CHAPTER 5—ELEMENTS OF COORDINATION

In this chapter, transcripts of student interviews are analyzed to identify student utterances related to the two structural parts of coordination classes: causal nets and readout strategies. Some of the questions raised in chapter four can be addressed here; others are addressed in chapters six and seven.

This chapter reports the first part of an analysis of interviews with 24 students from a psychology class and 12 students from a physics class. These interviews were audio taped and transcribed, as reported in chapter four. In section 5.1, the causal net and readout strategies, discussed at length in chapter two, are re-described in terms of the present study and the analysis in this chapter. Transcript analysis related to the causal net is discussed in section 5.2. Students described several expectations about realistic motion for balls on the two-tracks apparatuses. These expectations are described and identified as causal net elements. Transcript segments are related to the various expectations, and distributions of student utterances coded for each expectation are discussed. Transcript analysis related to readouts and readout strategies is discussed in section 5.3. Students described several observations about the motion of balls. Example student descriptions of accurate and inaccurate observations are presented and related to two general strategies for observing characteristics of motion. Several students made holistic or experiential statements that inextricably combined properties of causal net elements and readouts. Examples are discussed in section 5.4. Section 5.5 provides a summary of the major findings of this chapter, addresses selected questions from chapter four, and raises new questions about how students judge the realism of animated depictions of motion on the two-tracks apparatuses.

5.1 ELEMENTS

To determine that one computer animation depicted motion more realistic than the others from each set, students had to develop expectations about realistic motion and judge motions depicted in animations against their expectations. The coordination class construct, described in chapter two, includes structural parts that highlight both students' expectations and their strategies for observing animations. Those parts, the causal net and readout strategies, are discussed in this chapter. (Interactions among causal net elements and readout strategies in decision-making, including the performance specifications of integration and invariance, are discussed in chapter six.)

The causal net can be described as "the set of inferences that lead from observable information to the determination of things that may not be directly or easily observable" (diSessa & Sherin, 1998, p.1174). In this chapter, instances in which students indicate their expectations for realistic motion are identified. Such expectations can be understood as providing pathways from observable information (a speed change, for example) to something not directly observable (whether or not motion is realistic). It may be that students develop expectations for motion on these particular tracks from other knowledge. For some of the expectations described in this chapter, evidence pointing to other knowledge is available in transcripts, but this is often not the case. In this analysis, identification and description of students' apparent expectations about realistic motion are emphasized over making claims about the sources of particular causal net elements.

DiSessa and Sherin describe the utility of readout strategies as dealing "with the diversity of presentations of information." They point out that the job of readout strategies in quantity-like coordination classes "amounts mainly to determining the value of the quantity in a particular situation" (diSessa & Sherin, 1998, p.1176). To be effective, readout strategies for tasks in this study must provide students with information they can use to determine whether or not motions depicted in animations are realistic--in other words, observations that can be compared with their expectations for realistic motion. In the interviews, students provided reports of several readouts about the animations, but provided little description of the methods (or *strategies*) they used to make those readouts. Some deductions may be made about students' readout strategies from their statements and from common errors. In this analysis, examples of students' readout reports about speed changes will be presented, and two general types of readout strategies will be identified.

5.2 THE CAUSAL NET

After initial transcript analysis, a list of expectations was created to capture the ideas most prominent in students' decision-making. Statements in which physics students indicated ideas similar to those in the expectation list were coded. Coding was carried out in a similar way for psychology student interview transcripts. Statements made by psychology students were sometimes difficult to code with a small list of expectations, as described in section 5.4. In this section, the list of expectations codes is described, and transcript excerpts coded for each expectation are presented. Counts of students whose transcripts were coded with each expectation in each task are also provided.

5.2.1 Causal net elements

The list of expectations presented in Table 5.1 represents categories of relatively common and clearly described considerations that appeared to influence student judgments about individual animations. These were divided into four major categories: speed changes across sections of the tracks, sudden speed changes, race outcomes, and miscellaneous ad hoc expectations.

