Predators of Knowledge Construction: Interpreting Students' Metacognition in an Amusement Park Physics Program

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ABSTRACT: It is recognized widely that learning is a dynamic and idiosyncratic process of construction and reconstruction of concepts in response to new experiences. It is influenced by the learner's prior knowledge, motivation, and sociocultural context. This study investigated how year 11 and 12 physics students' metacognition influences the development of their conceptual understandings of kinematics. An interpretive case study approach was used to investigate students working in collaborative groups in the context of an amusement park physics program. The metacognitive character of individual learners was demonstrated to have a strong influence on their conceptual development. Moreover, the metacognitive character of individuals within the small group contexts investigated was a key factor influencing the groups' collective knowledge development. A *coyote–rabbit* metaphor was developed to interpret the resilience and weaknesses of individual and group knowledge construction processes, and elucidates new theoretical understandings regarding metacognition and its influence on knowledge construction. © 2006 Wiley Periodicals, Inc. *Sci Ed* 1–23, 2006

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INTRODUCTION

Organized school visits to informal contexts are important learning opportunities where students are allowed, and often encouraged, to manage and direct their own learning (Griffin & Symington, 1997). There is a developing literature on learning in out-of-school settings (Anderson, Lucus, & Ginns, 2003; Anderson, Lucus, Ginns, & Dierking, 2000; Ramsey-Gassert, Walberg, & Walbert, 1994; Rennie & McClafferty, 1996; Yagi & Kusaki, 2002).

Amusement park physics programs[1] are informal science-learning contexts that are becoming increasingly popular components of school physics experiences. This popularity can be attributed to the fact that they provide enjoyable, rich, authentic (Pedretti, 1997), and salient real-life experiences of physics principles that can be often quite conceptually challenging for students. Amusement park physics programs provide students with opportunities to "experience" the theoretical aspects of kinematics and to think deeply about their problem-solving processes, including their scientific reasoning ability. Despite their increasing popularity, there is limited knowledge of the nature of students' learning in general and their metacognition within such programs. As in other learning contexts, students' metacognition is important in determining the learning gained from experiences in such programs.

Yagi and Kusaki (2002) investigated students' experience of amusement park physics programs and found evidence that students become empowered learners who construct their knowledge of physics through conducting their own experiments. They also found that because students learn to create and use simple materials to conduct experiments, their self-motivation to discover new ideas by themselves is enhanced. Outside of this particular study, there are no systematic investigations of the impact of amusement park physics programs/experiences on student learning or metacognition. Moreover, as previously stated, research investigating relationships between students' learning, related to any out-of-school field trip experiences, and their metacognition is limited (Anderson, Thomas, & Ellenbogen, 2003). The need to investigate learning and metacognition in amusement park physics programs has been fueled by the now well-established evidence from formal classroom environments suggests that when students become more metacognitive their learning improves, and they become more empowered learners (e.g., Baird, 1986). Given the important role of metacognition in learning, it is prudent to investigate how it influences knowledge construction and conceptual development—beyond traditional formal school-learning contexts (Thomas, 2006). This study investigated metacognition and related learning and as such represents a significant step in addressing the gap in the research literature in this area of science education.

METACOGNITION

Meaningful learning (Ausubel, 1963, 1968; Bodner, 1986) involves among other things taking responsibility for one's own learning processes. Metacognition is often described as active monitoring, conscious control, and regulation of learning processes (Baird, 1986; Baird & White, 1996; Flavel, 1987; Gunstone, 1994; Larkin, 2006; Mintzes & Wandersee, 1998; Thomas, 1999; Thomas & McRobbie, 2001; White, 1993, 1998). While other frameworks exist (Veenman, Van Hout-Wolters, & Afflerback, 2006), it provides a useful view for understanding students' learning. Moreover, this view has the capacity to reveal underlying mechanisms related to student knowledge construction.

[1] For example, http://www.pne.ca/playland/education/education.htm.

Dimension Discernment

There appears to be no uniform definition of metacognition in the literature (Larkin, 2006). However, despite the lack of uniform definition, a review of seminal works in the field reveals some commonality of the aspects of metacognition that scholars consider as germane to their definition of the phenomenon. This leads to the consideration of the differing definitions and the underlying aspects of metacognition that they subsume. In this regard, Baird (1986) considered metacognition to be the *awareness* and *control* of one's own learning. Kuhn, Amsel, and O'Loughlin's (1988) conception of metacognition can be seen as an elaboration of Baird's view, in that they see metacognition in terms of students' ability to not only think with their ideas (knowledge), but about their ideas (knowledge). Furthermore, Gunstone (1994) considers metacognition as an amalgam of student knowledge, *awareness*, and *control* relevant to their learning. Although Baird (1996), Kuhn et al. (1988), and Gunstone (1994) do not specifically refer to *awareness* and *control* as dimensions, these terms can be readily seen as representing aspects of metacognition. White (1992) sees personal *evaluation* of knowledge to be a critical element of metacognition—"judging whether understanding is sufficient. . . [and] searching for connections and conflicts with what is already known" (p. 157). Also, Costa (1991) sees metacognition as in part, involving *evaluating* the efficiency of cognitive performance. Here, also, White (1992) and Costa (1991) place emphasis on *evaluation* which represents another aspect or dimension of metacognition. Moreover, Bellancea and Fogarty (1993) expand this view by seeing metacognition as deliberate and reflective thinking involving the individuals stopping to *plan, monitor*, and *evaluate* their cognitive processes. But these three attributes are different and yet they characterize metacognition, hence present a rationale for considering them as aspects (dimensions) of metacognition. Further, Biggs (1988) considers *self-knowledge* and *task knowledge* as elements of metacognition. These can be seen as reflecting the importance of self-perceptions of one's capacity to learn (*self-efficacy*), and includes how confident an individual is about the effectiveness of his/her learning process and the results of the learning process. Based on this synthesis, six key dimensions of metacognition are discerned: *awareness*, *control*, *evaluation*, *planning*, *monitoring*, and *self-efficacy* and operationally defined in the appendix. Although there might be other dimensions of metacognition, we have found these to be important and useful in understanding metacognition. It is possible that each of these dimensions is engaged differently depending on the characteristics of the learning contexts and the learner. In this study, the dimensions facilitated the interpretation and development of deeper understandings of students' metacognition. Additionally, they formed the basis on which an instrument (to be discussed later in this paper) that provided signposts to students' levels of metacognition and a means for subsequent interpretation of qualitative data pertaining to students' learning.

