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Metacognitive Engagement During Field-trip Experiences: A Case Study of Students in an Amusement Park Physics Program

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Abstract

This paper reports on a study that investigated students' metacognitive engagement of in both out-of-school and classroom settings, as they participated in an amusement park physics program. Students from two schools that participated in the program worked in groups to collectively solve novel physics problems that engaged their individual metacognition. Their conversations and behavioral dispositions during problem solving were digitally audio-recorded on devices that they wore or placed on the tables where groups worked on the assigned physics problems. The students also maintained reflection journals on the strategies they employed to manage their own understanding as well as learning processes.

Prior to the amusement park physics discourse, the students completed a specially-developed questionnaire instrument. This provided signposts of the students' metacognitive engagement during group problem-solving at the park and subsequent related physics learning tasks back in the classroom. This data, added to field notes arising from observations, and formal and informal interviews during post-visit learning activities provided the data corpus on the students' metacognitive engagement. Analysis of this data revealed three types of metacognitive engagement during group learning tasks: collaborative and consensus-seeking, highly argumentative, and eclectic, resulting from high levels of dissonance. In both cases, evidence of individual students' deeper understandings, which manifested through students' cognitive and social behaviors, demonstrated the invocation of metacognition to varying degrees. The novel physics problems tackled by the students created situations where discrepancies between their prior knowledge and the direct experiences enabled them to explicate their thinking through dispositions of behavior.

Key words: metacognition, field trip experiences, metacognitive experiences, amusement park physics

Introduction

Meaningful learning (Ausubel, 1968) in science involves active engagement in hands-on as well as minds-on activities in the process of developing understanding. In this regard, metacognition, which is about awareness and control of one's own learning processes (Nashon & Anderson, 2004; Baird & White, 1996; White, 1993, 1998), is a powerful thinking tool that empowers learners to construct knowledge for understanding and interpreting the world around them. This sometimes is a consequence of searching for viable solutions to discrepant events (Hodson, 1998; Matthews, 1994; Posner, Strike, Hewson & Gertzog, 1982). This view of the process of making sense of the world was employed in designing a study to investigate how students engage metacognition during group learning that involved solving novel physics problems in both out-of-school and in-classroom contexts.

In this study, students were assigned problems that placed cognitive and social demands on them as they experienced kinematics phenomena during a field trip to a local amusement park. The primary research question for the study was, *In what ways does student metacognition manifest while solving novel physics problems in both out-of-school and in-classroom contexts?*

Theoretical Framework

The importance of developing thinking skills as part of meaningful learning cannot be overstated, for this is the process whereby individual learners process incoming information relative to what they already know. It follows then, that metacognition, which involves the thinking skills of awareness, active monitoring and executive control over one's learning (Brown, 1987; Flavell, 1976; White, 1988), is an important tool for meaningful learning. A review of the literature attests that students' active engagement of metacognition is key to developing deeper conceptual understanding (Anderson & Nashon, 2007; Baird & White, 1996; Flavell, 1987; Gunstone, 1994; Mintzes & Wandersee, 1998; Nashon & Anderson, 2004; White, 1993, 1998). An important goal for teachers, then, is to create a learning environment that enables students to become more self-aware of their own learning processes, including the ability to identify these processes and subsequently master (control) them in the service of learning.

Quite often, there is a temptation to limit the conception of student learning to school or classroom settings. Emergent studies have continued to demonstrate the cross-contextual nature of learning, which is holistic and real. School field trip visits to places such as amusement parks, science centers and museums are among the important learning sites, outside the classroom, where students can manage and direct their own learning (Griffin & Symington, 1997; Hisasaka, Anderson, Nashon & Yagi, 2005). A developing literature base on learning in out-of-school contexts clearly demonstrates the value of these settings (Anderson, Kisiel & Storksdieck, 2006; Anderson, Lucas & Ginns, 2003; Anderson, Lucas, Ginns & Dierking, 2000; Falk & Dierking, 2000; Ramey-Gassert, Walberg & Walberg, 1994; Rennie & McClafferty, 1996). Yagi and Kusaki (2002) have investigated students' experience of amusement park physics programs and suggest that when students conduct their own experiments they become empowered to construct valid physics knowledge. Hisasaka et al. studied metacognition with Grade 8 students in Japan and concluded that there are strong correlations between several dimensions of metacognition, in particular, *behavioral evidencing of metacognition*, *evaluation* and *planning*. Anderson and Nashon's (2007) study of high school students' metacognition while visiting an amusement park demonstrated that the key dimensions of *awareness, monitoring* and *evaluation* are critical to the resilience and sustainability of individual capacity to engage in meaningful learning. These dimensions can be developed, with the result that students are empowered in their learning.

When learners are empowered to be aware of and in control of their own learning, they become better learners (Baird, 1986; Swan, 1988). Herein lies an important bridge between the out-of-school and in-school contexts. Such places as amusement parks provide novel opportunity for students to experience phenomena and solve related problems through metacognitive engagement.

Aspects of Metacognition

What has emerged from the varied definitions of metacognition is the fact that each definition seems to focus on aspects of metacognition as indicating different varieties of learner behavior. Discernment of these aspects is discussed below.

There appears to be no uniform definition of metacognition in the literature (Larkin, 2006). A review of seminal works in the field points to what we consider to be aspects of metacognition and which scholars consider germane to their definitions of the phenomenon. We are therefore obliged to consider the differing definitions and the underlying aspects of metacognition that they subsume. Kuhn (2000) and Kuhn and Dean (2004) consider metacognition to be a developmental process, wherein the learner comes to manage cognition through meta-level executive *control*. Metacognition, therefore, is strategic oversight to determine if the goals are met (Livingston, 1997). Thus, according to Baird (1986), metacognition is *awareness* and control of one's own learning. In the same vein, Kuhn, Amsel and O'Loughlin's (1988) conception of metacognition provides an elaboration consistent with Baird's view, in that Kuhn et al. see metacognition in terms of students' ability to not only think with their ideas, but about their ideas. Moreover, Gunstone (1994) considers metacognition as an amalgam of student knowledge, *awareness* and *control* relevant to their learning. Although Baird (1986) and Kuhn et al. (1988) do not specifically refer to *awareness* and *control* as aspects, these terms can be readily seen as representing aspects of metacognition. White (1992) considers metacognition to involve personal *evaluation* of knowledge, which is a critical element of metacognition: "judging whether understanding is sufficient… [and] searching for connections and conflicts with what is already known" (p. 157). Similarly, Costa (1991) sees metacognition as, in part, involving *evaluating* the efficiency of cognitive performance. Cognitive activity, in this sense, would dictate use of background knowledge of, for example, a physics formula into which numerical values are substituted, and then conducting the calculations, leading in turn to problem solution. Judging the efficiency or effectiveness of the solution pathway would be considered metacognitive.

It is quite clear that White (1992) and Costa (1991) are placing emphasis on *evaluation,* which we consider to represent another aspect of metacognition as applied to problem solving. Moreover, Bellancea and Fogarty (1993) expand this view in seeing metacognition as deliberate and reflective thinking involving the individuals stopping to *plan, monitor* and *evaluate* their cognitive processes. Planning is strategic; monitoring is in-process attention; and evaluating is judging efficacy and satisfaction with the ongoing process and its culmination. Finally, 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 thereof.