Label	Brief description
Expectations about speed changes	
DECELUP	Speed should decrease when rolling uphill.
ACCELDOWN	Speed should increase rolling downhill.
CONSTFLAT	Speed should remain constant on horizontal section of track.
DECELFLAT	Speed should decrease on horizontal section of track.
SAMESPEED	Ball B should have the same speed before and after the valley.
Expectations about relatively sudden speed changes	
NOGAIN	Speed should not increase without an apparent cause.
PAUSETOP	Ball B should pause upon reaching the top of a hill.
Expectation about the balls' relative positions at the end of the race	
TIE	The balls should reach the end of their tracks simultaneously.
VALLEYWINS	The valley ball (ball B) should win the race
VALLEYLOSES	The valley ball (ball B) should lose the race
Ad hoc expectations	
MAKEITUP	Ball B should convincingly roll as if it could make it up the slope.

Table 5.1 Common student expectations (causal net elements) for realistic motion.

The DECELUP and ACCELDOWN expectations involve speed changes on slopes. The next two, CONSTFLAT and DECELFLAT are conflicting expectations about speed changes on a horizontal segment of a track. SAMESPEED involves a comparison of speeds before and after the valley. The second category of expectations, NOGAIN and PAUSETOP, deals with speed changes that occur within a short time span. The third category of expectations applies to the race outcome, with all three possible outcomes represented.

The final category in this list represents a different sort of expectation, not so clearly defined as the others. The only entry in the final category of Table 5.1 is MAKEITUP, although others could have been included (see section 5.4 for more discussion of expectations with a different character than those discussed in this section.) Statements in which students described their feelings that some motions should result in the ball rolling back down the final slope, although it was shown continuing, were categorized as relating to the MAKEITUP expectation.

The set of tables from Table 5.2 to Table 5.9, on pages 74 to 81, consist of prototypical student statements illustrating each expectation listed in Table 5.1. Each statement is identified by the pseudonym of the student who made the comment, the set of interviews (physics or psychology) in which the student participated, the task during which the statement was made, and the particular animation (if any) to which the statement refers. When students referred to specific animations they did so by number; because the same number corresponded to different animations in different tasks, the animation's abbreviated label has been added for ease of interpretation. Because it is often impossible to disentangle readout reports from statements indicating expectations, formatting has been added to the statements to help clarify where an expectation is indicated. Student's words are *italicized*. Phrases that apparently relate to expectations are also *underlined*, and phrases that apparently relate to readout reports are printed in ***boldface***. Phrases that apparently relate to both are printed in ***underlined, italicized boldface***.

ACCELDOWN and DECELUP
· Stephen, psychology, one-ball V-valley [constvx]: "*I expect it to get faster on the way down and slower on the way up…*"
· Emilio, physics, one-ball flat-valley [constvx]: "…*this* ***looks like it's got, um, pretty constant speed****, like it should pick up speed coming down the ramp and lose speed going up the ramp, and* ***it doesn't look like it does that.***"
· Phyllis, psychology, two-ball flat-valley [fsl]: "…*number four [fsl] was the most realistic because* ***it gained momentum down the first hill and lost momentum going up the second hill***."

Table 5.2 Transcript excerpts indicating the ACCELDOWN and DECELUP expectations.

As shown in Table 5.2, students often expressed the ACCELDOWN and DECELUP expectations in close proximity, although this was not always the case. As Emilio did, students often indicated expectations for realistic motion when they believed they had been violated. The statement from Phyllis describes changes in momentum rather than speed changes, but she seemed (un-problematically, in this case) to treat speed changes and momentum changes as equivalent. Her claim that particular momentum changes make the [fsl] animation "realistic" transform her readout report about momentum changes into an indication of expectations for realistic motion; the combination also indicates a judgment about the [fsl] animation.

CONSTFLAT and DECELFLAT
· Gina, physics, one-ball flat-valley [fsl]: "… *number 2[fsl] is wrong because* ***it slows down on the flat part*** *and it shouldn't do that, or* ***it slows down too much*** *if it was essentially frictionless*."
· Paul, psychology, one-ball flat-valley [sl]: "*I'd expect it um, um like the um, um,* ***be able to visualize more that it slows, slow, almost slow down on this flat part***."

Table 5.3 Transcript excerpts indicating the CONSTFLAT and DECELFLAT expectations.

Gina's statement in Table 5.3 indicates the CONSTFLAT expectation. She apparently tied this expectation to school physics knowledge about friction as a potential cause for speed change, and appropriately expected friction to have a small effect on the valley floor. Paul's statement, on the other hand, indicates the DECELFLAT expectation. He apparently observed that the ball rolled across the valley floor at constant speed, violating his expectation. Paul did not explicitly tie his expectation to other knowledge. The DECELFLAT expectation is consistent with previous findings, discussed in the literature review, which have shown evidence for a naive expectation (or a P-prim) that motion dies away on its own in some situations (see for example, diSessa, 1993).