EPISTEMOLOGICAL POSITION ON LEARNING AND METACOGNITION

This study was framed on the basis of ontological and epistemological underpinnings that view learning as occurring holistically and not only in isolated contexts (Ausubel, 1963; Bruner, 1996), and metacognition as being dynamic and not the domain of any one single context or experience (Flavell, 1979). In this study, learning and metacognition are viewed as processes that manifest cross-contextually, and hence can be examined across both out-of-school and in-classroom experiences. Learning is seen in this study as being an idiosyncratic and dynamic process developed through experiences that are interpreted in the light of the learners' prior knowledge (Driver, Leach, Millar, & Scott, 1997; Hodson, 1986, 1998; Jenkins, 1996; Kilbourn, 1998; Nashon & Anderson, 2004), their attitudes, and their personal background (Guerts, 2002; King, Chipman, & Cruz-Janzen, 1994; Lave & Wenger, 1991). We also consider that learning can be interpreted as occurring at the group level, i.e., within a community of learners, and also at the individual level. Although the value of canonically correct knowledge is underscored, to understand learning and metacognition, necessarily requires the examination of both canonically viable and unviable knowledge (Kuhn, 1970). This is because learners' worldviews or paradigms are key influences on their perceptions or conceptions of their individual realities (Hodson, 1998). Moreover, learners' personal conceptions of themselves as learners, their self-awareness, and control of their learning processes may be both empowering and limiting factors in ways they construct knowledge. Indeed, the sociocultural identity of the individual and the group to which he/she belongs, in large part, determines the learning tools that he/she uses to make sense of the world (Bell, Lederman, & Abd-El-Khalik, 2000; Nashon, 2003a, 2003b; Nashon & Anderson, 2004). Additionally, we consider that all learners make decisions, to varying extents, about the strategies they employ to make meaning of the world. However, personal awareness or consciousness of the learning strategies available to them and the conditions in which they employ the strategies do vary. These considerations further informed the design, conduct, and interpretation of the study.

OBJECTIVES

This study aimed to elucidate the nature of students' metacognition and its influence on the knowledge construction process within the context of an amusement park physics program and within subsequent related classroom activities. Therefore, the study attempted to answer the questions: *What metacognitive character in individual students and groups participating in an amusement park physics program are evident? How are the individual and group metacognitive characteristics influencing and shaping knowledge construction?*

DESIGN OF THE STUDY

The study employed an interpretive case study methodology (Gallagher & Tobin, 1991; Merriam, 1998; Stake, 1995) to capture highly descriptive accounts of the richness of metacognition and knowledge construction. Interpretive strategies are appropriate for this type of investigation, since (a) the holistic, cross-contextual nature of metacognition is not well understood; (b) the strategies are congruent with the aforementioned perspectives of learning and metacognition; and (c) the research questions of this study required a series of cycles of data gathering, analysis, and interpretation, each cycle informing and shaping the subsequent cycles.

The study examined the development of individual students' and small collaborative groups' metacognition as they engaged in an amusement park physics program and subsequent related classroom postvisit activities. Individual student's and groups' metacognition and behavior, as they experienced physics concepts embedded in the amusement park rides and participated in the novel physics problem solving, were the subject of focus. Each small collaborative group from two different classes (one year 11 and one year 12 physics classes of 25 students each) comprised 3 to 4 students. From the physics classes, a subset of four collaborative groups was identified for in-depth study based partly on their metacognitive profiles and ability to work collectively, for more detailed investigation.

Developing a Metacognition Baseline Questionnaire

Based on the review of the definitions of metacognition employed by various scholars (see "Metacognition" section), six dimensions were discerned: *awareness, control, evaluation, planning, monitoring, and self-efficacy*. We consider these dimensions useful to our purposes of examining metacognition in this study. Subsequently, an instrument, called the *metacognition baseline questionnaire* (MBQ), was developed for determining individual metacognitive profiles on each of the six dimensions (see the appendix for descriptors and example items from MBQ). The instrument was designed to assess students' self-reported engagement in metacognition learning situations within both formal and informal learning settings. The instrument comprised 53 items distributed across the six dimensions on a 5-point Likert scale. The 5-point scale required students to self-assess their degree of agreement with propositions conveyed in the MBQ items, i.e., 5—this statement is *always* or *almost always* true of me; 4—this statement is *frequently* true of me; 3—this statement is true of me about *half the time*; 2—this statement is *sometimes* true of me; 1—this statement is *never* or *only rarely* true of me. Descriptions of these scales (from 1 to 5) were derived as a result of wide consultation with experienced high school teachers and our research partners.[2] In particular, the teachers involved in the study helped refine the descriptions to ensure construct validity of the scale. The instrument was similarly reviewed by the same teachers and research partners to improve the face validity of the dimensions, the items, and the instrument in general. The reviewers were required to consider (a) whether the items for each dimension would capture the specific aspect of student metacognition, (b) point out any items that might be confusing to the students, (c) evaluate the appropriateness and relevance of the items as a function of the dimensions, and (d) determine whether the items reflected their own understanding of the six dimensions. This scrutiny led to the deletion, modification, and inclusion of some items prior to field testing. This process was very important in validating the final refined items, which were further validated by our qualitative observations and assessments of the students' learning behavior during group problem solving as they wrestled with meaning making of the physics of the rides.

The instrument was piloted with 40 year 11 students from a school district in British Columbia. The Cronbach-α reliabilities of the dimension-specific statements were within an acceptable range, as follows: *control*, 0.798; *monitoring*, 0.717; *awareness*, 0.671; *evaluation*, 0.765; *planning*, 0.842; *self-efficacy,* 0.894, giving a degree of confidence in the instrument and enabling us to take measures of metacognition of the participants prior to their visit which later were validated by the learning behavior and self-reports of students over the course of the entire study.

