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A coordination class analysis of judgments about animated motion

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We use the coordination class construct to analyze interviews in which college students judged the realism of animated depictions of balls rolling on a set of tracks. We find the elements of coordination classes (readout strategies and the causal net) useful for understanding the interviewed students' decision-making processes. We find limited evidence for integration and invariance, the performance criteria of coordination classes.

Introduction

DiSessa and Sherin [1] invented the coordination class construct as a step toward clarifying what it means to learn and use scientific concepts. We believe it offers a valuable perspective from which to view physics education and PER, but published evidence of the construct's use by the PER community is limited [1-3]. We describe an analysis of interview data with the construct (detailed elsewhere [4]) and report on its utility in the context of this analysis.

In the interviews, students were asked to judge the realism of several computer animations depicting the motion of balls rolling on a pair of tracks. When an animation presented only one ball, most students focused on the presence or absence of realistic speed changes. Addition of a second ball drastically changed the judgments of students taking introductory physics; non-physics students were affected much less strongly. (Students surveyed in large lecture classes replicated these patterns [4].) A key task of the analysis is to explain these judgment patterns.

The construct

DiSessa and Sherin [1] describe coordination classes as a step toward articulating what it means for something to be a "concept" or for students to undergo "conceptual change". They argue that many scientific concepts shape the way we gain information about the world, helping to *coordinate* our perceptions. A coordination class is a hypothetical system whose purpose is to infer a particular type of information in varied situations.

DiSessa and Sherin [1] specify structural elements and performance criteria for coordination classes, as presented in Table 1. Wittmann [3] describes *readout strategies* as filters that focus attention on meaningful elements in the world. The *causal net* provides the reasoning pathways for inferences that link direct observations to the information needed.

Elements	Causal Net
	Readout Strategies
Performance criteria	Integration
	Invariance

Table 1: *Structural elements and performance criteria for coordination classes.*

To be reliable, a coordination class must coordinate in two senses. The first sense, *integration*, involves making consistent sense of the multiple sets of features in a single situation whose observation might lead to the desired type of information. If coordinating different feature sets in a single situation leads to different inferences, there is a failure of integration. The second sense of coordination, *invariance*, specifies that a coordination class should reach inferences about the same type of information in varied situations, even if the particular features available for observation vary. If a change in context changes the type of information constructed, then there is a failure of invariance.

We use the term *coordination system* to describe a collection of readout strategies and causal net elements that do not necessarily meet the criteria of integration and invariance.

The study

Computer animations (Quicktime digital movies, viewable with a web browser [5]) depict several motions of balls across a pair of ramps. Figure 1 presents composites of equally-spaced frames from each animation, numbered to indicate time progression. The animations are based on an apparatus with a pair of metal tracks (A and B). Track A is flat after an initial incline. Track B begins and ends at the same heights as track A, but includes a V-shaped valley. When metal balls are released simultaneously at the left end of the tracks, ball B wins the race. Leonard and Gerace [6] describe the kinematics of the race; the horizontal component of ball B's velocity is always at least as large as that of ball A.