Based on this synthesis, six key aspects are discerned in the current paper and are referred to as dimensions of metacognition: *awareness*, *control*, *evaluation*, *planning*, *monitoring*, and *self-efficacy*. Although there might be other dimensions of metacognition, we have found these six to be important and useful in understanding metacognition, and they are operationally defined in Appendix A. It is possible that each dimension has a contextual component that is manifest differently according to individual differences among learners. In this study, the dimensions facilitated the interpretation and development of deeper understandings of student metacognition. Additionally, *awareness*, *control*, *evaluation*, *planning*, *monitoring*, and *self-efficacy* form the basis on which a questionnaire was developed (Anderson & Nashon, 2007; Nashon, Anderson & Nielsen, 2005) and used in this study for further validation of its efficacy as a means for subsequent interpretation of qualitative data pertaining to students' learning as well as providing signposts to students' levels of metacognition. Conceptions of metacognition and how it is mediated can also be found in cognitive psychology and cultural psychology, which are discussed briefly in the next section.

Cognitive and Social Mediators of Metacognition

Cognitive psychology has been concerned with metacognition for many years. Metacognition has also been linked to other more general psychological processes (Flavell, 1987). Metacognitive knowledge is part of the activity of human cognition as well as a part of the individual's own cognitive system (Kluwe, 1987). Cognitive processes take place both in the head and between individuals, in a form of social sharing according to Cole (1991). Thomas (2002) views metacognition as nested at the center of a series of factors that move outward from the individual, to the classroom, through school and social/cultural levels, which suggests a significant interconnectedness between the individual and all of his or her social spaces.

Jost, Kruglanski and Nelson (1998), social psychologists, are of the view that metacognition is mediated by the social environment. Through the use of interviews with 8-year olds, Thomas and Mee

(2005) also demonstrated that metacognition is socially mediated, and offering young learners a language to talk about their learning and thinking processes is empowering. This is an important role for teachers. This follows earlier work by Mason and Santi (1994) that suggested talk in a community of discourse as a means to stimulate students' metacognitive reflection consistent with Brown's (1987) notion that in order to be metacognitive, an individual needs something to be metacognitive about. For Mason and Santi, metacognitive awareness exists on several levels: what one knows, why one knows this to be true, awareness of knowledge construction procedures and awareness of changes in one's conceptual structures. These are stages of dialogic argumentation as individuals enter the group setting, where connect individual thinking comes into relation with the group dynamic. More recently, Larkin (2006), in her exploration of the development of metacognitive knowledge among 5-year old children, distinguished between metacognitive knowledge, experiences, goals and actions. She provided metacognitive experiences for groups of students, which then encouraged the social construction of knowledge. Further, the student groups were also collaborating entities, which promoted social skill development. Giving students the opportunity to make their metacognitive processing overt is one place to consider the interaction of metacognitive skills and behaviours, and is just beginning to gain research attention (Larkin, 2006; Martin, 2004). The socio-cognitive perspectives summarized here demonstrate the importance of social settings in enhancing student metacognition in group, as well as individual learning.

The Study

The current study was largely phenomenological (Gay & Airasian, 2003; Johnson & Christensen, 2004; Palys, 2003; Willis, 1991) and employed a case study approach (Merriam, 1998, Stake, 1995, 1998; Stenhouse, 1988; Taylor, 1999; Yin, 2003). It was framed around a constructivist-interpretivist paradigm (Gallagher & Tobin, 1991; Schwandt, 1998), which provided a particular perspective through which data were collected, analysed, interpreted and understood. Grade 11 and 12 physics students from two high schools in the Lower Mainland of British Columbia were taken to an amusement park for the purpose of investigating how students' metacognition manifested as they participated in an amusement park physics program. The kinematics activities in the amusement park physics program are congruent with the provincial Physics 11 and 12 curricula. Further, the study sought to investigate the nature of encounters that triggered students' metacognitive engagement, individually and in groups, as they undertook problem-solving tasks. These tasks: 1) served as triggers of personal awareness of the learning process; 2) provided a focal point for students to gain conscious control and monitoring of their own learning processes; and, 3) catalyzed students' metacognitive engagement in order to elucidate the kind of learning and understandings that derived.

Data Collection

In groups of three or four, students worked collaboratively on novel problems while at the amusement park and during subsequent classroom tasks. The amusement park problem set was developed by a high school physics teacher, Jim Wiese, who for many years has taken his students to the amusement park for "Amusement Park Physics." (see Wiese, 2004). The problem set contains problems that are hands-on and minds-on and use the physical experience of the rides at the park to complement the kinematics units of the physics curriculum. The experiential nature of the problems makes them novel and thus an ideal context for studying students' engagement with their own learning. Sample questions from the workbook that the students completed during the field trip are found in Appendix B.

Prior to the field trip, the students' individual metacognitive dimensions were probed using a specially developed instrument, the *Metacognition Baseline Questionnaire* (MBQ) (Anderson & Nashon, 2007; Nashon, Anderson & Nielsen, 2005). The data gathered from this instrument resulted in metacognitive profiles for each student, which then served as indicators for observing student learning behavior as the students solved problems during the field trip to the amusement park. During the visit, the students' conversations while engaged in problem solving were audio-recorded. The students were also asked to listen to and reflect on their own conversations. Each student recorded reflections about his/her learning in a reflective journal maintained during the course of the entire research study. Early analysis identified critical incidents that informed follow-up focus group interviews, which were also recorded. These incidents were identified by the research group as indicating high levels of discussion between students and engagement with the process of problem-solving. Video clips of critical incidents, which the researchers considered to be signs of metacognitive engagement, were reviewed by students during the interviews and served as focal points for deeper probing by the researchers and deeper reflection by the students. Focus group interviews were semi-structured, but as issues emerged, we allowed (and encouraged) conversations that would elaborate students' awareness of themselves as learners or as participants in a group learning activity. In other words, we wanted to probe layers of universality and particularity with the groups and among all the study participants (Erickson, 1986).

After the amusement park visit, a classroom activity was used to both follow up and elaborate the amusement park encounters (see Appendix C for the Grade 12 version). The activities were specifically designed to extend students' experiences from the amusement park and other background knowledge. The problems were similar to the ones that they had encountered on the day of the field trip, but challenged them to think and process information more deeply. A second focus group interview, complete with additional video clip episodes for stimulated recall, followed several days later. The entire data gathering (pre-visit preparation and MBQ administration, field trip visit, first focus group interview, post-visit in-class activities, second follow-up interview) took about one month.

Instrument: Metacognition Baseline Questionnaire (MBQ)

We have already discussed how six key aspects or dimensions of metacognition were discerned from a review of seminal works on metacognition (Baird 1986; Bellancea & Fogarty, 1993; Biggs, 1988; Costa, 1991; Gunstone, 1994; Kuhn, et al., 1988; Larkin, 2006; White, 1992): *control, monitoring, awareness, evaluation*, *planning*, and *self-efficacy*. The *Metacognition Baseline Questionnaire* (MBQ) is a 53-item instrument that calculates a rating for each of the six dimensions on a 5-point Likert scale (Anderson & Nashon, 2007). Students are asked to consider their level of agreement with each proposition as conveyed in the MBQ items. Choosing 1 means that, "this statement is *never* or *only rarely* true of me." Choosing 3 means, "this statement is true of me about *half the time,"* and 5 means, "this statement is *always* or *almost always* true of me." Anderson and Nashon consulted widely with high school teachers in order to derive descriptions for the 1 to 5 scales. Additionally, reliability alphas were calculated for the items representing each dimension, all of which were within the acceptable range of $0.7 \leq \alpha \leq 1$, as shown below in Table 1.