PREMEASURES OF PARTICIPANT STUDENTS' LEVELS OF METACOGNITION

All the participating students completed the 53-item questionnaire. Analysis provided individual student's potential to engage the six dimensions of metacognition. The premeasures provided their individual baseline metacognitive self-reported profiles for the six dimensions. These profiles provided one measure of interpretive power on which subsequent student-learning behavior and metacognition were examined.

[2] This research is part of a larger study of metacognition and science learning across science-learning contexts that involves researchers with expertise related to metacognition and science learning from the United States, Canada, Japan, China, and Australia.

Figure 1. The wave swinger picture taken by Pacific National Exhibition (PNE) (http://www.pne.ca/playland/rides_games_ food/rides/wave_swinger.htm). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

Visit to an Amusement Park

Students spent about 4 hours in the park, and devoted about 2 hours of their time to specific tasks, which required them to make both qualitative and quantitative assessments of the rides. For example, students were required to make empirical measurements of the kinematics of the rides (i.e., angles, periods, accelerations, and velocities), using tools such as accelerometers, stopwatches, and protractors. They also individually and collectively wrestled with and formulated models to account for their empirical and sensory experiences. Their deliberations provided the basis for rich discussion and a context for exploring metacognition. Students were asked to consider three rides as cases for their amusement park physics analysis. One ride, the wave swinger, stimulated the most discussion and deliberation among the groups (see Figure 1).

The wave swinger comprises 48 seats suspended from the umbrella-like top that spins around. As this top spins, the seats swing outward while the ride gathers speeds up to 30 mph ($\sim$48.28 km/h). In their groups, the students worked on a set of novel problems requiring knowledge of kinematics or dynamics of the wave swinger ride.

The data corpus collected at the amusement park included researcher field notes, video recordings of the four groups' interactions, and individual voice recordings of each of the 14 case students' conversation. These voice recordings were captured by means of personal digital audio recorders and lapel microphones that students wore. Following the completion of the novel tasks, audio recordings of students' personal verbal discussions were burnt onto CDs. These CDs were then given to each of the case study students and they were asked to listen to their conversations, discussions, and deliberations recorded at the amusement park before being interviewed in their small group cohorts two to three days later about their metacognition and conceptual development.

Postvisit Interviews

All four case groups were interviewed as individual groups. The interviews were conducted in a conversational manner and probed the learning and metacognitive experiences students had during and 2–3 days following their amusement park experiences. The students viewed video clips of what the research team considered to be critical incidents of their group interactions in the amusement park. These critical incidents were indicative of episodes in which individuals or the group showed evidence of development of their knowledge and understanding. The video clips were instrumental in assisting the group members to self-reflect on their learning, and learning processes, in terms of their awareness, control, self-efficacy, evaluation, monitoring, and planning. Students were also given opportunities to discuss their self-reflections emanating from their listening to their personal conversations, discussions, and deliberations recorded at the amusement park.

In-Class Activities

Three days following the group interviews, the students in their original groups participated in classroom-based postvisit activities regarding the kinematics of the rides. The in-class activities were intended to further elicit and challenge students' conceptual understandings of the kinematics manifest in the *wave swinger* ride and to provide the conditions for them to think again about their own learning and cognitive processes as they engaged with conceptual problems centered on the physics related to the ride. Just as in the amusement park, the groups' activities and discussion were video and audio recorded for capturing critical incidents that could be played back to students to assist them to think about their own thinking during the activity. The in-class activities were designed to elicit students' deep understanding of the physics concepts manifest in the rides. The activity tasks included, for example, (1) explaining whether the rider feels a net lateral force while orbiting in the outer-most circle at maximum operational speed, (2) developing physics-based arguments as to why empty and occupied seats revolved at the same height from the ground while in the outermost orbit, and (3) sketching the forces that were acting on the rider while in the outer-most orbit of the wave swinger.

Postactivity Interviews

Two days following the in-class activities, each group was again interviewed about their learning and thinking in relation to the in-class activities. These interviews were also conducted and structured similarly and provided an additional platform for discussions of their own metacognition.

Data Analysis

Data analysis centered around (a) generating students' metacognitive profiles from the paper and pencil instrument, and (b) reviewing collectively and interpreting the video and audio data of the groups' interactions and conversations in the amusement park, postvisit interviews, in-class activities, and postactivity interviews concerning their knowledge construction and metacognition. These reviews involved an iterative process of case analysis and critical reflection by the research team who scrutinized each case group's activity, discussion, and reflection. This process led to rich descriptions of individuals' and their respective group's characteristics regarding their learning processes and metacognition.

OUTCOMES AND DISCUSSION

The metacognitive profiles of individual students were highly idiosyncratic in nature and served as initial quantitative *lenses* through which the qualitative data on metacognition and knowledge construction were described and interpreted. To analogize, we employ a *coyote–rabbit* metaphor to personify the processes of knowledge construction mediated by metacognition as one way to understand knowledge development in both individual and group contexts. In this metaphor, we see the *coyote* as "knowledge predator" and the *rabbit* as "canonical knowledge" (prey). In applying this metaphor, we consider a "*coyote*" to be a threat or predator to canonically viable concepts developing through experiential encounters across contexts—in the amusement park and classroom settings. We consider a "*rabbit*" to be an element of canonical knowledge held by individuals and potentially under threat from *coyotes*. Furthermore, we interpret the state of health of *rabbits* to vary as a function of assaults by *coyotes*. However, *coyotes are not seen* as individual group members but rather as ideas within groups that interact and often do not carry specific intentionality to attack *rabbits*. This metaphor is employed to elucidate new theoretical understandings on metacognition and its underlying influence on knowledge construction. We found evidence of *coyote* and *rabbit* interactions in all data sets, and chose to explore in detail the case of Harriet's group to elucidate examples of these interactions.