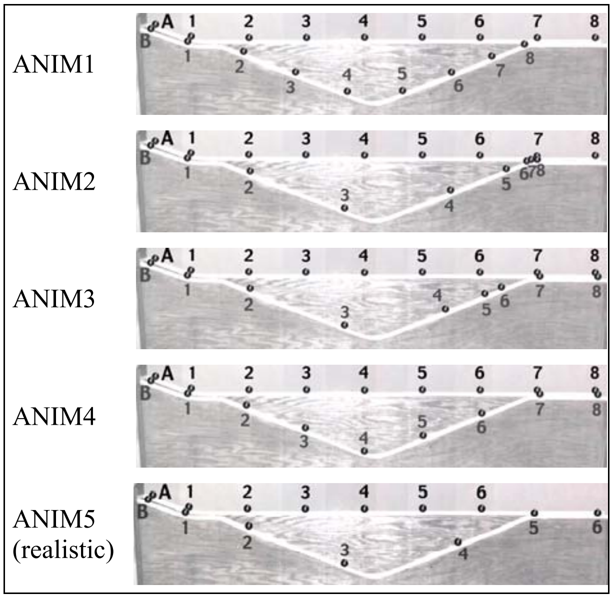

Figure 1: *Strobe diagrams for two-ball animations.*

In each animation, ball A rolls at constant speed after the initial incline. Ball B's motion deviates from realistic motion in all but animation 5 (ANIM5). Ball B loses the race in ANIM1 and ANIM2, and the balls tie in ANIM3 and ANIM4. In ANIM3, ball B accelerates normally into the valley and leads ball A, but slows down and speeds up again *while rolling uphill*, so that balls A and B have the same speed and position when ball B reaches the end of the valley.

We refer to the animations described above as *two-ball* animations. We also created *one-ball* animations, missing ball A but depicting the same five motions for ball B. (One-ball animations were presented to students with orderings different from those used for two-ball animations.)

Individual interviews were conducted with two sets of students. One sample (*physics*) of 24 students was taken from the honors section of a calculus-based introductory physics course, after kinematics and energy conservation had been discussed. The second sample (*psychology*) of 26 students was taken from an educational psychology course. The students had not seen the demonstration previously. Students were asked to identify the animation depicting motion most like that of real balls rolling on real tracks, and to describe their reasoning. Students chose first from the set of five one-ball animations and then from the set of two-ball animations. Students could review animations within a set in any order, at regular or half-speed. (Students also judged animations based on an apparatus with a long flat valley, not discussed here to conserve space.)

Table 2 presents the choices of students from each sample in the one-ball and two-ball tasks. In the one-ball task, most students identified ANIM5 or ANIM2 as realistic (note: ANIM2 roughly corresponds to high rolling friction motion.) No students identified the one-ball ANIM3 as realistic. Psychology student response patterns are similar between the one-ball and two-ball tasks The majority of physics students, however, identified the two-ball ANIM3 as realistic, despite having judged the same motion to be unrealistic minutes earlier in the one-ball task.

V-valley choices	**ANIM1**	**ANIM2**	**ANIM3**	**ANIM4**	**ANIM5**
one-ball (physics)	8%	42%	0%	0%	50%
two-ball (physics)	0%	17%	63%	17%	4%
one-ball (psychology)	23%	35%	0%	4%	38%
two-ball (psychology)	15%	42%	0%	8%	35%

Table 2: *One-ball and two-ball animations identified as "most realistic" by students from a physics course (N=24) and a psychology course (N=26).*

Coordination class elements

Twelve interviews with physics students and twenty four interviews with psychology students were recorded and transcribed. We used the coordination class construct to analyze students' decision-making from the transcripts.

To determine that one animation was more realistic than the others from each set, students appeared to develop *expectations* about realistic motion and to compare their observations against those expectations. We considered students' expectations to be causal net elements. Many students expressed similar expectations.

Several of the most commonly expressed expectations are presented in Table 3. Note that each expectation listed is appropriate (consistent with ANIM5) except TIE, and that no animation depicts motion consistent with all five expectations. The most consistently expressed expectations were ACCELDOWN and DECELUP. The NOGAIN expectation was commonly expressed in objection to ANIM3. Physics students often related the SAMESPEED expectation to the principle of energy conservation, but psychology students rarely expressed it. Physics students confidently (and inappropriately) related the TIE expectation to SAMESPEED and to energy conservation principles; psychology students expressing the TIE expectation did so with relatively low confidence.

Expectation	**Description**
DECEL-UP	Speed should decrease when rolling uphill.
ACCEL-DOWN	Speed should increase when rolling downhill.
SAME-SPEED	Ball B should have the same speed before and after the valley.
NOGAIN	Speed should not increase without an apparent cause.
TIE	The balls should reach the ends of their tracks simultaneously.

Table 3: *Common student expectations (causal net elements) for realistic motion.*

Considering the causal net elements in Table 3, it may be unsurprising that students described many observations (readouts) of speed changes. Two general types of readout strategies were identified. In the one-ball animations, the fixed background was the only reference available, limiting students to *fixed-referent* readouts. In the two-ball animations, the second ball provided an additional reference, so students could make either fixed-referent or *relative motion* readouts.