Insert Table 1 about here

Initially, all students in the current study completed the 53-item MBQ. Metacognitive profiles were computed prior to taking part in the amusement park physics program. The profiles then formed the basis for observing students' metacognitive engagement of the various dimensions through the field trip visit and during subsequent classroom-based activities. Each group of three or four students worked on the problem-solving tasks at the amusement park where the experiences acted as triggers of argumentation and discussion, hence creating conditions necessary for the manifestation of the various dimensions of metacognition. The individual metacognitive dimensions for the students in our four study groups are presented in Table 2 below.

Place Table 2 about here

We consider the profiles to be signposts or lenses to view metacognitive engagement (Anderson & Nashon, 2007), and while the individual metacognitive profiles are believed to be dynamic, the MBQ captures a relative indication of how the learner views him or her self. Our intention was to describe how the students' learning behavior or manifestations of the dimensions of metacognition matched their respective profiles, and these, in part, informed our qualitative analysis. We consider the problem-solving situations as prompting metacognitive engagement, which, in turn, can be used to elicit students' use of prior knowledge in the process of constructing new knowledge and deeper understandings.

Analysis of Subsequent Phases of the Study

As described in the section on data collection, in addition to the questionnaire, data was collected from several sources: group interactions at the amusement park were audio and videotaped; group problem-set worksheets were collected; the post-visit focus group interviews were audio and videotaped; subsequent in-class activities were audio and videotaped, and the worksheets collected; a second round of focus group interviews were audio and videotaped; and, students kept personal reflection journals throughout the study.

Data analysis began in the form of video review of the records from the day of the amusement park visit, where summaries were generated and incidents flagged for follow-up. Emergent themes were explored and refined through serial and repeated review of the data corpus. The themes were elaborated and refined as new phases of the study were initiated with other groups.

Each of the sequential steps in the conduct of the study enabled us to probe deeper and deeper into the workings of the group and the individuals within each group. Prompted by our observations of effective individual or group problem-solving behavior, and as suggested by individual dimensional profiles from the MBQ, we focussed our attention on such behaviors. Through the use of video clips of critical incidents during the focus group interviews, and conversation with the students as a group, successive layers of individual and group interaction were elaborated. For example, after showing a video clip of a critical incident during a focus group interview, the interviewer might say something like, "Ok, let's just have a think about what was going on there. There was a lot going on. Can you tell me about yourselves as learners? What was going on? What was happening?" The episode from the clip served to stimulate questioning and further probing about the manifestation of various metacognitive dimensions.

An initial coding scheme was developed using data from the field trip visit and the first focus group interview with two of the student groups. Codes were used to identify stretches of data that represented and captured that code. For example, two codes for awareness were used: one for awareness of self, and one for awareness of the group as it functioned. Other codes parsed aspects of the methodology, our own metaphors for learning behaviors or different kinds of interactions. The coding scheme was revised and tested again with subsequent steps of the data gathering process, and then again as data sets from the first two groups were revisited.

Each step in the procedure became an opportunity for iteration and subsequent theorizing about the role of individual metacognitive behaviors directed toward the group problem-solving and learning processs. Focus group interviews were directed by these emerging ideas, and probed in a semi-structured manner. Quite often, the focus group conversations involved asking individual students to explain what was going on during a video episode. Students were also asked to elaborate their own thinking about the process of engaging with their own thinking, something that many had not given intentional effort to prior to their involvement in the study. Pseudonyms are used throughout.

Outcomes and Discussion

The baseline data from the MBQ was a starting point for attending to student behaviors during the amusement park visit. Noteworthy are the patterns of behavior that manifest through student interactions within their groups during the day of the field trip and during subsequent in-class activities, because the patterns revealed how the individual functioned within the group and how the group members interacted with one another and the information they were processing. Based on the data from this study, the student's individual profiles from the MBQ, which the researchers considered as signposts of individual metacognitive engagement, were in many respects validated by the behaviors manifested both in terms of their approach to a learning task and involvement with the group. The following sections demonstrate how metacognitive profiles were indicative of behavioral dispositions and learning outcomes.

Metacognitive Profiles

This section briefly describes and characterizes the four case groups for this study and how the dimensional profiles were used to observe group behavior. Through our review of the audio and video records, we watched for individual examples of particular kinds of metacognitive behaviours and skills. Episodes and dialogue presented here were chosen because they reflect the kinds of interactions that typified the groups' behavior. We also watched for patterns of individual and group behavior that corresponded with how similar or varied individual metacognitive profiles were, relative to each other within the same group. Low or high values on any of the dimensions could suggest a propensity for a particular kind of individual approach to problem-solving, either at the amusement park or in-class. Variation of scores within groups led us to consider that intra-group variation may indicate a pattern of behavior at the group level. While group sizes are too small to consider tests of homogeneity of variance, considering minimum/maximum values within a group may offer some insights.

Behaviorally, two of our groups seemed to frequently achieve consensus on group-developed explanations, regardless of the scientific validity of the explanation as an underlying group locus. The other groups seemed to be more argumentative in their approaches to group problem-solving. We wondered if there were some pattern to the intra-group dimensional profiles that could, in part, account for these differential group approaches. Groups A and B, comprised of three and four students respectively, had a smaller range of variation across their dimensional profiles throughout the group. For example, the lowest dimensional score was 3.3 in Group A, while the highest was 4.7. This minima/maxima difference of 1.4 units is comparable to that of Group B (min/max: 3.2/4.7, difference, 1.5 units). Compared to Groups C and D, Groups A and B have a much smaller intra-group variation. The minimum dimensional scores in Groups C and D are 2.4 and 2.3, respectively, while the maximum score is 5.0 in both groups, representing an intra-group variation of 2.6 and 2.7 units, respectively. Further, Groups A and B have no individuals with scores below 3.2, while Groups C and D both have six individual scores less than 3.0. Using the cardinal value as a signpost suggests differential tendencies towards engaging metacognitive skills and behaviours. The presence of several scores in the range 2.3 to 2.9 in Groups C and D suggests weak metacognitive engagement on the part of those individuals on that dimension.

We have come to characterize these intra-group differences by the terms *homogeneous* and *heterogeneous*. Homogeneous groups have min/max dimensional profile values that differ by less than 1.5 units within group, while heterogeneous groups have a variation of 2.5 or more units on their min/max dimensional profiles within the group.

With their smaller variation across the dimensional profiles, homogeneous Groups A and B appeared to use a collective approach to the learning task, and we have labelled this category *collaborative and consensus-seeking*. The members of the groups seek the others' opinions during all phases of working together, from problem clarification to task assignment and problem strategizing. They expect that all members of the group will contribute to the collective effort, and more importantly, value the contributions of each member. The collective effort results in a solution with which all group members are satisfied.

Perhaps as a result of their greater variation across the metacognitive profiles, heterogeneous Groups C and D seemed to use different approaches to tackling the kinematics problems, both at the amusement park and during in-class activities. This observation gave rise to the second of our categories: *Highly argumentative.* The individual members of Group C all had strong opinions about their own ideas and were willing to share them. However, individuals within the group do not easily give up their own ideas, and hence, discussions do not result in a common understanding or even necessarily agreement. This is not to say that the group members were not learning. Rather, the strategizing and problem-solving was characterized by high levels of engagement and *argumentation.*

Individuals within Group D were also reluctant to give up their own ideas, and engaged in occasional argumentation, but also used consensus-seeking and collaborative approaches that were sometimes ineffective or unproductive dialogues, but none of these behaviors predominated. Rather, the members of the group seemed to adopt various of these strategies independent of the other members of the group. We call Group D an *eclectic* group. Elaboration of the three categories and the basis on which we come to understand them is presented below.