The Case of Harriet's Group

Harriet was part of a group of three that included two boys—Gary and Jack (all names are pseudonyms). Harriet was well liked and respected within her physics class. Her metacognitive profile indicated that she had perceived that she was low in *self-efficacy*, but moderate to high in *control* and *awareness,* respectively. Her academic performance in physics was satisfactory, and commensurate with the class average. Gary was considered by his peers to be the most knowledgeable member of the class, and consistently demonstrated high levels of academic achievement. He was a quiet, self-confident learner and a high achiever, generally preferring to work independently, and highly skilled at solving mathematically based physics problems. His metacognitive profile suggested that he perceived himself to be a highly metacognitive learner, scoring highly in all dimensions. Jack was an extremely self-confident physics student who, like Harriet, had demonstrated average academic attainment in physics. He was able to easily generate conceptual models to account for the kinematics of the rides, but was often dogmatic about his views, irrespective of whether they were canonically viable or not. His metacognitive profile indicated that he perceived himself to have low levels of *control*, *monitoring*, and *planning*, but high levels of *self-efficacy*. Table 1 details the group's baseline metacognitive profiles.

TABLE 1
Case Students' Levels of Metacognition

Group A	Harriet	Jack	Gary
Control	3.6	2.4	3.8
Monitoring	3.1	2.9	4.3
Awareness	3.7	3.3	4.8
Evaluation	2.7	3.9	4.4
Planning	2.9	2.4	4.2
Self-efficacy	2.3	4.0	5.0

These MBQ profiles were then used to interpret the learning behaviors discerned from the students' actions during the problem-solving tasks at the amusement park and the subsequent in-class activities. We considered these profiles, determined at the beginning of the study, to be pointers to the individual students' perceptions of their own potentials to be metacognitive during their knowledge construction processes. We use the *coyote–rabbit* metaphor to encapsulate our interpretations of four critical incidents of learning which the group experienced and how these students' metacognition dynamically influenced knowledge construction. The critical incidents are represented as tables that show the discourse in the left column (including footnotes) that are connected to our interpretation of the discourse (commentaries) directly across in the right column.

Critical Incident #1—The Accelerating Forces a Rider Experiences on the Wave Swinger

At the amusement park, Harriet's group was challenged with the task of determining the accelerating forces a rider feels on the wave swinger ride once the ride had reached normal operating speed. Such a task is complex and involves an appreciation of the resolution of forces on the rider. The rider feels neither a forward nor backward push and does not feel a push to either side of the chair at normal rotational speed, but does feel a downward force of about $1.7g$ due to the vertical component of centripetal force, and a constant change in direction due to a net centripetal force.

The incident commences as the group strategizes how to determine the accelerating force felt by the rider. Students are provided with several tools including accelerometers, protractors, and stopwatches.

Critical Incident #1. The Amusement Park—Encounter With the Wave Swinger

Excerpt From Transcript	Commentaries
J: We could either do the math and then ride it or ride it and then do the math. I am in favor of riding it and then doing the math.$_{1.1}$	1.1. Jack chooses a strategy and a plan for evaluating *g* force experienced on the ride.
J: We've got our accelerometer (Jack clutches a vertical accelerometer—spring-based)	
H: No! But don't you have to use the other one to measure g's on this ride? (Harriet points to the lateral accelerometer—protractor-based.) $_{1.2}$	1.2. Harriet questions Jack's choice of accelerometers in order to measure *g*.
J: Because gravity is going to change.$_{1.3}$	1.3. Jack defends his choice of tools. Harriet argues that *g* is a constant.
H: Why would the force of gravity change?	
J: Because, you're going a little bit faster—don't ruin it [my thinking] $_{1.4}$	1.4. Jack does not want his conceptual model challenged.
H: No, that's not going to make a difference. . . Gravity [side to side] isn't going to change! Think about it . . . look at those seats with no one riding them, if gravity made a difference here why	

Continued

Continued

Excerpt From Transcript	Commentaries
would that chair not be way higher than one with someone riding in it?$_{1.5}$	1.5. Harriet declares and rationalizes her conceptual model.
G: How does that work though?	
H: Gravity doesn't work like this [gesturing side to side] . . . it works like this [gesturing downwards] so it's not going to change gravity.	
J: But, it is still going outwards!	
H: Because there was a chair with no one sitting in it, it would be way higher than the rest of them!$_{1.6}$	1.6. Harriet further rationalizes her conceptual model with reference to empirical observations of the ride.
G: If you think about it there is one acceleration going this way and another acceleration going that way.$_{1.7}$	1.7. Gary correctly discerns that there are multiple forces operating on the rider.
J: NO!	
H: Ok, there is no change in Gravity [earth gravity] but there is a change in acceleration!	
Researcher 1: What possible directions could the forces be operating?	
H: Well, there is the force of gravity acting down and the force as the ride starts to spin around.	
Researcher 1: So, do you think these people on the ride are feeling a side to side [lateral] force?	
H: No, that's because the chair is suspended! If the chair was fixed then they would feel a side to side force.$_{1.8}$	1.8. Harriet declares a conceptual position on balanced lateral forces.
[Jack comes off the ride with his accelerometer readings]	
J: It started going from 1 to 1.75 g's . . .	
H: So it changed?	
J: Yeah . . . So you were wrong! [Harriet]. I told You!$_{1.9}$	1.9. Jack strongly defends the validity of his model of acceleration of the ride backed up with his claimed empirical evidence [a *coyote*].
H: Mmmmm. . . [facial expression of dissatisfaction] $_{1.10}$	1.10. Harriet is left unable to defend her conceptual model—but feels dissatisfied!

From this excerpt, we discern that Harriet has some developing appreciations of the forces that are operating on the riders. She correctly holds the view (a *rabbit*) that the rider should not feel any net lateral (side-to-side, push or pull) forces as they sit in the chair as evidenced by commentaries 1.5, 1.6, and 1.8. She also asserts the view that acceleration due to gravity should be constant and hence the rider should not feel any net forces (another *rabbit*). However, she does not seem to appreciate the vertical component of acceleration due to centripetal force. Implied in her view is that Jack's attempts to measure acceleration on the ride are ill-founded. Jack, on the other hand, seems only to be conceptualizing the accelerating forces of the ride in terms of one plane—that of the chain intersecting through the rider, and can find no place for the position of Harriet's embryonic conceptions of both the gravitation and centripetal effects of acceleration. At the conclusion of this incident, Jack (commentary 1.9) feels victorious in the validation of his conceptual understandings of the acceleration of the ride, and Harriet is left with her developing conceptual models under attack by a *coyote*. However, the health of the *rabbit* remains unchanged but vulnerable. It should be pointed out that neither Jack nor Harriet attributed the constant change in direction to the centripetal force of the ride. Jack clearly was referring to experiencing [his perception] a net pull toward the center, which is not what the physics of the ride demonstrates—a view on which Harriet and Jack disagreed.

