research tool for simulation design. When there is a point in a simulation that requires supplementary gesture, it is an indication for the developers that students must draw on other resources to explain or understand the concept.

IV. Two Lenses

I would like to analyze the above rate and type of gesture use with simulations using two lenses. The first being simulation use as an extension of gesture. The other is to evaluate through gesture, how the simulations are used to support student understanding.

With all of the students, their rate of gesture in the above analysis appears to be extremely low. I argue that this actually is not the case. To thoroughly analyze gesture when using simulations, I believe it may be useful, as Roth and Welzel did with objects, to include the use of the simulation as part of gesture. The mouse becomes an extension of the student's hand. Mouse movements combined with the animation of the simulation take the place of gesture. If one were to include the use of the simulation as gesture, the rate of gesture would be comparable to these students' rate of gesture while talking without simulations. Further support of this idea comes from instances where students resort to gesture, with their hands, in the case where it takes to much time to make the simulation animate their thoughts.

Another useful facet of gesture analysis is that one can see evidence that the simulations are supporting student understanding. After using the simulations, students' descriptions of various physical phenomena are supported by gestures that clearly mimic a simulation they have used in the past. A review of the interviews and conversations with the instructor of the non-science majors course reveal many examples of this occurring. To pull an example from the

above transcripts, Larissa mimics what she has seen happen in the Nuclear Physics simulation a few days before during a lecture demonstration. She uses gestures that match the visuals from the simulation to support her description of fission and chain reactions before she makes the simulation demonstrate either of these phenomena during the interview.

V. Future Work

In this paper I have only looked closely at the Nuclear Physics simulation. A quick look at interviews with the same students using different simulations has elicited some very tantalizing ideas about the potential analysis of simulations. One possibility would be to look closely at the other interviews to see if the rate of gesture correlates with the level of interactivity for all simulations. Another intriguing possibility is to follow the line of research sited at the beginning of this paper attempting to differentiate explanation of concepts versus constructing meaning during simulation use.

Preliminary analysis shows that the Nuclear Physics simulation elicits a slightly higher rate of gesture and type of gesture than many of the other simulations. I hypothesize that the nature of the Nuclear Physics simulation, it is animated however not as interactive as some, is the cause of this difference in gesture. There are fewer options for the student to choose; however, the major difference is that it takes from five seconds to two minutes to see the complete result of an option change. Many other simulations show an immediate change when an option is selected or an object in the play area is moved. This makes the predominant role of the student in the Nuclear Physics simulation that of setting up the simulation and watching what happens. I believe this elicits a greater number of gestures, most of which are deictic in nature, because it's

easier and faster for the user to gesture than to get the simulation to show the supporting visual to their verbalization.

A supporting example of this is seen in the gesture where both hands move apart to indicate the results of a nucleus undergoing fission. While on the fission panel, the simulation shows a single fission. If the user would like to see it again, they must reset and fire another neutron. In this case, while discussing what is happening the students use their hands rather than wait for a reset and new fission. If the student is on the Chain Reaction Panel and has the correct combination of nuclei, they may have the good fortune of watching many fission events over a period of at least a minute. While watching the chain reaction screen and talking about fission, students do not use the fission gesture described above during an event where the simulation is continually showing nuclei fission. Some students do point at the screen while explaining as this occurs because the chain reaction does not require user control.

A set of interviews with a slightly different use of the simulations appears to support this hypothesis as well. During these interviews, students were asked to think about all the simulations they'd used in the past and pick their favorites in two categories: 1) how much fun the simulation is to play with, and; 2) how useful the simulation is for understanding physics. Because of the slightly different situation, the level of interactivity and reaction time of the simulation stands out. Larissa, when explaining the various simulations she had previously used, even when the simulation was running in front of her, tended to describe the simulations using many lexical gestures rather than taking time to demonstrate the simulations' abilities with the simulation. However, when describing Springs and Masses, one of the most interactive simulations in the PhET suite, Larissa only used a couple of motor gestures with her left hand while quickly demonstrating her favorite features of the simulation with the mouse.

Tackling the second question, explanation of concepts versus meaning construction, will be a far greater challenge. A first step will be to use the interviews mentioned above where students are describing previously used simulations. It appears that a transition can be seen in these interviews from explanation to construction of meaning. During all of these interviews there comes a point where the student will be in the midst of quickly describing a simulation while playing a bit when they stumble across a feature or behavior of a simulation they can not adequately explain. When this happens their talk becomes slower and disjointed, their focus shifts from a combination of the interviewer and simulation to a solitary focus on the simulation, and their rate of gesture slows dramatically. I believe coding this set of interviews and carefully analyzing the results could possibly bear fruitful information on the very difficult problem of identifying sense making.

VI. Conclusion

Analysis of gesture while using interactive computer simulations can be a very powerful tool for analyzing both the simulations themselves and student understanding through simulations. This paper has shown a decrease in rate of gesture while using simulations and that students generally use deictic gesture while using the simulations. Instances where students use lexical forms of gesture are indicative of students drawing on prior knowledge or if the gesture mimics the simulation, the simulation is not quick enough in demonstrating the necessary animation. These observations support the notion that the simulations can be considered an extension of gesture. It also gives evidence that students use the simulations to support their understanding of concepts. I believe further analysis of gesture will provide many more useful

insights for the development of simulations. In addition it may provide a tool for identifying students' construction of meaning.

VII. Bibliography

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