SAMESPEED
· Brook, physics, one-ball flat-valley (general statement): "… *my intuition tells me that it's gonna have a certain velocity at this horizontal point and a certain higher velocity at this horizontal point. And then at this point it's going to approach, call this v1 and this v2, it's gonna approach v1 again*."
· Emilio, physics, two-ball V-valley [fsl]: "*Number 2[fsl] I don't like because* ***the ball that went down and up the ramp pretty much loses all its speed once it gets to the top of the ramp*** *it should have the same speed as it did at the beginning before it went down the ramp*."

Table 5.4 Transcript excerpts indicating the SAMESPEED expectation.

In Table 5.4, Brook and Emilio indicate ideas consistent with the SAMESPEED expectation, that the ball should have the same speed before and after the valley. From the surrounding context (not shown here) it is clear that Brook intended to describe speeds on the initial shelf, the valley floor, and the final shelf of the flat-valley apparatus. Neither Brook nor Emilio indicate ties between the SAMESPEED expectation and other knowledge in these excerpts, but in other parts of their interviews both students made reference to conservation of energy as providing information about speeds at different heights. Physics students often indicated the SAMESPEED expectation and psychology students only rarely did so. Connections between the SAMESPEED expectation and energy conservation knowledge are consistent with previous findings about the two-tracks apparatus (Leonard & Gerace, 1996) and with diSessa's (1993; 1996) claims about student recognition of the "abstract balance" P-prim and application of the "narrative" of energy transformations in situations that involve height changes.

NOGAIN
· Brook, physics, one-ball flat-valley [fst]: "***It looks like it accelerates again when it gets to the top****, which is very weird. Like there's a magnet on the end or something*."
· Rosemarie, psychology, one-ball V-valley [fst]: "*2[fst] is not realistic, because it wouldn't just* ***start going fast, up hill***."
· Samantha, psychology, one-ball V-valley [fst]: "*On number 2[fst] slow,* ***it just seems like right as it almost gets to the top, something gives it a little push up****. I don't think, I don't know, unless a wind came by*."

Table 5.5 Transcript excerpts indicating the NOGAIN expectation.

In Table 5.5, student statements indicate the NOGAIN expectation, apparently in reaction to observations about sudden speed changes depicted in the flat-valley and V-valley [fst] animations. Brook's and Samantha's suggestions that the observed speed changes could be caused by an outside force missing from the two-tracks situations (such a force could be supplied by "a magnet" or "a wind") suggest connections between the NOGAIN expectation and an underlying expectation that sudden speed changes do not occur in realistic situations unless something causes them.

PAUSETOP
· Emilio, physics, one-ball V-valley [fsl]: "…*when **it pauses right at the top of the ramp it looks like it's got just enough, um, forward momentum to keep going, yeah once it gets to the flat level**, so I like 5[fsl]*" · Jackson, physics, one-ball V-valley [fsl]: "*This one is right because **it accelerates as it's go down the gradual ramp and it accelerates more as it goes down the steep ramp, and it shows a constant deceleration as it goes up the steep ramp, a momentary stop at the point where, um, the steep ramp joins the level track and then it travels at the slower but constant speed**.*" · Patricia, psychology, one-ball V-valley [fsl]: "*I don't know. I'm trying to picture…I mean **it seems like the hesitation shouldn't be as much as it is**. But I know there should be a little, I mean it's coming to, to the top of something*...."

Table 5.6 Transcript excerpts indicating the PAUSETOP expectation.

In Table 5.6, Emilio and Jackson appear to accept the "pause" or "stop" they observe at the end of the final slope in the one-ball V-valley [fsl] animation as realistic, as part of a description of the motion depicted in the animation. Physics students never indicated the PAUSETOP expectation except in the context of accepting this particular animation as realistic--for instance they never explicitly judged an animation to be *un*realistic because it was missing such a pause. By contrast, Patricia's statement seems to indicate that she expects a "hesitation" when a ball comes to "the top of something," although she was apparently concerned that the pause depicted in the one-ball V-valley

[fst] animation might be exaggerated. Interactions of readouts and expectations in student judgments of this animation are discussed further in chapter six.