Consistent with our view of metacognition and learning and the *coyote–rabbit* metaphor, we consider Jack and Harriet's baseline metacognitive profiles (MBQ) as pointers to their individual potential to engage certain dimensions of metacognition (Table 1). Jack possesses a strong sense of *self-efficacy* as a physics learner, average levels of *awareness*, but relatively low in the dimensions of *control*, *monitoring*, and *planning* for learning. We see this combination of metacognitive characteristics to be somewhat debilitating in relations to Jack's abilities to be able to look beyond his conceptual models and consider the alternatives of others. Harriet is low in her perception of her *self-efficacy* as a learner, but moderately high in *awareness* and *control* of her learning. We see her lack of *self-efficacy* as a weakness that leaves her developing knowledge and understanding (*rabbits*) vulnerable and exposed to attack. In this critical incident we see her developing, partially valid knowledge mauled by the arguments and claimed empirical evidence from Jack (a *coyote*). In this sense, Harriet's knowledge (*rabbit*) was mauled and attacked by Jack's position strengthened by his arguments that point to his arsenal of claimed empirical evidence (the *coyote*) as evidenced by commentary 1.9. In terms of the *coyote–rabbit* metaphor, we see evidence at the end of this incident that Harriet's *rabbit* is not dead, given the dissatisfaction she had with Jack's assertions (1.10). We propose that it is Harriet's metacognitive dimensions of *awareness* and *monitoring* that sustained her dissatisfaction with Jack's position at the end of this critical incident and that ultimately maintains the *life* of the *rabbit*.

Two days following the groups' amusement park experience, the group was interviewed together for about 1 hour about their reflections of the experiences in the amusement park. Critical incident #2 below depicts elements of the transcript that elucidate the group's developing knowledge and their metacognition. It commences with a question from one of the researchers.

Critical Incident #2. The Postvisit Interview—Metacognitive Reflection of Learning

Excerpt From Transcript	Commentary
Researcher 1: I want to ask you now about listening to yourselves on the CD of your conversations in the Amusement Park? How did you find that?	
H: I found, with the Wave Swinger in particular—and I was listening to myself, I was so convinced on the day that g's did not change, and when I was writing in my book about the two different concepts—about lateral acceleration and the force of gravity, and I was thinking "I know this" — why was I so convinced otherwise? $_{2.1}$	2.1 Harriet resolves in her own mind that her thinking in the amusement park was wrong.

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Continued

Excerpt From Transcript	Commentary
Researcher 1: How do you know that you knew?	
H: Well because, when I was writing it I was writing about lateral acceleration about how they could be vectors and added together and that the resultant would be the change. And, I've done this in class—I know how to do this, but how-come when I was there looking at it I was so convinced it was otherwise. I couldn't figure why I didn't get it.$_{2.2}$	2.2 Harriet justifies her "wrongness" with reference to common classroom experiences in vector addition, and struggles to understand how she could hold a different view in the amusement park compared to her accepted view at the time of this interview.
J: I found that when I went back and I was listening to it I originally didn't have any questions. But, when I listened to it and when I thought of my own thought processes again—and I remembered what I was thinking and some things I didn't say, and then I thought about it a little bit further and more [and now] there are a few things that just didn't really make sense. There are one or two little things that I didn't get and I feel I should go back and ask questions, which I don't really [tend to] do.$_{2.3}$	2.3 Jack has developing awareness that there may be gaps in his conceptual model.
G: I was listening to myself and other conversations around me. Because usually I don't talk that much. . . and people are like having their arguments over stuff, and I just kind of wait until the end and then I bring up whatever I think at the end.$_{2.4}$	2.4 Gary comes to the realization that he listens to others a strategy for learning and personal knowledge development.
H: Yeah. . . I am the exact opposite . . . I'm right in there!	
Researcher 2: Tell us what is going on in your mind when you are quiet?	
G: Well, I'm am just thinking "how are they thinking" of the same problem. . . I thinking about their thinking so I can do it better.$_{2.5}$	2.5 Gary reveals his strategy for evaluation of others ideas.
Researcher 1: So are you evaluating what others are saying? $_{2.5}$	
G: Some of the stuff I would hear . . . I'd be thinking "no, that's not right". . . And also when I was listening to myself I was confirming to myself a lot of the things that I did, that I was doing the right thing.$_{2.6}$	2.6 Gary recognizes his metacognitive skill for *evaluation.*
Researcher 1: What have you learnt about yourself as a learner?	
J: Well I get distracted sometimes in my thinking. So I won't have complete thoughts. I will get half a thought, and	

Continued

Continued

Excerpt From Transcript	Commentary
just end it, and then go onto something different. And I have found that when I go back listen to myself, I can finish that thought and take that thought further and have more complete understanding.[2.7] Researcher 1: And this is a new awareness that you got in the last few days. J: Oh Yes! H: It's kind of a reality-check that learning isn't always going to be as easy as I thought it was going to be . . . Now, going through the tape and listening to the recording . . . it was almost confusing for me . . . I can't understand why I would say that when I knew it was otherwise. So, I would say things that I would be totally convinced of, but when I look at my notes and think [later] about what I do in class, I was totally wrong. Researcher 1: So, what have you learnt about yourself.	2.7 Jack recognizes his deficiencies as a learner—his personal deficiencies/lack of *monitoring* and *control*.
H: That I second guess myself.[2.8]	2.8 Harriet struggles to resolve her inability to recognize and self-evaluate the validity of her conceptual model in the amusement park.
Researcher 2: We saw you engaged in a discussion and there were very important things that you were saying. To us initially you were on the right track, but you did not persist in defending your idea. What could have happened? H: Arrhhh! [despair] the Wave Swinger! *Students are shown a video of critical incident #1* Researcher 1: So, what do you think?	
G: Ok. . . I was trying to think about what Harriet was saying. . . some of the stuff she said actually kind of fitted to what I thought, like she said the force of gravity was going down and there was another force going out. She actually said that "the force of gravity doesn't change" because it's a constant force acting down. [2.9] Researcher 1: So you were thinking about the correctness of her [Harriet's] thinking? G: Yes. [2.9] Researcher 1: Harriet can you reflect back and tell us about what was going on in your mind at that time. H: I remember myself looking up at those swings, and seeing how the chairs with people in them were swinging out the same as ones with no	2.9 Gary demonstrates and illustrates his metacognitive evaluation processes and concludes components of Harriet's thinking were canonically correct.

