# A COORDINATION CLASS ANALYSIS OF COLLEGE STUDENTS' JUDGMENTS ABOUT ANIMATED MOTION

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The coordination class construct was invented by diSessa and Sherin to clarify what it means to learn and use scientific concepts. A coordination class is defined to consist of readout strategies, which guide observation, and the causal net, which contains knowledge necessary for making inferences from observations. A coordination class, as originally specified, reliably extracts a certain class of information from a variety of situations. The coordination class construct is relatively new. To examine its utility, transcripts of interviews with college students were analyzed in terms of the coordination class construct.

In the interviews, students judged the realism of several computer animations depicting balls rolling on a pair of tracks. When shown animations with only one ball, students made judgments consistent with focusing on the ball's speed changes. Adding a second ball to each animation strongly affected judgments made by students taking introductory physics courses, but had a smaller effect on judgments made by students taking a psychology course. Reasoning was described in this analysis as the coordination

of readouts about animations with causal net elements related to realistic motion. Decision-making was characterized both for individual students and for groups by the causal net elements expressed, by the types of readouts reported, and by the coordination processes involved.

The coordination class construct was found useful for describing the elements and processes of student decision-making, but little evidence was found to suggest that the students studied possessed reliable coordination classes. Students' causal nets were found to include several appropriate expectations about realistic motion. Several students reached judgments that appeared contrary to their expectations and reported mutually incompatible expectations. Descriptions of students' decision-making processes often included faulty readouts, or feedback loops in which causal net elements or readouts were adjusted. Comparisons of the interviewed groups' coordination were found to echo differences and similarities in animation judgments made by larger groups of students who were not interviewed.

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# CHAPTER 1—INTRODUCTION

## 1.1 MOTIVATION

This dissertation examines the utility of the coordination class construct, in the context of investigating students' judgments about the realism of several different animated depictions of balls rolling along two pairs of tracks. To motivate such an examination, four questions are briefly addressed in the following paragraphs.

*Question 1: What is the coordination class construct?*

The coordination class construct was introduced in an article titled "What changes in conceptual change?" (diSessa & Sherin, 1998) with the claim that, in order to understand conceptual change, it is valuable to address shortcomings in our understanding of what it means to "have" a concept. A key implication of the coordination class construct is that it is profitable to consider reasoning as the application of knowledge elements much smaller than those that would be typically identified as concepts.

The coordination class construct is a model intended to describe how people recognize, or metaphorically "see", information in the world. A coordination class is a hypothetical knowledge structure that allows a person possessing it to reliably make observations and infer from them information of a certain type, in many different contexts. In the terminology of coordination classes, when a person makes observations and uses prior knowledge to make inferences from those observations, the person has performed an act of *coordination*. Possessing a coordination class for *force* (or *location*), for example, would allow a person to reliably coordinate information about forces (or locations) across a variety of situations.

*Question 2: Why choose students' judgments of motion as a context for examining the utility of the coordination class construct?*

Previous work, described in section 1.3.1, indicated that the two-tracks apparatuses (shown in Figure 1.1) could provide a rich arena for the study of student reasoning. They also provide a rich arena for studying students' coordination. The task of judging the realism of a set of animated depictions of motion on the two-tracks apparatuses requires extended acts of coordination; to accomplish the task, one must make several observations about each animation, decide (implicitly or explicitly) which observations lead to information useful for judging realism, and make the necessary inferences from those observations.

In the course of investigating students' judgments of the realism of animated depictions of motion on the apparatuses, it became apparent that, under slightly different circumstances, many students pay attention to different features of identical motions and come to very different conclusions about which animations depict realistic motion. This is naturally interpreted with the coordination class construct as the result of reliability problems in students' coordination; in short, students "see" the motions in incompatible ways under slightly different circumstances.

The situation of interest is complex enough to yield interesting patterns of coordination, but is simple and well-controlled enough to allow comparative analyses of students' coordination. Because the animations were created by the investigator, the external stimuli for students' observations are well-understood. This simplifies the matter of understanding students' observations. Although students' coordination is complex, the task of sorting out how students coordinate information in this situation is more manageable than it might be in many situations.

