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Technology Supported Collaborative Learning

PAREA REPORT PA2007-014

Technology Supported Collaboration and Learning

How do we build learning environments to build communities & conceptual knowledge?

.

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RÉSUMÉ

Le processus d'apprentissage se situe dans le courant des activités humaines et est facilité par les interactions sociales (Lave et Wenger, 1991; Vygotsky, 1978). Nous devons donc mieux comprendre comment concevoir des activités socioconstructivistes et socioculturelles permettant aux étudiants de collaborer, et comment ces collaborations facilitent l'apprentissage. La présente recherche est divisée en quatre études sur l'apprentissage conceptuel, menées auprès d'étudiants en première année de science durant un cours d'introduction collégial à la physique. L'Étude 1, de conception quasi expérimentale, compare l'efficacité de divers types d'enseignement collaboratif – trois différents modes d'enseignement par les pairs et un cours virtuel encourageant la construction du savoir – à l'efficacité de l'enseignement traditionnel. Les résultats démontrent que les étudiants en mode d'enseignement collaboratif réussissent nettement mieux le test conceptuel (l'Inventaire du concept de force ou FCI) que les étudiants en mode traditionnel. L'Étude 2 vérifie l'efficacité de la discussion par opposition à l'autoréflexion. L'Étude 3 comporte 3 parties. L'Étude 3A présente une analyse de l'apprentissage réalisée dans deux des cours d'enseignement par les pairs : (1) un cours traditionnel et (2) un cours consensuel. Cette analyse ne révèle aucune constante différentielle dans la participation étudiante aux périodes de questions des deux cours. Par contre, l'analyse ethnographique de l'Étude 3B démontre que la classe consensuelle développe un sentiment de responsabilité mutuelle. L'Étude 3C examine de près les échanges verbaux de deux groupes échantillons (2 ou 3 étudiants) dans chaque classe. L'Étude 4 analyse la collaboration au sein d'une classe virtuelle et le développement de la construction du savoir. Les Études 3 et 4, analyses fouillées du discours, montrent comment les étudiants collaborent pour apprendre la physique (c'est-à-dire les facteurs et processus nécessaires à l'apprentissage collaboratif) et amplifient notre compréhension de l'apprentissage collectif.

ABSTRACT

Vygotsky (1978) argues that all higher mental functions (e.g. perception, voluntary attention) develop through social interactions, which are culturally mediated. From this socio-cognitive perspective learning can be described as a social process of participation, which is situated in the course of human activities (e.g., Lave & Wenger, 1991). While research shows the effectiveness of pedagogies based on these theories of learning, there are many unanswered questions. This research was divided into four studies that examined issues related to the effectiveness of differential designs of social interactions to promote concept learning in an introductory physics course at the college level. Study 1 used a quasi-experimental design to compare the effectiveness of two collaborative instruction approaches: (1) three modes of Peer Instruction (PI), and (2) online knowledge building. These 4 treatment groups were compared to a control group (teacher-led instruction). Results show students in all 4 collaborative instruction approaches significantly outperform those in the traditional instruction on the concept test (Force Concept Inventory, FCI). Study 2 verified the effectiveness of discussion versus self-reflection in PI. Study 3 was composed of 3 parts that looked closely at the learning in two of the PI classes: (1) Traditional PI, (2) Consensus PI. Study 3A shows no differential patterns of class participation during PI questions. However, Study 3B shows the Consensus PI class participated more fully. Study 3C, was an ethnographic study of two representative groups within each of the classes (four groups of 2-3 students). Study 4 investigated online collaboration and knowledge building practices. Studies 3 & 4 both used discourse analysis to reveal how students work together to learn physics. Results show several factors and processes involved in collaborative learning and the process of group cognition. The results of these four studies add to the understanding of how to design collaborative activities, particularly in regards to the PI approach.

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CHAPTER 1

Introduction

Constructivist (e.g., Piaget, 1975) and social-constructivist (e.g., Vygotsky, 1978) theories of learning influences our current thinking in the fields of educational psychology, cognitive science, educational technology, teacher education and the *Learning Sciences*[1]. A major assumption of those two paradigms is that learning is a social phenomenon and situated in the course of human activities (e.g., Levine, Resnick & Higgins, 1993). When instruction is informed by these views it creates opportunities for students to interact with others while engaged in appropriately designed learning activities (Brown, Collins & Duguid, 1989; Engle & Conant, 2002). Such social interactions can involve *Peer Instruction* (Mazur, 1997), small group collaboration (Stahl, 2006), or whole class working together (Brown & Palinsar, 1989 – community of learners; Kolodner, Camp, Crismond, Fasse, Gray, Holbrook, Puntambekar, & Ryan, 2003), to list a few. These learning environments can be face-to-face and supported by various technologies such as clickers, or involve various modes of computer supported collaborative learning (CSCL) including online, networked or any combination. What is common in all these instances is that students' productive engagement with the content is necessary for "deep" learning (e.g., Engle & Conant, 2002). Though many studies show positive results of collaboration and cooperation (Johnson, Johnson & Smith, 1998) what is still not clear is how the design of instruction for collaboration and social interactions impacts students' engagement and how does it promote productive learning. And, whether there is an economy of scale for such educational initiatives. In other words, if we are to devote time, effort and money to designing and implementing instruction to promote social interaction we need to better