Continued

Continued

Excerpt From Transcript	Commentary
one in them . . . I knew that none of them were leaning against the sides of their chairs, so I knew that the chairs must have been absorbing some of that force, like the chairs were moving with them, and I knew that none of them were feeling heavier, cause it didn't look like any of them were doing like this [being pulled down into the chair] like you feel on some rides, cause like *g*'s are really intense. They were all sitting really comfortably, so I could not understand how the force of gravity could change — I just wasn't relating it to the lateral acceleration, why I didn't make that connection, I don't know. 2.10	2.10 Harriet continues to struggle with her model, and again wonders whether she was wrong as earlier declared in 2.1.
J: Something just connected in my mind — Because the chairs were on chains and the chairs moved — that's kind of like the adaptation, and your body adapts to the feel. That helps with the adaptive feeling like the astronauts in space. 2.11	2.11 Jack constructs now constructs new knowledge (alternate view) that there is a lateral force, but that the riders just get use to it.

The excerpt provides some interesting and affirming insights concerning the students' metacognitive processes.

Gary comes to new self-realizations (*awareness*) that he listens to others as a strategy for knowledge construction in addition to his recognition of his metacognitive skill for *evaluation* of his own and other's ideas. Jack declares his deficiencies as a learner, which we characterize as a lack of depth in his metacognitive *monitoring* and *control* dimensions. Jack does not demonstrate any awareness that his interactions within the group have an effect on the knowledge development of others. In other words, Jack appears unaware of the *coyotes* manifest through his interactions with the group. This is unlike Gary who appears to be developing self-awareness that he unobtrusively evaluates, and likely uses, the ideas of others to the service of his own knowledge construction. Additionally, we see Harriet struggling to resolve her inability to recognize and self-*evaluate* the validity of her conceptual model while at the amusement park. Ultimately, Harriet concludes that her views must be wrong but the strength of her metacognitive trait of *awareness* ultimately leaves her struggling still with her current model: the *rabbit,* although severally mauled, still lives. Finally, Jack appears to be considering constructing new knowledge (an alternative view) that there is a lateral force, but now claims that the riders just get used to it.

Three days following our postvisit interview, students in their original groups participated in in-class activities concerning the physics of the wave swinger. The 1-hour activity required the students to discuss further the forces a rider experiences on the ride when it is operating at full speed. The students had to reflect on their experiences on the ride and collectively describe the set of forces in effect. In doing so, the students revealed and developed their theoretical models of the ride's kinematics in addition to making known their metacognitive processes that interceded in the knowledge construction. Critical incident #3 below commences with the group collectively discussing the kinds of forces the riders experienced.

Critical Incident #3. *Postactivity Discourse*

Excerpt From Transcript	Commentary
G: You don't really feel the net lateral forces, because as you're sitting in your chair like this [he models in his own chair] you're straight on with gravity—it's pulling you down—you spin outwards, your chair actually tilts and F_{net} goes straight down into your chair, and you can't really feel any forces going out to your side—so you don't feel squished up against [the side] of your chair.$_{3.1}$	3.1 Gary expresses a canonically correct view he has constructed.
J: I did a little bit.	
J: Ethan did too. . . and Ethan and I went on that ride three times! $_{3.2}$	3.2 Jack challenges Gary's view by drawing on the evidence that Ethan (another student), who also claimed to have felt forces repeatedly.
H: STOP!!!! [placing her hand over her face in despair].$_{3.3}$	3.3 Harriet experiences extreme cognitive dilemma over the opposing views with reference to her own cognitive struggles described earlier.
G: I like my answer better!	
J: Then you put that down and get it wrong!	
H: Ok, let's skip this one and then come back to it![Jack and Gary now huddle together inaudibly and appear to debate over a force vector diagram—Gary emerges abandoning his previous view]	
G: You feel some lateral force! Jack convinced me!$_{3.4}$	3.4 A prolonged debated causes Gary to abandon his previously held view and accept Jacks conceptual model.
H: I don't understand how, tell me!	
G: Well, on one side of the ride on the tilt he slides to the side of his chair and when he came down on the other side of the ride he slid back to the middle.	
H:. . . I don't believe it!	
Researcher 1: So, just let me clarify, who believes there are no net lateral forces? [Gary and Jack raise their hands]	
H: Gary, he skipped out on me!!!	
Researcher 1: Gary, so you believe there are net lateral forces now? So, Harriet you are the only one that now believes that there are no net lateral forces?	

Continued

Continued

Excerpt From Transcript	Commentary
H: Yes, I can only go by what I saw. . . . I can't believe you're skipping out on me! 3.5	3.5 Harriet now holds the view that there are no net lateral forces acting.
G: Well, Jack explained it and I couldn't deny that there was another force there! I had to agree.	