TIE
· Felix, physics, two-ball flat-valley [fst]: "… *ideally, since, you know there's no real change in height because it drops and then it comes back up they should finish the same velocity at the same time*."   · Gina, physics, two-ball V-valley [fsl]: "… ***even though the ball in the front looks ok, for the same reason as the last video***, *they should finish at the same time because they're both starting off with the same amount of energy …*."

Table 5.7 Transcript excerpts indicating the TIE expectation.

In Table 5.7 are statements from two physics students indicating the TIE expectation. Felix mentions his TIE expectation in connection with observations about height changes and the SAMESPEED expectation (perhaps, again, related to the "abstract balance" P-prim and the narrative of energy conservation (diSessa, 1993, 1996)). Gina indicates a judgment that an animation is unrealistic, "even though [the motion of] the ball in the front looks ok," because the balls should tie. Neither Felix nor Gina mention their apparent assumptions that ball A, on its flat track, continues with a constant speed after the initial slope. Interactions of readouts and expectations associated with judgments related to the TIE expectation are discussed further in chapter six.

VALLEYWINS and VALLEYLOSES
· Kent, physics, two-ball flat-valley [real]: "*up to the point where they break apart they have to be going the same speed, and then* ***as it goes down the speed for the ball that goes down gets faster and faster, so for this area, it's when the whole time the balls are apart … the one that goes down is going faster, but when it comes back to here, the ball is going the same speed as the other one****, so if it was going faster for that time, then it would definitely have to be ahead of the other one*."
· Samantha, physics, two-ball flat-valley [constvx]: "*I think that the bottom one actually has further to travel, than the top one, so I think that the top one would get there first, and would be a little faster.*"

Table 5.8 Transcript excerpts indicating the VALLEYWINS and VALLEYLOSES expectations.

In Table 5.8, a physics student indicates the rare and appropriate expectation that ball B should win the race to the end of the tracks. Kent's expectation that ball B should win was connected to the SAMESPEED expectation, as was Felix's TIE expectation in Table 5.7, but with a more careful logical connection between the expectations and a different prediction for the race outcome. Samantha, a psychology student, indicates the VALLEYLOSES expectation, common among psychology students interviewed but rare for physics students interviewed, in connection with her observation that track B is longer than track A.

MAKEITUP
· Don, physics, one-ball flat-valley (general comment): "***some of the other ones seem to die down about midway through****, and if they die down that early it wouldn't make sense for them to be able to have enough energy to get back up the ramp at the end.*"
· Samantha, psychology, one-ball flat-valley [sl]: "*Yeah, that one [sl] just* ***seems like the pace is a lot slower than number 5[fsl] was****. And uh, if it would be slower than number 5[fsl], it wouldn't make it up that ramp. Whereas* ***number 5[fsl] just barely made it up that ramp****.*"
· Sharon, psychology, two-ball V-valley [fsl]: "… *it should have enough speed coming down the hill to get it right up over the next bump and it,* ***stopping right on the angle****, it seems like it would fall back down too.*"

Table 5.9 Transcript excerpts indicating the MAKEITUP expectation.

In each of the statements in Table 5.9, a student has described his or her judgment that the ball is not moving in such a way, in some animation, that it could realistically be expected to roll up the final slope. The MAKEITUP expectation, that the ball ought to move so it could realistically make it up the final slope, is different from the other expectations in Table 5.1. The others provide inferences that connect the realism of the motion depicted in an animation to the presence or absence of some relatively concrete motion feature--a speed change or a race outcome. The inference inherent in MAKEITUP depends on a readout of whether the speed of the ball at some point is above a certain threshold (presumably, a subjectively determined threshold). A few expectations of this type, each appearing to provide inferences based on subjectively determined readouts, are discussed in section 5.4.

Student statements included in the tables above establish the plausibility of the idea that students developed expectations about realistic motion and that these expectations allowed students to make inferences about the realism of animations based on their observations. The ability to make such inferences is a primary feature of a causal net.

5.2.2 Expectation distributions

In the previous section, the plausibility that students developed expectations about realistic motion was established. It was suggested that many expectations were relatively similar across different students. Further indications that different students expressed similar expectations, and that individual students expressed similar expectations across different tasks, are presented in this section.