Students often failed to report particular expectation-related speed changes depicted in one-ball animations; variations in the sensitivity of fixed-referent readout strategies are indicated in Table 4. Using relative motion readout strategies, students often appeared to inappropriately infer relative speeds from relative positions; "faster" and "ahead" were used interchangeably, as were "same speed" and "tied". Relative motion readout strategies may also have been insensitive to the sudden speed change in the two-ball ANIM3, as it was not associated with a sudden change in the balls' relative positions.

Expectation	**Fixed-referent readouts**	**Relative motion readouts**
ACCEL-DOWN	good sensitivity	good sensitivity
DECEL-UP	poor sensitivity for ANIM5	systematic error for ANIM5
SAME-SPEED	poor sensitivity	systematic error for ANIM5
NOGAIN	good sensitivity for ANIM3	poor sensitivity for ANIM3
race outcome	not applicable	good sensitivity

Table 4: *Patterns of success and failure for Fixed-Referent and Relative Motion readout strategies.*

Coordination processes and decision-making

Decision-making may be seen as a series of coordination processes. The most commonly observed process was that of making readouts that could be directly compared with expectations. In the majority of small-scale judgments (comparing a readout with an expectation to temporarily rule an animation "in" or "out") students made successful comparisons. The majority of students' final decisions, however, involved identifying an animation as realistic despite its apparent incompatibility with one or more of their own expectations.

The processes presented in Table 5 allowed students to make choices apparently incompatible with their expectations. Readout problems are self-explanatory. For example, students often ruled out ANIM5 for violating the DECELUP expectation or failed to rule out ANIM2 despite having expressed the SAMESPEED expectation, by virtue of imprecise readouts. The process of *feedback* occurred for some students after a determination that all five animations in a set were unrealistic. They were forced to change their expectations, or their readouts about a particular animation, in order to identify an animation as realistic. Feedback often appeared to occur without the students' knowledge.

Process	**Effects**
Inaccurate or missed readouts	Can limit choices
	Can extend choices
Feedback	Changing expectations to accommodate readouts
	Changing readouts to accommodate expectations

Table 5: *Coordination processes allowing students to make judgments incompatible with their causal nets.*

The response patterns in Table 2 raise questions about how physics students judged two-ball animations, and about how their judgments differed from those of psychology students. Students in each group consistently expressed the ACCELDOWN and DECELUP expectations in both tasks. Students in each group consistently expressed the NOGAIN expectation during the one-ball task and ruled out ANIM3; psychology students (but not many physics students) also did this in the two-ball task.

Psychology students who had expressed the TIE expectation were almost always able to rule out ANIM4 as well as ANIM3. Having objected to all five animations, they resorted to a feedback process, which usually resulted in dropping of the TIE expectation. In contrast, physics students who expressed the TIE expectation appeared to use relative motion readout strategies to find ANIM3 consistent with ACCELDOWN, DECELUP, SAMESPEED, and their confidently held TIE expectations. They consistently failed to report NOGAIN-related readouts for the two-ball ANIM3, possibly due to reliance on relative motion readout strategies.

Physics students who chose the two-ball ANIM3 exhibited a surprising lack of invariance between the one-ball and two-ball tasks. They also failed to account for the available NOGAIN-related readout in their final decision (a problem of integration). Psychology students judged the two versions of ANIM3 invariantly, but did not usefully integrate race outcome information.

Conclusions

The coordination class analysis proved useful for understanding and comparing decision-making processes, regardless of whether students' coordination systems met the integration and invariance criteria of coordination classes. The analysis highlights the adaptability in students' coordination, and the lack of internal coherence; individuals expressed expectations that were mutually contradictory, used readout strategies that gave conflicting readouts, and adapted their coordination systems without expressing awareness that changes had been made. An implication for research or instruction is that students' cognition in any particular situation may not depend on factors crucial to their cognition in other situations, even if the situations seem closely related to the researcher or instructor.

The analysis also highlights readout strategies as a central and often under-appreciated factor in cognition and conceptual change. An implication for instruction is that students with appropriate causal nets but inappropriate readout strategies may be confused by interventions based on the assumption that their causal nets need work.

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