Their key debate centered on the argument about whether the rider experienced a net lateral force. The canonical reality is that the rider does not feel side-to-side force in their seat while the ride is at normal operating speed—but its existence is manifest in a change of direction of the rider. There was some initial agreement with the alternate view that there exists a sideward force that is experienced by the rider. This agreement was based initially on empirical evidence of the protractor-based accelerometer reading (which was incorrectly used—specifically, the group held the protractor level with the horizon and not level in the plane of the rider, thus a measure of $0.5g$ was recorded by Jack). Harriet became aware early that something was not right about the group's model. Gary also questioned the group's model and others' claimed feelings of a sideways force. Jack favored his supposed experience of a pull toward the center to validate his model—a canonically unviable perception. It can be argued that this conceptual understanding of forces held Jack a prisoner to his perception (Nashon & Anderson, 2004). However, Harriet encountered a strong sense of dissonance about the proposed model—and continued to demonstrate high levels of awareness of the precarious nature of the situation. We see awareness as sustaining the life of their (Harriet and Gary's) *rabbits*. Jack, in an attempt to rationalize his model, adds the notion of vector addition over one complete cycle of the ride to appease Gary's and Harriet's view of no feeling of net lateral force. However, Harriet turns to her empirical observations of the riders on the ride to justify her re-emerging view that the riders experienced no sideways pull or push. Gary's *rabbit* is now attacked and is subdued by Jack's model. Consequently, Gary succumbs to the view that the rider must have felt a net lateral (side-by-side pull) force. We consider the *coyote* onslaught to have killed Gary's *rabbit*. Harriet's awareness continues to sustain and solidify part of her original conceptual position—Harriet's *rabbit* still lives.

Finally, two days later, the group was interviewed again about their in-class experiences, their developing conceptual understandings, and their metacognition as depicted in Critical Incident #4 below.

Critical Incident #4. *Postactivity Interviews*

Excerpt From Transcript	Commentary
Researcher 1: What other thoughts have you had about your thinking since we last met? G: I was thinking more about this on the way home for a long time. J: Yeah, it happened to me. I was working on cleaning my punching bag. I was just sitting there moving the cloth over it like that, and I found myself thinking about the physics stuff.	

Continued

Continued

Excerpt From Transcript	Commentary
Researcher 1: And what have you learned about yourself as a learner?	
J: I'll think about something and I'll push it so far and then I'll get to the point, the end result that I really like, and then I'll remember the end result and tell people the end result of things. But, I'll forget how I lead-up to the end result. So I'll be trying to explain it to them, and I won't be able to explain it to them. $_{4.1}$	4.1 Jack reflects on his learning processes and limited abilities to explain his conceptual position
Researcher 1: What did you conclude about your thinking when you were cleaning the punching bag about the physics?	
J: I concluded that what I thought before was right! $_{4.2}$	4.2 Jack affirms his conceptual model through metacognitive reflection.
Researcher 1: So, you affirmed your thoughts about the existence of net lateral forces.	
J: Yeah.	
Researcher 1: What was actually going on in that incident that made you affirm it in your thinking.	
J: I started thinking about it, and I kind of didn't believe myself. But, through the argument we were having I kind of pushed myself to believe it. So, later by myself I went over stuff and tried to convince myself that I was right.	
Researcher 1: So, are you saying that at the end of the in-class activity you had some doubt and you wanted to go back [in your mind] and reaffirm it?	
J: Yes!$_{4.2}$	
Researcher 1: And Harriet what did you learn about yourself?	
H: I hate to be wrong, but that I am often wrong! $_{4.3}$	4.3 Harriet accepts that she ultimately must be wrong in her conceptual model, given the weight of evidence of the group consensus.
Researcher 1: So, just to clarify, where do you now stand on this net lateral force thing?	
H: I [now] think that they are there, but I don't think they feel it.	
Researcher 1: And where are you on this now Gary?	
G: Well I think they are there, and I kind of felt it a little bit.	
H: It's two on one!	
Researcher 1: Have you been struggling with this since we last met, Harriet?	
H: No!! they told me that I could change it [my answer] if I want, but I'm sticking to it. Because, like, obviously I am wrong, but I have no other way to	

Continued

Continued

Excerpt From Transcript	Commentary
describe it. So, why would I change it when I am so sure that I am right, even though it is obvious that I am wrong! 4.4	4.4 Harriet declares that underneath she is still feeling she is right, but also acknowledges the seemingly overwhelming reality that she must be wrong.
Researcher 1: So where do you stand now.	
H: I think that there are lateral forces, but that the chair moves with you, so you don't feel it! 4.5	4.5 Harriet adopts a compromise position—forces exist, but cannot be felt.
Researcher 1: So have you conceded to these guys' view?	
H: No, I don't believe them.	
Researcher 1: So you believe the rider feels no side to side forces?	
H: Yes!	
Researcher 1: But, Gary, Jack, you think the rider does feel a net lateral force.	
G,J: Yes.	
Researcher 1: So, just to summarize thus far. . . Just reviewing the video of the classroom activity, it seems the key issue you have been wrestling with is this business of the net lateral forces. And, so, Jack, right from the beginning, at the amusement park, you have always felt that there was a net lateral force acting on the rider, and you built and maintained this view right the way through. There were a couple of places where you wavered, but you've reaffirmed it again in your mind.	
J: Yep!	
Researcher 1: And, Gary you changed part way through.	
H: Yeah!, he skipped out on me, that's what he did!	
Researcher 1: You were originally of the view that there were no net lateral forces, but part way through these experiences you came to the conclusion that there were. And, Harriet was the last man standing in the army.	
G: Well I just listened to what Jack said and it made sense to me—so I kind of took it in.	
Researcher 1: Let's watch the video of your in-class activity about these lateral forces. [Students watch video of Classroom activity]	
Researcher 1: Let's have a chat about what you were thinking at the time. . . What processes were you harnessing to resolve this issue of the net lateral forces. What were you doing? What was going on?	