Collaborative and consensus-seeking.

The members of Group A were all very similar on their dimensions of self-efficacy, planning and monitoring. The similarity is noted by comparing the range of profiles in Table 2 on each of these dimensions. Behaviorally, each member of Group A proffered problem interpretation and solving strategies for the group to consider. This process was observed during the time at the amusement park and in subsequent follow-up activities and interviews, and the following series of dialogues represent their general approach:

Sal: Since we were all brainstorming and we were all thinking, as soon as someone comes up with an idea, you know they're thinking about it and as soon as they can defend--it's not just coming up with an idea, to be able to defend it, you have to be able to explain it to the other people and both of them can do that.

Nan: When Sal starts off thinking about a question, and then she explains it to us, and then she says, 'No, no, no, wait! That's not how it goes' and then she goes back. I can see that she's thinking about it, and actually figuring.

Mar: When I get an idea, I always either wait for somebody else to say the same thing, or maybe I'll actually say it and see what the other girls are thinking too, because I'm not usually so sure of myself. I always think, when we're doing a question, about Sal and how about a million things must be going through her mind at once, she says 'Maybe it's this one. No, no, no, it's this one. No wait. It's the first one. No wait,' (all laugh) and I only have this one little thing in my head, and she has like 30 of them.

The brainstorming generated ideas, and the group subsequently selected from among these, and it was evident from their behavior that this was the usual group functioning. Group A typified a highly collaborative approach to problem-solving, as depicted in the following episode from the first focus group interview, where the members had been asked to reflect on the process of solving problems as a group within the context of the amusement park:

Nan: We will try to see if everybody agrees. So, one person would say an idea, and then we would each say ours. I think we were checking with each other.

Sal: Because if two of us thought something, [and] someone else had a different idea, then we would listen to both, and it is possible that that person might change their mind, or both of us might change our mind. We wanted to have the same thing.

The members of this group collectively determined a strategy for approaching the problem at hand, and they wanted to have each member of the group contribute and then agree to the chosen strategy. This group behavior of consensus-seeking through checking in with each other was apparent through our observations. Their collaborative approach appears to correlate with their high levels of awareness (Sal: 4.7, Nan: 4.1, Marty: 4.9) and moderate to high levels of monitoring (Sal: 3.6, Nan: 4.1, Marty: 3.5). The generation of ideas was also observed to be a group process of solving problems, in a way signposting the high levels of individual awareness among the group members, not only for the process of problem-solving but also for the general process of learning.

In some cases, the group's highly collaborative approach inclined the group to social harmony in the development of collective knowledge. This social behavior was particularly evident among the members of Groups A and B as the individuals within these groups encouraged each other to make contributions to the group effort. In the following episode from the second follow-up interview, members from Group B were asked to comment on the group problem-solving process, and in particular, what happened in the group if they didn't understand the question or were stuck somewhere along the solution path. The comments reveal the nature of the social interactions within this group:

Nora: yeah, it makes you feel better when you're right. 'I understand,' and you don't want to get stuck

Elly: or argue it

Ana: it takes a lot to say that I was wrong [all agree with her] and you were right

Int: At what point do you surrender to your colleagues? Because it is group work.

Nora: I think, when we agree with them, maybe that is right?

Ana: when it clicks

Carol: when what everyone has said and when other things that have come into your mind as they speak, when all that is weighed against it, it is whatever takes the most weight. It makes you [agree].

Ana: Sometimes it just makes sense.

Elly: and then all of a sudden, you'll be just like ohhh!

Ana: ahhhhh! That's what it is.

Carol: I didn't think about that part!

Elly: or a sudden realization

While individual members like to be correct in their thinking (and recognized as such), they are willing to allow the others to scrutinize the proposed thought or strategy. This leads to a provocative sense-making among the group members, which is fruitfully directed toward a collective group product.

Persuasion with the aim of convincing other group members characterized the collaborative and problem-solving nature of Group A as can be discerned from the interview excerpt below:

Int: Tell me more about changing your mind.

Nan: I know I had to think about it a lot, so if somebody proposed another idea, [I] would just have to think about the steps that would eventually lead to the answer.

Sal: If she thought of an idea, her criterion for me to change my mind would have to outweigh my idea. It would have to prove me wrong, and it did, a lot of times. And it worked both ways.

In an effort to build group knowledge, the members of this group used a particular strategy: the members suggested ideas and then compared them before choosing the one to pursue. Brainstorming, as suggested earlier, was a group process of monitoring and evaluating others' thinking, including considering alternative strategies of problem-solving. Persuading others was a give-and-take process of asking questions, seeking clarification, and evaluating the veracity of the claims. The resulting explanatory model was collaboratively developed. This, we believe, is a function of the similarity (e.g. low variation) among the group members' metacognitive profiles, while their individual abilities to suggest and then defend their ideas seemed to be indicative of their high self-efficacy as individuals within the group (Sal: 4.5, Nan: 3.9, Marty: 3.9). Each group member was free to challenge the rationale for the proposed model, independent of who originated the model.

Their strong willingness to listen carefully to other group members' ideas led the group to form a consensus as demonstrated from pieces of conversations shown here. This strongly collaborative approach correlates with the similarity of individual metacognitive profiles for these group members. In particular, the dimensions of monitoring, planning and self-efficacy are most similar. As well, the group members were all high on the awareness dimension.

Highly argumentative.

Group C (Jack, Harriet, Ethan, Gary) had individuals with high variation among their metacognitive profiles, and a noted propensity for minimal effort at achieving consensus. This resulted in strong argumentation as the group approached problem-solving. The following episode from Group C, which occurred on the day of the field trip visit demonstrates this group's generally argumentative interactions, and this type of interaction was a general pattern for this group. This particular episode came as the group was planning for solving a problem involving a ride on the *Wave Swinger* (see Figure 1). It must be pointed out that this ride was highly challenging for students because the forces in operation are challenging to comprehend or measure, quantify and resolve. As well, students were asked to detect and comment on how and when they felt lateral forces operating. In this group, planning for the solving of the problem at the amusement park often involved dynamic exchanges as the individuals wrestled with interpretations and explanations offered by the members of the group:

Jack: 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.

Jack: We've got our accelerometer.

Harr: No! But don't you have to use the other one to measure g's on this ride?

Jack: Because gravity is going to change.

Harr: Why would the force of gravity change?

Jack: Because, you're going a little bit faster—don't ruin [my thinking].

Harr: 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 would that chair not be way higher than one with someone riding in it?

Gary: How does that work though?

Harr: Gravity doesn't work like this (gesturing side-to-side) … it works like this (gesturing downwards) so it's not going to change gravity.

Jack: But, it is still going outwards!

Insert Figure 1 (photo) about here

In this episode, Harriet and Jack have different ideas about which accelerometer to use in order to measure the force of gravity, *g,* on the *Wave Swinger*. Harriet pointed to the lateral accelerometer, which is a protractor-based tool that Ethan, another group member, was holding, while Jack clutched a vertical accelerometer, which is a spring-based tool. Part of their argumentation centred around their individual views of the effect of the force of gravity on the system of the *Wave Swinger*. The forces on the ride are quite complex, and dealing with the issue of what the rider feels in terms of lateral forces requires knowledge of vector resolution, hence the appropriateness of this problem to cause students to wrestle with generating explanatory models for the system.