*Question 3: What form does the coordination class analysis of student reasoning take?*

Transcripts of interviews, in which students describe their reasoning as they make judgments about the realism of sets of motions, are analyzed with the coordination class construct. The analysis largely takes the form of identifying common elements involved in students' coordination and identifying common processes by which students coordinate information about the realism of the motions. The products of the analysis are applied to an examination of how students made decisions about the realism of the motions, and to a comparison of the coordination patterns of students from two different groups.

*Question 4: What can be gained from using the coordination class construct to analyze students' judgments about motion?*

The coordination class construct promises a more articulated understanding of how knowledge and observation interact, and of what it means to learn and use scientific concepts. A more articulated understanding of these issues could have several implications for teaching practice; for instance, if the elements hypothesized for coordination classes prove useful for understanding student reasoning, it may indicate that instruction based on helping students to modify those elements, or the processes by which they interact during reasoning, could be a more effective means to promote conceptual change than instruction based on other models of scientific concepts.

The coordination class construct is relatively new, and has not been well-investigated. The most important aspect of the work in this dissertation may simply be that it represents a concrete application of the construct to student data. Such an application promises to improve our understanding of the construct and its implications. If the analysis presented in this dissertation sheds light on student reasoning, it will represent progress toward resolving several issues about the application of the construct to data and will provide an indication that it is worthy of continued use.

This analysis also provides a step toward improving the theory base of PER. Closely tying results about student judgments of motion on these tracks to a cognitive model increases the probability that findings from this investigation can be informative for other situations.

## 1.2 OVERVIEW

As part of an investigation of student reasoning about balls rolling on tracks, students were asked to judge the realism of animated depictions of motions. A change in the presentation of the motions had a strong effect on the judgments made by introductory physics students. When shown motions with only one ball, most students made judgments consistent with focusing on speed changes of the ball. When shown two balls rolling on adjacent tracks, many students made judgments different from their one-ball judgments. In particular, many students judged one of the two-ball animations to be realistic, minutes after recognizing that the same motion contained unrealistic speed changes in the corresponding one-ball animation. Students in a psychology class did not exhibit this apparent inconsistency to the same degree as introductory physics students.

Interviews with students from an introductory physics class and a psychology class provided evidence for students' use of complex reasoning processes in judging the realism of the depicted motions. Students reasoned causally about how the shape of a track would affect the motion of a ball. Students determined which features of the animations were important for their judgments, and made observations to extract information from the animations. Students made inferences from their observations to judge the realism of each motion. For many students, the information attended to and the types of inferences made depended strongly on whether one or two balls were shown.

The processes of student decision-making in this situation will be analyzed in terms of the *coordination class* construct. As a preliminary step toward clarifying what it means to learn and use scientific concepts, DiSessa and Sherin described coordination classes (1998) as knowledge structures capable of flexibly recognizing and reading out certain classes of information (location or force, for example) in a range of situations. A coordination class contains two structural parts, a collection of *readout strategies* and a *causal net*. In the study introduced above, readout strategies are, roughly, the strategies students used to make observations about animations, and the causal net is the collection of reasoning strategies used by students to make inferences about the realism of motion depicted in individual animations. Coordination classes are hypothesized to be reliable, so that the many observations possible within one situation can lead to a single stable conclusion (*integration*) and so that the same type of information can be reliably inferred from observations made in many different situations (*invariance*). The apparent inconsistencies in student judgments about balls rolling on tracks must be accounted for in light of these two types of reliability.