Continued

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Excerpt From Transcript	Commentary
G: I was listening to what everyone else said, and trying to test it myself. 4.6	4.6 Gary affirms his personal metacognitive strategy.
J: Well I was trying to visualize it, so that I could get other people to visualize it too. 4.7	4.7 Jack affirms his personal metacognitive strategy.
H: Well I saw it, I watched you ride and ride it so many times! [despair]	
G: When he [Jack] described it to me, I could visualize it too.	
Researcher 2: Were you thinking about "knowledge in books" might be or your experience on the ride?	
J: You have to read it, and re-live the experience while you read, and kind of put the two together—sometimes what you read doesn't make sense, and I don't know, I'd rather believe what I felt than what somebody wrote.	
H: Ohhh. . . [disgust].	
Researcher 1: Harriet can you tell me how you feel emotionally about this now?	
H: I feel out numbered. . . I don't know, it made me feel like every time I am so sure, It's like I am wrong. It's kind of a weird feeling to have cause I feel really strongly about it and I don't want to give up on what I have worked on so hard, because I am sure I am right, but at the same time I know I am wrong.4.8	4.8 Harriet strengthens her resolve that she is correct, and demonstrated a strong awareness of the problems of the other group members' model.
Researcher 2: Why are you not believing?	
H: Well, from what I saw and what they are telling me, it does not make sense!	
Researcher 1: Why don't you want to give up your model—have you rationalized it in your mind in terms of the vectors?	
H: All I can go with is what I saw! What they are telling me does not make sense!	
Researcher 1: What part is not gelling for you?	
H: That they slid to the outside of the seat and then the seat also moved.	
Researcher 1: You know, you are an amazing resilient learner, because here you are still standing after two weeks.4.9	4.9 Harriet does in fact possess the correct canonical model for the lateral forces.
[Researchers start to unpack the canonically correct model of the forces]	
Researcher 1: Let me model this with this bottle of water on the desk. Look at the water in that bottle. Are there any net lateral forces on that body of water?	
G & J. . . [Silence]	
H: No! There is no net lateral force!!4.10	4.10 Harriet realizes that her canonical view is correct.

Continued

Continued

Excerpt From Transcript	Commentary
Researcher 1: Now, let me spin this around like the Wave Swinger,. . . what is that water doing?	
H: It's staying in the same spot, because there are no net later forces! [said with a big smile]$_{4.11}$	4.11 Harriet feels excited and relieved that her view was correct.

In this critical incident, Jack reflects on his learning processes and limited abilities to explain his conceptual position and affirms his conceptual model. Harriet, grudgingly, accepts that she ultimately must be wrong, given the weight of evidence and the majority consensus. Affected by the death of Gary's *rabbit*, Harriet's *rabbit* is again almost killed off. However, Harriet declares that underneath she still feels she is right, but also faces the seemingly inescapable reality that she must be wrong. To reconcile these tensions she adopts the compromise position that forces exist, but cannot be felt. Both Jack and Gary affirm the consistent use of their personal metacognitive strategy and their view that net lateral forces exist. Finally, Gary confirms the death of his *rabbit*, and Harriet's *rabbit* remains robust throughout the discourse, despite the strength of the attacks of the *coyotes*.

CONCLUSIONS

The hallmarks of this group's learning and metacognition evidenced in the data center on Harriet's resilience regarding her developing knowledge of kinematics in the face of conditions that continuously threatened to stifle her canonically viable knowledge and understanding. Additionally, Jack's lack of *control* and *monitoring* of his knowledge combined with his high levels of *self-efficacy* as a learner in physics led him to develop canonically inaccurate conceptual models that not only imprisoned his thoughts but unleashed ideas (*coyotes*) that convinced Gary to abandon his developing valid models for those of Jack's alternate frameworks. Moreover, at the end of the 2 weeks, we are of the view that it was Harriet's dimension of *awareness* that enabled her to maintain a viable and canonically fruitful conceptual model (a surviving *rabbit*).

Many times in the group, individual canonically correct views, *healthy rabbits,* were seen to be *mauled* by *coyotes* manifest through group members who were high in metacognitive dimension of *self-efficacy*, even when the constructs or models were incorrect. Evidence of foundational knowledge was seen blossoming in canonically viable ways, but being "killed-off" or mauled due to these perceptions sometimes manifest in seemingly insignificant comments of other group members who may have no agenda to kill-off blossoming knowledge. The resilience of these *rabbits* to live on and survive attacks by *coyotes* appears to be strongly associated with the possession of strong metacognitive dimensions of *awareness*, *monitoring*, and *evaluation*. We regard high levels of metacognitive *awareness* to be a key factor in ultimately withstanding *coyotes* in the face of low *self-efficacy* as demonstrated by the case of Harriet. Metacognitive awareness may be key to the self-realization of dissonance in the conceptual models being proposed among the group in their deliberation of the kinematics. Furthermore, the resulting and continued dissonance maintains the *rabbit*'s life. The benefits we attribute to metacognitive *awareness* could be manifesting despite the individual's apparent acceptance of the alternative views promoted by the group or the trusted member(s).

The outcomes of this study highlight the central importance of developing the *awareness* dimension for improvement of learners' capacity to engage meaningfully in learning. Our examination of students' metacognition across a series of experiential episodes within both informal- and formal-learning contexts has provided insights about the means by which metacognition shapes and influences knowledge construction. In particular, we examined a specific component of knowledge construction—that of the influences that shape knowledge construction using a metacognitive framework and the *coyote–rabbit* metaphor.

APPENDIX

Metacognitive Dimensions, Descriptors, and Example Items From MBQ

Dimension	Descriptor of Dimension	Example Item From MBQ
Awareness	An individual's character of consciousness about the way he/she learns or constructs knowledge or develops understanding.	*I am aware of when I don't understand an idea.*
Control	An individual's self-regulation and executive control of his/her learning process. The individual consciously regulates and manages his/her learning process.	*I adjust my thinking to suit different science subjects (physics, chemistry, biology)*
Evaluation	An individual's ability to assess the fruitfulness of the learning strategies he/she adopts. It is not about getting right or wrong answers. Rather, it is about strategies that are deemed by the learner to be successful.	*I stop from time to time to check my progress on a learning task.*
Planning	An individual's awareness of his/her learning process that leads him/her to deliberately plan strategies for learning new information. The individual has a conscious awareness of where to start and where to look for tools to manage his/her learning.	*I adjust my plan for a learning task if I am not making the progress I think I should.*
Monitoring	An individual's ability to keep track of his/her learning process by ensuring that things make sense within the accepted cognitive frameworks. Judging whether understanding is sufficient and searching for connections and conflicts with what is already known.	*I keep track of my level of thinking when I am trying to learn something that is new for me.*
Self-efficacy	An individual's self-perceptions of one's capacity to learn, and includes how confident an individual is about the effectiveness of his/her learning process and the results of the learning process. It is about an individual's awareness of the fruitful nature of his/her learning process and the products thereof.	*I know I can master the skills being taught in this course.*

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