The transcripts of recorded interviews were coded for the expression of the expectations listed in Table 5.1. Table 5.10, below, indicates the number of students from each group of interviews coded as having expressed each expectation in each of the four tasks. Students were not always so explicit about their ideas as they were when making the statements in the tables above, and coding student utterances often required interpolation among what a student said about expectations, what the student reported as a readout about a particular animation, whether the student judged a particular animation to be realistic or not, and what the student had said about other animations. Coding, therefore, was somewhat subjective, and counts of coding instances must be taken as somewhat approximate. Note also that students may have held expectations that they failed to express, either in an individual task or over the four tasks as a whole.

	Frequencies (Psychology interviews / Physics interviews)				
Expectation	**1-flat**	**1-V**	**2-flat**	**2-V**	**overall**
DECELUP	71% / 92%	83% / 83%	75% / 100%	58% / 83%	92% / 100%
ACCELDOWN	71% / 92%	79% / 92%	79% / 100%	75% / 100%	96% / 100%
CONSTFLAT	8% / 33%	0% / 0%	13% / 58%	0% / 0%	21% / 75%
DECELFLAT	25% / 0%	0% / 0%	13% / 8%	0% / 0%	33% / 8%
SAMESPEED	0% / 42%	13% / 50%	4% / 25%	0% / 50%	13% / 67%
NOGAIN	29% / 58%	83% / 100%	4% / 0%	75% / 25%	92% / 100%
PAUSETOP	0% / 0%	21% / 33%	0% / 0%	4% / 0%	25% / 33%
TIE	0% / 0%	0% / 0%	46% / 83%	29% / 92%	50% / 100%
VALLEYWINS	0% / 0%	0% / 0%	0% / 17%	8% / 8%	8% / 17%
VALLEYLOSES	0% / 0%	0% / 0%	25% / 0%	8% / 0%	25% / 0%
MAKEITUP	17% / 8%	33% / 17%	4% / 0%	25% / 8%	50% / 17%

Table 5.10 Fractions of students in recorded Psychology interviews (N=24) and Physics interviews (N=12) coded as expressing common expectations about realistic motion during each task, and during the entire interview.

Table 5.10 presents several patterns. The ACCELDOWN, DECELUP, and NOGAIN expectations were expressed in most psychology and physics interviews, and in both one-ball and two-ball tasks. Some expectations were expressed by a much larger fraction of students from one group than the other--CONSTFLAT, SAMESPEED, and TIE were expressed in a larger fraction of physics interviews, while DECELFLAT, VALLEYLOSES, and MAKEITUP were expressed in a larger fraction of psychology interviews. The NOGAIN expectation was expressed by physics students in the one-ball V-valley task far more often than in the two-ball V-valley task, while a large fraction of psychology students expressed the expectation in both.

5.3 READOUT STRATEGIES

One function of readout strategies is to serve as the interface between the outside world and a students' causal net. In this capacity, readout strategies act as an active filter, capturing and encapsulating information from the outside world so that elements of the causal net can operate on that information. As presented in the previous section, students were often concerned with judging whether or not speed changes presented in animations were realistic. Their readout strategies were, not surprisingly, often focused on gathering information about speed changes depicted in animations.

Students provided much more information about their readouts than about the methods (*strategies*) they used to obtain those readouts. Students' statements suggest that their strategies for reading out information about speed changes can be separated into two major categories: those that produce "fixed-referent" readouts and those that produce "relative motion" readouts. In the one-ball tasks, the fixed background of the two-tracks apparatus was the only reference that students had to work with for judging speed changes; students were therefore limited to making fixed-referent readouts in the one-ball tasks. In the two-ball tasks, students had the additional option of judging one ball's motion relative to the other; in the two-ball tasks, students were presumably free to make either fixed-referent or relative motion readouts.

5.3.1 Fixed-referent readouts

Table 5.11 presents examples of readout reports from four students. These reports must refer to fixed-referent readouts, because they describe students' observations of one-ball animations. Several more examples of fixed-referent readout reports can be found in the tables in section 5.2.1.

Fixed-referent readouts
· Huan, physics, one-ball V-valley [real]: "***Definitely goes faster, it's, it's going fastest at the bottom of the hill, the bottom of the V***."
· Phyllis, psychology, one-ball flat-valley [fsl]: "…***it picked up a little bit of momentum there and then it slowed down again going up the hill…..***"
· Gina, physics, one-ball V-valley [constvx]: "***it speeds up as it goes up again,*** *which is wrong,* ***when it comes up the V***…. "
· Carol, physics, one-ball flat-valley [sl]: "***Number 3 [sl] looks like it slows down when it's going down the second hill***….."

Table 5.11 Student statements indicating fixed-referent readouts.