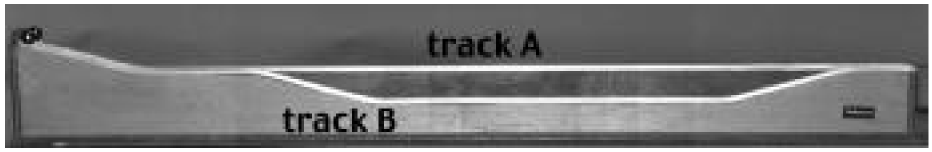
Although the coordination class construct points to a more articulated description of certain types of cognition, it is relatively new and its implications are not yet well-understood. To add to understanding of the utility of the coordination class construct, this dissertation examines the adequacy of the construct for describing student decisions about balls rolling on tracks. Several questions are addressed, including questions about how viewing student data through the lens of coordination classes can structure an analysis of student reasoning, and questions about the similarities of coordination episodes for different students in the same situation, or for the same student in slightly different situations. The dissertation concludes with a report of the utility of the coordination class construct as a tool for analyzing the data available from this study. Possible changes to improve the utility of the construct, and suggestions for future study of student reasoning with coordination classes, are proposed.

## 1.3 THE STUDY

### 1.3.1 The two-tracks demonstration and previous findings

The study described here is based on a pair of physics classroom demonstrations. In each *two-tracks* demonstration, two metal balls roll along metal tracks A and B (see Figure 1.1). The major difference between the flat-valley apparatus and the V-valley apparatus is the shape of the valley on track B. When the two balls are released from rest at the left end of the tracks on either apparatus, the ball on track B (the valley track) wins the race to the right end of the tracks.

*Flat-valley apparatus*




*V-valley apparatus*

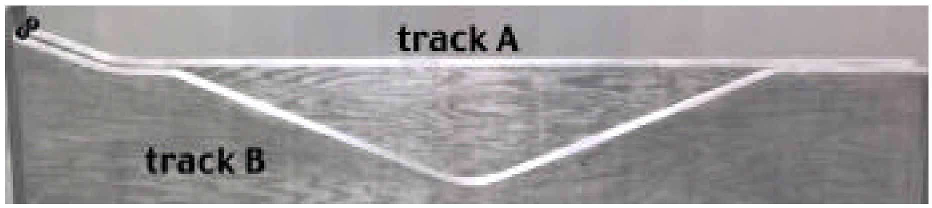



**Figure 1.1 Equipment for two-tracks demonstrations, shown with a ball at the beginning of each track. The tracks are approximately 1.5-meter long.**

In a previous investigation performed at the University of Massachusetts-Amherst, students in introductory physics classes were asked to predict the winner of the race for the flat-valley apparatus (Leonard & Gerace, 1996). After an introduction to the actual apparatus, but before viewing a performance of the demonstration, the majority of students in the study predicted that the balls would reach the end at the same time. Many students offered reasoning related to energy conservation to support this prediction. Even after viewing the flat-valley demonstration and discussing explanations for why the ball on track B reached the end of the track first, nearly half of the students in the investigation predicted that the race on the V-valley apparatus would result in a tie. Introductory physics students are not unique in this respect; in informal explorations of their beliefs about these demonstrations, a large fraction of educators (including physicists) have predicted that the balls should tie.

### 1.3.2 Preliminary investigation: Depictions of motion

Leonard and Gerace investigated student reasoning about the race outcome. The majority of students predicted outcomes that do not occur when rolling friction is kept to a minimum, as it is for the two-tracks demonstrations. These outcomes necessarily correspond to unrealistic rolling for the two-tracks situations. The investigation results raised the question of whether students could distinguish depictions of realistic motion from depictions of unrealistic motion in the two-tracks situation.

To investigate this question, five motions were developed for each set of tracks, with four corresponding to unrealistic motion and one corresponding to realistic motion. Each motion was represented in two different ways: with an animated depiction to be shown on a computer screen and with a strobe diagram, printed on paper. Only the motion of ball B varies; the motion of ball A is the same in all choices. Of the five choices for each apparatus, two result in ball A winning the race, two result in a tie, and one (the realistic motion) results in ball B winning the race. The choices for which the balls tie on the V-valley apparatus, in particular, include unrealistic speed changes. (The choices and their representations are described in detail in chapter three.)

In a preliminary investigation, a set of students in an introductory physics class who had not seen the two-tracks demonstrations was identified. The students were shown the actual flat-valley and V-valley tracks, and were then asked to identify the motion from each set of animations and each set of strobe diagrams most like the motion that would occur for real balls rolling on the tracks of the corresponding demonstration apparatus.