Even though Harriet and Jack were working in the same group, they independently constructed different conceptual models. Jack's model included a notion of a varying g, while Harriet argued that g is constant. In terms of metacognitive profiles, Jack is high in self-efficacy (4.0), while Harriet is high in awareness (3.7). It appears that Harriet's high awareness kept her suspicious of others' models, since they did not appear to have explanatory power for her, and she contested them. But, Jack was discontent with the challenge Harriet offered to his own explanatory model. Harriet is correct that the rider feels no lateral force (side-to-side in the plane of the seat of the rider) once the ride achieves equilibrium at its maximum velocity. Jack holds a different view, and asserts his position repeatedly, that the rider does feel a side-to-side force. His efforts at convincing the others include going on the ride with a measuring device in order to attempt to capture the lateral forces empirically. Even though they both have different models of the reality, both Jack and Harriet are probably right: Harriet is focusing on the "feel" and not the overall experience of net lateral force, while Jack is focusing on the correct net lateral force, the centripetal force. It is true that there is no net side-by-side pull or push experienced. But, there is a net lateral force that acts toward the centre of the ride and is experienced in the ever-changing direction, due to the invariable length of the chain connected to the swing that results in the ride's circular motion.

Later, Jack questions the use of the measuring device, seeming unsure of what information was gained therefrom. His colleagues indicated a reading of $0.5g$ on the protractor-based accelerometer for the side-to-side forces, and Jack wonders: "Are we saying that because the device indicates it, or was that what we felt?" This comment reveals Jack's relatively low capacity for monitoring (2.9) and control

(2.4), but nonetheless, he experiences some self-doubt. Yet, almost for the sake of arguing with Harriet, Jack remains convinced by his own view, although unable to articulate it in terms convincing to his group.

In reality the rider experiences a force reactive to the effect of gravity on the seat (e.g. the "normal") and a centripetal force that manifests in changing direction. The argumentation continued into the in-class activities, where the students were asked to resolve the issue of net lateral forces. The members of Group C (Ethan, Harriet, Gary and Jack) were highly mixed (e.g. heterogeneous) in all of their individual metacognitive profiles, especially along three dimensions: control, monitoring and awareness. And although Gary was uniformly high on all dimensions, it appears that the diversity among the group members' metacognitive profiles, in a significant way, seemed to promote argumentation and wrestling among the group members. In this group, individuals argued their points of view, attempted to justify their reasoning and then tried to persuade others to take their view, resulting in others' self-reflection and experiences whereby they could make their own thoughts the object of cognition. Jack, in particular, worked more at rallying others, attempting to convince his colleagues of the correctness of his perceptions. Duschl, Ellenbogen and Erduran (1999) refer to this as "rhetorical argumentation." This was most likely due to Jack's high personal self-efficacy, despite his low control, monitoring and awareness profiles. But Harriet remained unconvinced by Jack's arguments, and we believe this reflects her high level of metacognitive awareness. Harriet is likely using a different type of argument, "analytical argument." We see the use of these different types of argument as particularly fruitful in building scientific models, as frequently evidenced in this group's interactions.

The argumentation continued into the in-class activities, as the students worked to resolve the issue of net lateral forces on the *Wave Swinger*. In the following episode, from the in-class activities, Jack showed Gary how to resolve the forces using a vector diagram and was able to persuade Gary to adopt his position:

Gary: You feel some lateral force! Jack convinced me!

Harr: I don't understand how, tell me!

Gary: 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.

Harr: I don't believe it!

Int: So, just let me clarify, who believes there are no net lateral forces?

Harr: Gary—he skipped out on me!!!

Int: 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?

Harr: Yes, I can only go by what I saw…. I can't believe you're skipping out on me!

Gary: Well, Jack explained it and I couldn't deny that there was another force there! I had to agree.

While these students (with the possible exception of Harriet) demonstrated high self-efficacy as individuals, this may have prevented them from listening to Harriet and considering the reasoning that supported her own conceptual model.

Eclectic.

Like every other group in the study, Group D spent most of their time and energy at the amusement park wrestling with the kinematics of the *Wave Swinger*. In particular, the students focused on which forces were felt and at which point during the ride's operation they felt them. In this episode, Conrad was not convinced that there was a felt force vertically (both upwards and downwards) while on the ride. In a later episode, he takes the opposite view:

Cary: There was centrifugal force and it was bouncing up and down so there were vertical *g*'s.

Con: It was bouncing up and down?

Cary: Yeah, I was. Did you feel it getting lighter and heavier? Going down a little bit?

Con: No, not really.

Cary: Ok.

Con: And there was horizontal force because we were moving forward, right?

Cary: Ahh, well, some, you mean like horizontal acceleration? Forward acceleration?

Con: Yeah.

Cary: You mean, yeah, at the beginning, when you started spinning. And then for most of the ride though, there was just velocity.

Con: Ok. Constant force.

Conrad concludes that there must be a horizontal force because of the observed forward motion, alluding to a common misconception among physics students: a force must be present and operating if there is motion. He apparently had difficulty “feeling” any of these forces, as suggested by Cary.

Part of the amusement park physics problem set asked students a series of qualitative questions, which included describing sensations as the *Wave Swinger* accelerated to its maximum velocity, and subsequently explaining these sensations in terms of physics concepts. It should be noted that the students in Group D were Grade 11 students (as were students in Group A), and circular motion is a topic for Grade 12 physics, so these students had not yet encountered theories and formulas for completing problems in this topic. However, the amusement park physics workbook did guide students through the problems by asking them to attend to particular types of data to collect: radius of rotation, length of chain, time for one revolution, among others. The concept of circular motion remained problematic for Group D, but not Group A, throughout the various phases of the study. While their background knowledge may have been limited, the members of Group D were also limited by their own self-reflective capacities.

One of the tasks given to the participating students was to listen to a recorded CD of themselves talking out loud as their group members worked on problems at the amusement park. The following episode reveals a great deal about the individuals within Group D:

Int: Let me ask you about listening to yourselves…what was it like?

Con: I found out how stupid I was.

Int: So when you're listening to yourself and you're hearing yourself, you thought that you said some things that were stupid?

Con: Yeah.

Int: Like what in particular?

Con: Umm, just making mistakes.

Int: This is like physics things?

Con: Yeah.

Int: When you listen in hindsight, you think, ah.

Con: How could I have ever done something like that? Oh, gravity…pushes you.

Int: But you weren't aware of it at the time you said it?

Cary: At the time.

Con: I was, well, some of the times I was and then I would correct myself later.

Cary: You don't realize how dumb it sounds. You just kind of keep on going.

Con: I didn't care at the time. I was just trying to say something.

The students in this group, through the process of listening to themselves, became aware of the inconsistencies or errors in their thinking as revealed in the group dialogue, but this awareness did not automatically result in a new search for better understanding. Conrad was observed on the day of the amusement park visit and during the first interview to defer to Cary's knowledge, even though he

(Conrad) did ask pertinent questions. He was willing to go along with whatever Cary suggested, though, and was uncritical on several occasions. Later in the interview, it was noted that Cary verbalizes his thinking to the others in his group. He does this to check out his ideas, but others in the group do not necessarily help him to think deeper or to build better understandings, as we observed to be the case in the other groups. Cary was asked about what he was doing while others responded to him 'thinking out loud.' He reflected on an earlier episode where the group members were wrestling with the angle that the swing would make if a heavier rider were seated in the chair. While Cary was reflective, Conrad simply agreed with Cary's notions, uncritically, even when two opposite ideas were proposed:

Cary: The problem with the first idea I had here that they'd swing out different lengths, and you agreed with me.

Con: Yeah, I concur.

Cary: If you agree, then, I kind of took that as, ok, well, we have someone else who follows through the idea, who understands what I just said and things that make sense, so that's good, but unfortunately it was wrong.