Fixed-referent readouts are apparently sometimes accurate and sometimes inaccurate. Readouts reported by the first two students in Table 5.11, Huan and Phyllis, are accurate. Readouts reported by the second two students in the table, Gina and Carol, are inaccurate. What are collectively described here as fixed-referent readouts are likely the result of somewhat different readout strategies, some of which may be more reliable than others in particular situations or when employed with particular attention to detail. Student statements provide little information to fuel speculation about the precise nature of their fixed-referent readout strategies.

5.3.2 Relative motion readouts

Table 5.12 presents three examples of readout reports. The wording of these reports strongly suggests that students' readouts about speed changes were affected by observations of the relative positions of balls A and B. The examples also suggest patterns of accuracy and inaccuracy that may be attributable to inferences about speed changes based on observations of relative motion.

(Likely) relative motion readouts
· Emilio, physics, two-ball flat-valley [constvx]: "*All right, it's not 4[constvx], because* ***the two balls are always at the same, um, I guess I'll call it 'x' value, they're always at the same position going down the ramp*** *and they shouldn't be. When the ball's going down the ramp it should be going faster than the ball going straight so it should be further along the ramp*." · Sharon, psychology, two-ball flat-valley [sl]: "**the top ball stayed a little bit ahead of the one that went down the ramp** and the one that went down the ramp seems like it should pick up at least some momentum to get ahead of it at some point." · Lauren, physics, two-ball flat-valley [fst]: "…*I chose 2[fst] because I thought that the balls, um,* ***the speed of the ball that was going down on the incline should be, um, at a different speed at certain points in going down and up than the ball that, on the straightaway, but that they should meet at the end*** *because their velocity, after that ball goes down and goes up it should have the same velocity as it did before*."

Table 5.12 Student statements suggestive of relative motion readouts.

In the first two examples in Table 5.12, Emilio and Sharon make accurate inferences about the speed of ball B on the second slope, apparently based on the observation that when ball B does not move ahead of ball A on this slope, its speed has not increased. In this case, the inference is appropriate because the two balls had the same speed and position before ball B reached the second slope.

In the final example, Lauren reports appropriate expectations for speed changes, and relates them to an inappropriate expectation for relative position at the end of the race. Her description of velocity and relative position implies that when the balls have the same velocity at the end of the track they must also have the same position. It is unclear whether her claim that the balls had different speeds during the two-ball flat-valley [fst] animation was based on fixed-referent readouts, relative motion readouts, or some combination of the two.

The first two examples in Table 5.12 provide particularly clear examples of students making inferences about speed changes from observations of relative positions. In many descriptions of speed changes in two-ball animations, students were not so explicit about the inferences they made. They often made mistakes similar to those in Lauren's description of the two-ball flat-valley [fst] motion, suggesting the possibility that, although they did not describe relative motion readout strategies explicitly, they may have used relative motion readout strategies or some combination of relative motion and fixed-referent readout strategies.

As described in the literature review, Trowbridge and McDermott (1980) report characteristic mistakes made by students in situations where students might use information about the relative positions of two objects to judge the relative speeds of the objects. Students' readout reports in the present study suggest that students may have used strategies similar to those reported by Trowbridge and McDermott: treating "getting ahead" as equivalent to "getting faster", treating "losing ground" as equivalent to "slowing down", and appearing to treat "same position" as equivalent to "same speed". These strategies, each appropriate in some circumstances, are inappropriate in other circumstances and can lead to mistaken readouts of speed changes. Potential effects of relative motion readout strategies on student judgments are pursued in chapter six.

5.4 EXPERIENTIAL AND HOLISTIC MOTION DESCRIPTIONS

Several student statements combined elements of readout strategies and causal net elements. For some of these statements, straightforward decomposition in formal physics terms might do injustice to the intent with which the students made them. Such statements were made more often by psychology students than by physics students. Statements such as those in the tables in this section appeared useful to the students who made them, and almost certainly contain information about the students' attempts at coordination. They are, however, difficult to interpret unambiguously and are not generally pursued in the coordination class analysis beyond the discussion here.

This type of statement is separated into two broad categories. Statements presented in Table 5.13 are classified as experiential descriptions, because they appear to directly relate motion in an animation to motions students have experienced. Statements presented in Table 5.14 are classified as holistic descriptions. They appear to be the result of judgments about the *overall* speed of the ball in an animation, rather than judgments based on the presence or absence of particular speed *changes*.