It was expected that students might notice unrealistic speed changes in the depictions of unrealistic motions, and might therefore choose tying motions with lower frequency in the preliminary investigation than that with which they had predicted a tying result in the Leonard and Gerace study. In contrast to these expectations, the fraction of students who identified a tying motion as most realistic in the preliminary investigation, from either the strobe diagrams or the animations, was similar to the fraction predicting a tie in the Leonard and Gerace study. Although students commented on some features of the ball motions in addition to the race outcome, many students offered reasoning related to energy conservation to support their choice of a tying motion, as they had done to support their tying prediction in the Leonard and Gerace study.

### 1.3.3 Primary investigation: How do students identify realistic motion?

The results of the preliminary investigation suggested that the identification of unrealistic speed changes may not have been the main consideration for students as they attempted to identify the most realistic motion for the two-tracks situation. Comparisons between the motions of balls A and B, along with the application of formal physics knowledge, each seemed to play a role in students' decisions. To further investigate questions about how students judge motions, computer animations were developed with no images of ball A, showing virtually the same motions for ball B as those used in the preliminary investigation. These will be referred to as *one-ball* animations, and the original animations will be called *two-ball* animations. Students in several large introductory physics lectures, as well as in a large educational psychology lecture, were asked to identify the one-ball and two-ball animation for each apparatus depicting the most realistic motion. Strobe diagrams were not used in the primary investigation.

For the one-ball animations, the majority of students in each course made choices consistent with having focused on the speed changes of the ball, and only a small fraction of students in any course chose the unrealistic one-ball V-valley motions that would result in a tie with two balls. For the two-ball animations, a smaller fraction of students in the educational psychology course than in the physics courses chose tying motions; in particular, the fraction of students who chose tying motions for the V-valley apparatus ranged from 20% of students in the educational psychology course to more than 60% of students in two of the introductory physics courses. These results suggest that most students can recognize some unrealistic speed changes in animations when only one ball is present, and that the observing ball A's motion may have had a larger influence on the judgments of students in the introductory physics courses than on the judgments of students in the psychology course.

The response patterns described above raise several questions about what students expect for realistic motion in the two-tracks situations and about what they observe when viewing the animations. To address these questions, individual semi-structured interviews were conducted with students from an introductory physics course and students from an educational psychology course. In these interviews, students described their reasoning while completing the one-ball and two-ball tasks for each apparatus.

### 1.3.4 An interpretive framework: The coordination class construct

The coordination class construct will be used here to interpret the interview transcripts and to create a model for interpreting the response patterns of students in the large lecture task administrations. The specifications for coordination classes capture some of the prominent features of students' interviews. These include:

- Developing expectations about realistic motion for the two sets of tracks with a mixture of (potentially contradictory) ideas.
- Focusing on a limited number of observations about information-dense animations.
- Judging two-ball animations differently from one-ball animations.

DiSessa and Sherin (1998) describe a *coordination class* as "a systematic collection of strategies for reading a certain type of information out from the world" (diSessa & Sherin, 1998 p. 1155). The task of a coordination class is to coordinate information that can essentially be directly observed, so as to reliably infer information that cannot be directly observed. For example, a sudden change in the speed of a moving object may be readily observed, but a change in kinetic energy cannot be directly observed. A change in the kinetic energy of the object might be inferred from the observed speed change, other knowledge about the moving object (for instance, its mass distribution and rate of rotation), and appropriate physics knowledge.

In information-dense environments, a coordination class must direct attention to the particular observations that will be useful for inferring the desired information. A coordination class consists of two major parts: the strategies used to accomplish the observations (*readout strategies*), and the resources used to make inferences with the results of those observations (*the causal net*). DiSessa and Sherin describe two types of reliability required of a coordination class: it must coordinate several different observations from one situation to arrive at a coherent set of inferences (*integration*) and it must coordinate the different types of observations available across different types of situations to reliably infer the same type of information (*invariance*). Continuing the kinetic energy example, a coordination class useful for determining kinetic energy would include knowledge about the information necessary for determining kinetic energy, readout strategies for making observations to obtain that information in a variety of different situations, and the causal net resources necessary for reliably determining kinetic energy from different types of observations in different circumstances (*invariance*). A person with such a coordination class would *integrate* the available observations to reach a stable conclusion about kinetic energy in a given situation (rather than, for example, obtaining one result when considering the rate of rotation and a contradictory result when considering the speed of the center of mass).