Con: I agreed with him when he was wrong.

Cary: Yeah, and then you agreed just as much when I made my other idea which proved the first one was wrong.

Con: But I was still agreeing with your first idea when you were halfway through your second idea.

Cary processed responses from his group members and assumed they understood what he was talking about. From Conrad's last statement above, it is clear that the assumption made by Cary was invalid. Perhaps Cary was simply thinking too fast and his group members were unable to keep up with him. This would seem to be consistent with Cary's low metacognitive profiles for evaluation (2.4) and monitoring (2.8). Or perhaps Cary's group members do not have enough background knowledge with which to engage his thinking. In any case, though particular to this group, it might point to a challenge for group work, and for developing new, collective understandings when the individuals are 'on different pages.' The difference between Cary and Conrad in terms of their metacognitive profiles, as reported in Table 2, is marginal except for the dimensions of evaluation and self-efficacy (where Cary is much higher on both). While Cary is capable of evaluating the quality of others' contributions, the others do not have much to contribute to Cary's understanding or, as a result, to the group effort. But, Cary's high self-efficacy keeps him engaged with the learning process anyway. For him to advance his understandings, he needs access to additional information, as the quality of his own theorizing is not critically examined or judged by any authority in the context of this group. While this could be seen as a critical role for group construction of knowledge, in this group, it was a weakness that resulted from individuals' poor background knowledge and lack of conceptual awareness. And, with their inability to be metacognitive in any meaningful way for each other, the group was ineffective in its learning behavior.

The in-class activities, a few days after the first focus group interview, stimulated recall of the amusement park experiences and provided the students with further opportunity to explore the kinematics they encountered during the field trip, and even subject the developed propositions to further scrutiny by group members. The study groups continued to struggle with where the forces ought to be felt as they analyzed the problems during the in-class activities. While the research protocols and interviews provided opportunity for students to engage in self-reflection (and this type of self-reflection was evident in other groups), qualitative evidencing of significant changes in how the students in Group D approached problems was not revealed during later phases of the study. Conrad remained unable to critically consider previous engagements, including listening to himself or what he had said previously. Despite earlier attesting (during the field trip) that he couldn't feel gravity, he assures Cary that he can in this episode:

Cary: You can't really feel gravity, because you don't

Con: Yeah you do.

Cary: No, you feel the lack of gravity. You don't notice gravity because

Con: feel gravity

Karl: You have special senses.

Cary: Ok.

The third member of Group D, Karl, interjects a facetious comment here, and in fact, is one of the rare times he spoke at all. He seems to be aware of Conrad's absurdity, and teases him about it, while Cary simply disengages.

In this group, the individuals did very little to contribute to the building of collective understanding. Individuals, rather, seemed to pursue their own lines of reasoning. When prompted, their engagement was more highly metacognitive, but it seems that with the normal patterns of their group interaction and insufficient background knowledge, they were unable to further interpret the amusement park experiences and develop them into deeper, more coherent knowledge structures. In other words, the experiences were not meaningful learning opportunities for this group. So, while, in Group C (Grade 12 students whose background knowledge is assumed to be sufficient to engage more deeply with the physics of circular motion, since this is a topic they had covered in class already), where differing metacognitive profiles of the individuals led to argumentation, the Grade 11 students in Group D had limited background knowledge compared to their Grade 12 counterparts, and the variation among their dimensional profiles could not be called into service to build new knowledge.

The student groups functioned as learning groups, more or less effectively, according to the individual metacognitive profiles of the members of the group. An additional facet to the learning experience was the nature of the problems that the students encountered while at the amusement park. The next section elaborates the experiential nature of the learning activities at the amusement park. The experiences were often discrepant, in the sense that students were faced with forces and kinesthetic feelings that challenged their prior knowledge. Engaging with their group members to explore these discrepancies served to promote development of deeper understanding of the physics concepts.

The Nature of Student Learning Experiences

While at the amusement park, students encountered a series of problems, the nature of which required students to call upon prior knowledge, attend to the actual experience of the forces while on the rides and engage socially with their group members in order to strategize and solve the problems. The activities and problems revealed discrepancies between students' theoretical understandings and their direct experience of the kinematics while on the rides, discrepancies that would not be apparent but for the experience of actually going on the rides. These discrepancies then prompted alternative problem-solving strategies and hypothesizing, which in many cases, were beyond the scope of the classroom learning experiences the students had encountered prior to the field trip. For three of our four groups, this level of engagement was highly fruitful in terms of students' learning. The resulting social discourse as the students engaged with the problems and worked as a group of learners, served to stimulate metacognition.

All of the participating students seemed to be aware of discrepancies between their observations and experiences and individual understandings, but this condition was not sufficient in itself to enable the building of new knowledge. For the Grade 11 students in Group D, this was obvious in their lack of ability to even suggest theories and offer reasoning to support ideas. But for Group A (also Grade 11 students), the discrepancies seemed to provoke the desire for developing new understandings. Both of these Grade 11 groups had been in the same physics class all year (the amusement park visit took place in May, near the end of the school year). The students' marks distributions to this point of the term were as follows: Group A: Sal, 84%; Nan, 86%; Marty, 85%; Group D: Cary, 84%; Karl, 72%; Conrad, 95%. In a way, the groups' background knowledge in terms of exposure to physics concepts could be assumed to be similar, since they all had been in the same Physics 11 class all year. We argue that it is individual characteristics and collectively, the group profile that is different in this study. We have termed the group profiles in Group A homogeneous and thereby collaborative and consensus-seeking, while Group D was heterogeneous and thereby eclectic, and its members were unable to contribute to building deeper group knowledge. The metacognitive characters of the group, thus, appear to be key. This proposition is being investigated in other learning contexts in subsequent phases of the current study.

Group C provides an interesting contrast to Groups A and B because of the individual metacognitive profiles of the members of these groups. The behaviors of students in these groups seem to reflect the individual metacognitive profiles of the group members, suggesting a tendency to work in certain types of ways. Groups A and B, whose members had similar metacognitive profiles were highly collaborative. Group C, being a mixed or heterogeneous group, appeared to use argumentation as the predominant mode of theorizing and problem-solving, this being most probably the result of their different ratings on the metacognitive dimensions. Members of Group D, although mixed, were unable to draw upon relevant background knowledge or call upon their own or others' metacognitive skills and behaviors in order to develop deeper understandings.

Inferential Discernments Across the Groups

The students became aware of the discrepancies in their own understandings through the field trip experiences because the problems: a) promoted social interaction and mutual group reflection of members' ideas; b) promoted argumentation and challenged interpretation of members' experiences; and, c) offered experiences that were counter-intuitive or contrary to earlier predictions or hypotheses.

Many participants became increasingly aware of the functioning of the group through participation in the study. This awareness served to promote Nora's (Group B) own deeper understanding by connecting various pieces of information together in the group problem-solving process:

Nora: You'll have two pieces that you can't connect at all and someone will give you that middle piece and then you can put everything together.

Int: This awareness—you're talking about others helping you to learn. Is that something that you've been aware of before? Or is it a new thing to you?

Nora: I think it is somewhat because we did know to ask each other. We always asked each other.

But the awareness also served an important social function in terms of building new knowledge. The members of Group A relied on each other for confirmation of their individual as well as collective thinking. In the following episode, they were talking of their estimation skills:

Sal: When you measure something, you would think, you would usually compare it to something that I know the length of, like she said the height of a person, so I would ask myself, well, does that make sense? I mean if you look at, and we would work backwards.