Experiential descriptions of motion
· Teresa, psychology, one-ball V-valley (general comment): "*If you think about it like a bowling alley, it still comes up and doesn't really slow down ….*"
· Rosemarie, psychology, one-ball V-valley (general comment): "*This kind of reminds me of riding my bike up a hill.*"
· Samantha, psychology, two-ball V-valley [real] and [fsl]: "*…number 5[real] seemed* ***kind of like a sling shot****, kind of thing … once* ***it goes it just goes whsht****, you know? … we go mini golfing sometimes, and they have the little … green[s], and there is one and it has little bumps on it, like little waves, but they're pretty big. But, that one, the ball just kind of goes, and* ***it just seems to fly like the whole way through, like number 5[real]*** *… and then another one it goes straight, drops down a lot and comes up and,* ***I would definitely, relate that the ball would lose its momentum as it goes back up. But, I think that one kind of compared to number 2[fsl]****.*"

Table 5.13 Examples of experiential motion descriptions.

There is nothing inappropriate about basing judgments of motion on experience. Teachers often encourage students to relate experiences in physics classes to their daily lives. Samantha demonstrates one of the pitfalls of an experiential approach, however, when she appears to have experience with different types of motion, and exhibits difficulty in deciding which experience is useful for the task at hand. Without principles to guide the choice of an appropriate experience on which to base expectations, and to guide the choice of readout strategies, such an approach may lead to idiosyncratic and context specific coordination, resulting in low levels of integration and invariance.

Holistic descriptions of motion
· Patricia, 368, 2122, 2-V [real]: "***The bottom ball seems <u>way too fast</u>***. *Now I'm gonna try to concentrate more on the top ramp ball.* ***Which also seems like it's going <u>kind of fast</u>***."
· Sharon, 370, 1125, 2-V [sl]: "*And 5[sl] it just seems that* ***the ball that goes down the ramp is <u>just too slow</u>***."

Table 5.14 Examples of holistic motion descriptions.

The statements included in Table 5.14 appear to be judgments based on the overall speed of the ball. Expectations for what is a "reasonable" speed must be based on something, but it is difficult to judge what that is or whether it is appropriate. Again, an approach based on judging the overall speed of the ball may lead to idiosyncratic and context specific coordination with low levels of integration and invariance.

5.5 DISCUSSION

The analysis in this chapter suggests that a large fraction of interviewed students had some causal net elements in common, and that many of the students consistently brought some of these elements to bear across the different contexts presented by the four tasks. There were also, however, variations in the frequencies with which particular expectations were expressed, across different tasks and across different students. Yet to be addressed are the questions of how such patterns in causal net elements should affect the invariance of coordination episodes for individual students and how they should affect similarity of coordination episodes across different students. A key task for this analysis is, of course, to determine whether students with these expectations could plausibly produce features of the response patterns described in chapter four.

The analysis in this chapter suggests that students interviewed made both accurate and inaccurate readouts of features of motion depicted in the computer animations. Although the precise nature of students' readout strategies cannot be determined from interview transcripts, students attempting to read out speed change information from animations apparently had access to at least two different classes of readout strategies. One class of strategies was based on fixed-referent observations, and the other was based on observations of the relative motion of two balls. Patterns of success and failure associated with different types of readout strategies may have implications for interpretation of the integration and invariance of students' efforts at coordination.

It was found in chapter four that students often judged two-ball animations depicting a tying race outcome to be realistic, when they had judged the one-ball animation depicting the same motion to be unrealistic. One reason for this difference, in terms of coordination classes, might be that different causal net elements or readout strategies are brought to bear in the one-ball and two-ball situations. A detailed discussion of the possibilities is premature at this point, but some preliminary patterns can be pointed to. First, the pattern of expectations expressed by students suggests that in the two-ball tasks many students held onto the same set of expectations they had used for the one-ball tasks, but added expectations about the race outcome. (A potentially telling exception to this pattern is that fewer physics students expressed the NOGAIN expectation in the two-ball V-valley task than in the one-ball V-valley task.) Second, students had access to relative motion readout strategies in the two-ball tasks that had been unavailable in the one-ball tasks. Chapter six is devoted to further interview analysis and an exploration of how causal net elements and readouts can interact to produce judgments about animations; a more complete discussion of student coordination, including coordination that could lead to identification of tying animations as realistic, is presented there.