### 1.3.5 The utility of coordination classes

If the coordination class construct is to endure, it must prove useful for understanding human behavior. Analysis of the interview transcripts and interpretation of response patterns in coordination class terms will thus serve the dual purposes of illuminating student reasoning in the one-ball and two-ball tasks and testing the utility of coordination classes. Many of the issues associated with students' negotiation of the tasks in this study can be described in terms of the components and the reliability requirements of coordination classes.

- Each task involves the extraction and synthesis of perceptual information from the animations to construct a judgment about the realism of the motions portrayed; information construction is precisely the type of work *coordination classes* are supposed to accomplish.
- The animations present a great deal of information, so that students must selectively attend to the features of the animations that can be useful for making inferences about whether or not a depicted motion is realistic; this is tantamount to saying that students must select *readout strategies* that will gather information that their *causal nets* can interpret in terms of the motion's realism.
- The animations present information in the context of objects moving under the influence of gravity, the familiarity of which leads students to base their judgments on several different observations; this can be used to address the *integration* type of reliability hypothesized for coordination classes.
- Switching between flat-valley and V-valley apparatuses or one-ball and two-ball animations changes the context of the animated motions without greatly changing the motions themselves; this can be used to address the *invariance* type of reliability hypothesized for coordination classes.

## 1.4 GUIDE TO THE DISSERTATION

The literature review in the second chapter is primarily concerned with a discussion of coordination classes. Motivation for the use of the coordination class construct, its specifications and previous use in the literature, prior research related to balls rolling on tracks and specific findings of PER relevant to student reasoning in the one-ball and two-ball tasks are also discussed in the second chapter.

The development of the two-tracks animations and detailed descriptions of each motion are presented in chapter three. Realistic and unrealistic features of motions depicted in each animation are emphasized.

Response patterns for each task formed by the complete collection of students represented in the study are presented in chapter four, with a discussion of those patterns in terms of animation features. Response patterns for one-ball tasks are compared with those for two-ball tasks and response patterns for students from less technically oriented classes are compared with those from more technically oriented classes. This raises several issues to be addressed with coordination class analysis and sets the stage for later chapters. Also included in chapter four are descriptions of procedures for administering the tasks in large lectures and in interviews, and a description of student samples.

The main purpose of the fifth chapter is to establish connections between the vocabulary of coordination classes and segments of transcripts from student interviews. Students' expectations for realistic motion are identified as parts of their causal nets. A collection of codes for students' apparent expectations is developed, and the distribution of coding for those expectations within interview transcripts is discussed. Transcript segments describing specific readouts, and suggesting two different readout strategies, are presented.

A student's apparent expectations for realistic motion are sometimes incompatible with features of animations the student identifies as realistic. A student's judgments about an animation can be interpreted in terms of interactions among features of the animation, the student's readout strategies, and the student's causal net. Processes by which students appear to make judgments about animations are examined in chapter six, in terms of the expectations and readouts discussed in chapter five. Extended examples are used to discuss integration and invariance for some interviewed students.

The coordination class analysis is quantified in chapter seven with path diagrams that describe student decision-making in the V-valley tasks. These diagrams facilitate comparison between coordination class descriptions of student reasoning and some features of the response patterns of large groups of students, described in chapter four.

The usefulness of analyzing student decision-making with the coordination class construct is discussed in the final chapter. The importance of coordination processes, readout strategies, and coherence are particularly highlighted, in addition to students' explicitly stated beliefs about realistic motion on the tracks. Potential ambiguities in the coordination class construct and limitations of the procedures used in this study are pointed out, and possible improvements are proposed. Finally, implications of the coordination class construct and the results of this study are suggested for research and instruction, along with potential paths for future research.