Mar: We were checking.

Sal: Yeah, we were checking ourselves. She would say something, I would check in my head, or if I would say something, she would probably check too.

Sometimes, the individual thinking of group members led the rest of the group astray. This may seem to be a natural function of having several people, of differing abilities contributing to a group effort, all brainstorming ideas. Some ideas were fruitful, while others were not. Group B talked about this during the second focus group interview:

Ana: Sometimes you're just thinking too hard, (Carol points at her and nods). Grabbing the wrong thing.

Car: Yeah.

Elly: Especially if you go off in one direction and then once you're going that direction, it's hard to turn back and reroute.

Nora: It's hard to think of [something] completely different. You start to get rid of information, like if you thought you were going to do it this way and it turned out to be wrong, it's kind of like, 'how else am I going to do this?'

Elly: 'I thought I was right' kind of thing.

Int: Are there times when you believe you understand the question, but you are not getting it?

Nora: Oh yeah.

Elly: It's true.

Int: So, what happens?

Nora: Like the stuff we're doing right now is confusing.

Int: What happens when that is the case?

Elly: It's hard to step out of that box.

Ana: Sometimes you usually don't know unless people, other people, find out for you.

Through social interaction and willingness to collaborate, the Group B members collectively built new knowledge. Part of the social skill revolved around an awareness of what the other members of the group were considering or the pathways they were interested in pursuing. Determining the value or plausibility of any idea involved group monitoring, which in turn depended on the social skills of individual group members in articulating their thinking, but also an understanding of each other as learners. This mutual reflection about others' ideas was, in our view, key to developing group knowledge, as Group B describes in this episode from the second focus group interview:

> Nan: I think some of us are good at different things. Some of us know more about momentum.
>
> Car: Yeah.
>
> Nan: And some of us know more about energy. I think we all use that to help.
>
> Elly: Yeah, it helped working in a group, definitely. Because I didn't remember all the circular motion stuff, and they were just kind of like doing it, and I was like, oh yeah!
>
> Int: Ok, and who was good at momentum?
>
> Nan: Oh, I knew about how to find the velocity at the bottom, the E_p, the potential energy plus the kinetic energy.

Individuals in the group benefit from each other's thinking. For Groups A and B, the collaborative effort was intentionally used to build new knowledge. The members of the two groups became aware of the gaps in their understanding through the social process of talking through and strategizing the problem-solving process. Their collaborative and reflective activity was productive in terms of building collective knowledge largely because within the group there was a wealth of background knowledge, and each person offered ideas for the group to consider. Each member's opinion or thinking was valued by the rest of the group and given due consideration in the group's thinking, reasoning and problem-solving. However, Group C was highly argumentative. This also resulted in productive learning, but perhaps in a different way.

The argumentation happened on many levels, but centred on how the individual group members perceived the problems that the group was tasked to solve. Some group members used argumentation as a means to externalize their thinking (Osborne, Simon, Erduran & Monk, 2002), sort of 'thinking out loud' in a collective problem-solving process. Others attempted to use logic to promote their own point of view, although there is some evidence that individual students were using different criteria for judging the quality of evidence (Toulmin, 1958), and hence, the quality of their arguments varied (recall the episodes between Jack and Harriet from the field trip and in-class activities). This seems most obvious in Group C, with Jack in particular. It may be that his individual metacognitive profiles, especially those of monitoring and planning, do not encompass a very sophisticated reasoning scheme or structure of logic, which in turn prevents him from being persuasive in his arguments when he tries to convince his group members of his point of view. Argumentation was a means whereby this group engaged the open-ended nature of the problems, which in turn served to elicit many and diverse conceptual models from individual group members upon which the metacognitive skills of monitoring and evaluation could be applied. The group members then sought to explain and justify their positions to the others in the group on either the process or the solution. By challenging each other's interpretations of the problems, as well as the conceptual understandings they were developing, relatively deeper understanding of the kinematics evolved.

An additional source for making discrepancies visible was in the nature of the experiences while at the amusement park. Quite often, students failed to connect their classroom learning with any sort of direct experience in the "real world." We consider this to be a failing of the school and classroom environment (although it negates the importance and reality of other constraints placed upon classroom practice) and was identified as a major benefit of the out-of-school experience as noted by the students from the study. In many cases, the activities built around the amusement park rides required the students to comment on their sensations of the forces felt while on the ride. This type of question could not ordinarily be asked in a textbook-based or classroom-based lesson without invoking a layer of abstraction from the actual experience. As a result, students' attention at the amusement park was drawn to trying to explain the feeling in terms of the book knowledge they had already encountered. Quite often, the feeling was counterintuitive from the previously "learned" physics concepts. The members of Group A talked of this in the first focus group interview:

Nan: I think that, yeah, in this field trip, we had to think about things really in a different way, because usually in class, we get a formula and we just put that information into the formula and that's it, [and] sort of found it all more useful when we went [to the amusement park] because we had to actually think about what we were doing. We had to think about why each one was the way it was and how we can apply it to other formulas, how we can apply it to other things, as opposed to just in class, where we get one, and you're like, oh, you can do this and substitute this in for this and you don't really have to think about what you're doing.

Sal: I agree that you don't have to think about it. A lot of things are really very simple, but even in class, we get the challenging problems. Like, for me, as soon as it's challenging, I notice myself picturing it, like the roller coaster, the roller coaster questions that we had in class. I was actually picturing, 'ok, this is up here and…' in my brain, things are going. Because I'm a real visual learner, too, I think, so I was thinking that way. For some of the more challenging questions in class, it's the same thing. We have to apply all of our knowledge, because we have to figure out from where to start, where to begin with the question, and that was something that happened at the field trip.

Mar: Yeah, I kind of thought that too. When it was a challenging question, you would think, 'well, what's the main thing that we need to find?' And then there would be extra stuff that you need to find, like the information to put in that formula, so there was a lot of little stuff.

The fact that the challenge offered by the problems elicited reflective consideration by each of the group members leads us to conclude that the problems were successful in creating cognitive dissonance and metacognitive engagement. As a result, these discrepant events promoted the generation of alternate problem-solving strategies. The format of the problems, situated as they were in the field trip activities, allowed thinking to be vocalized and dialectically reflected upon, thereby exposing discrepancies with prior understandings. It is under this situation of "cognitive dissonance" that students begin to wrestle with the observed and felt experiences and how it fits with their own knowledge. Germane to this is the rehearsal of previously learned material that in a way improved their understanding of the knowledge they had gained earlier without having opportunity to experience or apply in real life situations. At this point, metacognitive skill comes in and the tool kit represented by the metacognitive skills and behaviors can be put into service. These understandings, developed in the out-of-school context of the field trip, then become part of background knowledge that can be called up when similar or other situations arise in later learning challenges. The individuals then contributed to the group learning with the result being deeper and wider knowledge development that integrated prior knowledge, experiences at the amusement park and subsequent learning from in-class experiences.

Conclusion

In conclusion, we believe that the problem-solving activities from the field trip and in-class activities enabled the students to develop deeper understandings of the kinematics concepts they encountered, enriching their prior conceptions. Further, participation in the study allowed them to learn about themselves as learners. The out-of-school context provided a rich environment for the type of experiential learning that engaged the bodies and minds of the participants, and the in-class activities further engaged the students and afforded them the opportunity to consolidate knowledge and develop deeper understandings. In this study, students worked in groups during field trip encounters with exciting and highly motivating problems. We observed that the nature of the problems with which the students were tasked stimulated metacognitive reflection through group interactions. The participating students also showed a growing awareness of themselves as learners through the progress of the study: by asking them to be metacognitive through talking to each other and to us, they came to understand themselves better as learners. We see these deeper understandings (of physics and of self) to be the result of several factors.

In the first place, the individuals within the groups brought personal metacognitive skills and behaviors to the group effort. The individual combination of dimensions in many ways seemed to dictate the student's approach to working within the group setting, but also how the task of learning was approached and new understandings sought. Groups that had little variation among the six dimensional profiles seemed to work to achieve a consensus, and with the motivational environment of the amusement park field trip, these students had the potential to build rich new understandings of the forces they experienced while riding the rides, irrespective of their levels of background knowledge.

In this case study, when dimensional profiles for members within the group are highly varied, a different type of collective effort by the group resulted. High self-efficacy and low monitoring, in particular, are dimensional profiles that seemed to dictate an argumentative approach that resulted in diverse explanatory models being proposed among the group members. The effort became a group learning situation when individuals were able to rationalize their thinking patterns and justify their thinking to their group members. However, when the dimensional profiles of group members are mixed and their background knowledge is weak, such as in Group D, the lack of constructive argumentation resulted in 'information stagnation' where the potential richness of the experiential activities cannot be utilized to deepen conceptual understandings.

An individual’s metacognition requires an object on which to act (Brown, 1987). The problems that engaged the students in this study were also experiential, thus offering several levels of involvement with the physics concepts. Both the experiences and the concepts became objects for metacognitive processing and strategizing, as well as for cognition. This study allowed us to observe individuals using metacognition in the process of meaningful learning, and this occurred through the group activity of collective problem-solving. If, as Kuhn (2000) suggests, that meta-knowing is a goal of cognitive development, then engaging learners in novel problem-solving contexts represents a place to observe the acquisition of new knowledge. This study offered such a place where metacognitive awareness and executive control move planning for problem-solving into the realm of building conceptual understanding.

Implications for Science Teaching

This study suggests that if teachers had some idea of their students’ individual metacognitive profiles, it would be possible to utilize this information to a learning advantage in terms of group configurations and problem development for various classroom activities. For teachers to attempt an assessment of their students’ metacognitive profiles is unlikely, and may not be practical. However, through careful management of the problems being assigned, the varied metacognitive dimensions will be automatically called upon in the service of functioning within the group. This is to say open-ended, experiential and counter-intuitive problems will serve the function of drawing out individual thinking. It is when the individual’s current understandings can be brought out into the open, in a setting such as a group learning situation, that the need to rationalize and justify one’s position becomes part of the social discourse of the group. Herein lies the importance of the nature of the problem to stimulating use of metacognitive tools in developing higher quality learning objectives.

The problem-solving activities reported in this study were designed for groups, and it is herein argued that the problem's ability to promote social interaction on multiple levels should be given top priority in instructional planning. When students must verbalize their thinking, rich potential exists for developing collective understanding, through the process of negotiating meaning, sharing knowledge and collaborating on a social level. We saw this to be quite fruitful for the four case groups from this study. And, although our findings are particular to these cases, we believe that there are important implications for the wider science education community. Along with the social nature of group interactions, when the problems also require individual or collective interpretation of the problem, the solution path or the connection to learning in a more formal sense, then the experiences from the field trip become more productive in terms of students connecting assorted pieces of knowledge together into a more coherent and structured knowledge system, Kelly's (1955) *personal constructs*.

In terms of group configuration as collaborative or argumentative, it may be less important to identify which group type(s) are present than to offer problem-solving situations where all students can actively contribute to the group processing. We see this as a function of not only background knowledge, but also the individual characters of self-efficacy and awareness. In one of our collaborative groups, we noted a consensus-driven strategy adopted by the group, suggesting that there was insufficient discrepancy apparent in the problems with the result that individuals were satisfied with the group result prematurely. This may also reflect a lack of background knowledge for solving the problems.

Finally, the experiences that the participating students were afforded in this study provided opportunity for students to directly experience the kinematics concepts through the rides at the amusement park. These concepts are the focus of physics instruction in the classroom, and thus the students were enabled to consider the amusement park experiences alongside what has previously been understood or learned. The chance to expand and deepen conceptual understanding through integrating the knowledge gained through the more formal or traditional classroom type of learning with the direct experiences from the field trip serves to challenge student understanding, call up metacognitive strategizing, allow students to develop collective problem-solving strategies and to work together in a highly social environment. Carefully designed problems serve the role of creating cognitive dissonance, which in turn allows students potentially fruitful opportunity to engage in meaningful learning through the calling up of individual metacognitive characters in the service of developing new understandings.

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Appendix A *– Descriptors of Metacognitive Dimensions and Example Items from MBQ* (Anderson & Nashon, 2007)

Dimension	Descriptor of Dimension	Example item from MBQ
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, biology, chemistry).
Monitoring	An individual's ability to keep track of his/her learning process by ensuring 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 new for me.
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.
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 the 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 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 process learning task if I am not making the progress I think I should.
Self-Efficacy	An individual's self-perception 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.

***Appendix B**. Sample Questions from Amusement Park Physics workbook (*Wave Swinger *ride)* (Wiese, 2004)

A. Data

1. distance from center of rotation to chain attachment
2. length of chain
3. radius of rotation
4. time for one revolution
5. angle of swing to rotation axis
6. accelerometer reading

B. Qualitative tasks

1. Will an empty swing or one with someone in it ride higher? Why?
2. Describe your sensations as the ride increased in speed.
3. Explain your sensations described in #2 in terms of the physics of the ride.
4. Watch the ride from the beginning until it reaches full speed. What happens to the angle of the chain attached to the seats as the ride increases in speed? Why?

C. Quantitative calculations

1. Using radius of rotation, determine the centripetal acceleration of the ride. Determine the centripetal force.
2. Draw a vector diagram of the forces acting on you during the ride. These are due to the different accelerations you are undergoing.
3. Using the calculation in #1 and the acceleration due to gravity (9.8 m/s^2), determine the resultant acceleration you should feel. How many g's was it?
4. Compare #3 with your accelerometer reading. How do they compare? Explain any differences.
5. From #3 above, determine the angle you should have been swinging at. Compare this to Data #5. Explain any differences.
6. What is the tension in the chain of the swing that held you? Assume the chain and chair have a mass of 25kg.

Appendix C. Grade 12 Post-Visit In-class Follow-up Activity

Post-Playland Thinking Task

University of British Columbia – Metacognition Study

Think about your Wave Swinger experiences at *Playland*

1) Describe the forces you felt over one complete rotation of the ride at full speed. You should describe in detail a) the forces you felt, b) the direction(s) of these forces, c) the durations of these forces, and d) the periodicities of these forces.

2) Draw the path of a rider, in one of the chairs of the *Wave Swinger,* over one complete rotation. [Hint: Think about the plane of rotation of the ride].

3) Now illustrate diagrammatically the forces described in Question 1) (above) using *free body diagrams.* You may use multiple diagrams to describe the forces you experienced during the course of the ride. In each of your diagrams show F_{net}.

4) Does the rider experience net lateral forces? Explain your answer.

5) How does the mass of a rider affect the overall lateral forces experienced on the ride?

6) How does the mass of a rider in one of the chairs of the *Wave Swinger,* over one complete rotation, affect 1) the overall forces experienced, and b) the path of a rider?

7) If time permits: Challenge Question: Imagine the angle of the plane of rotation of *Wave Swinger* increased from 20^0 to 45^0, predict how this would affect the forces you experienced on the ride.