[1] In the last 20 years an interdisciplinary field called the Learning Sciences has emerged as a new discipline, which brings together the fields of educational psychology, computer science, cognitive science, anthropology and sociology. This new field investigates learning, whether formal or informal, from a scientific perspective. Furthermore, it focuses on the design and implementation of instructional innovations so as to improve opportunities for learning (i.e., affordances for learning). These innovations include the construction of learning environments that use what cognitive science tells us about human learning, what educational psychology tells us about methods and best practices for learning, what computer science tells us about technological innovations that may enrich learning and what anthropology and sociology tells us about human interaction and socialization involved in everyday learning.

understand collaboration and the activities that promote collaboration. Additionally, we need to understand how to take full advantage of the “minds on” actions and discourse produced when individuals and collectives engage in knowledge building and knowledge sharing.

Theoretical Foundation

In the upcoming section we will describe the theoretical foundations that our research is built on. We will then elaborate on what this means for the pedagogical designs that forms the heart of this study that investigates how collaboration and technology influences how students learn physics at the college level (CÉGEP).

Background to theories of social constructivism

Emerging from the major perspectives of constructivism (e.g., Piaget, 1975, 1985) and social constructivism (e.g., Vygotsky, 1978) are a variety of socio-cognitive and socio-cultural models that describe how knowledge construction and learning are social processes. These models include *situated cognition* (Brown, Collins, & Duguid, 1989; Greeno, 1998; Lave & Wenger, 1991), *distributed cognition* (Hutchins, 1995; Salomon & Perkins, 1998), and *group cognition* (Stahl, 2006).

Vygotsky’s Social Constructivist

Vygotsky argued that all higher mental functions (e.g. perception, voluntary attention) develop through social interactions, which are culturally mediated. From this perspective learning is a process that starts without (*externalization*) and continues within (*internalization*). In short, learning is a process of participation and use of representational systems (cultural tools and signs, e.g., language, discipline concepts, knowledge and tools). This theory of cognitive development further suggests that the social interactions begun between the adult (expert) and child (novice) continue on to include interaction with peers. Such processes promote mental functions at the *intrapsychological* level.

Furthermore, the most instructively productive of these social interactions are those that occur within the Zone of Proximal Development (ZPD), which defines the working limits of a student's capabilities and knowledge. On one side of this zone students are capable of working on their own. Within this zone, however, students need support of an adult or a more knowledgeable other (MKO). And, beyond this zone students are lost even with help.

In addition to these important notions, Vygotsky's (1978) work foregrounds the role of language in the processes of enculturation and socialization. For him language plays a critical role, it allows us to internalize "the meanings and patterns of thought that are current in our culture or profession. In this way, we "make up" our own minds and, in time, acquire inner experiences modeled on the public activities of our culture and society" (Toulmin, 1999, p. 58). It is this socially driven modeling of language, and associated symbols, that we should enact when we teach and when we design learning opportunities for peers to engage each other in discourse.

Situated Cognition

Situated cognition is a theory of human learning and knowledge construction. It suggests that knowing cannot be separated from doing because knowledge is situated in activity tied to a physical and social context (Brown, Collins & Duguid, 1989). Situated cognition views learning as a change in the ways that individuals participate in activities related to practices of a community or discipline (Lave & Wenger, 1991). To that end, the study of human knowledge and interaction must be set in real events, which allow us to examine how people act and how practices develop *in situ*. We must study the system in action otherwise we run the risk of destroying the very thing we wish to study (Norman,1993).

What does situation cognition tell us about the development of conceptual knowledge? Greeno (2006) states that "conceptual growth in a domain can be considered as change to the discourse practices of a community, or in the ways an individual participates in discourse, that involve understanding of that conceptual domain" (p.7). These ideas are close to Vygotsky's, and others, as discussed. And, they set the stage for designing ways to promote and assess learning. From this perspective we would want to examine how students begin to participate in the conceptual discourse of their discipline and study how this participation in the discourse changes over time. In other words, to understand learning we should examine their activity and interactions.

A Social Characterization of Learning

Koschmann's (1999), in response to Mikhail Mikhailovici Bakhtin, proposes that learning is more than participation or the transfer of knowledge. Rather, learning happens through *transaction*. From this perspective learning is a change that occurs from interactions with others and their context. Such interactions require a certain amount of *agency*.

British sociologist Giddens talks about the triadic relationship between *structure, culture and agency*. He describes structure as a product of the pattern of human practices – one that emerges from human activity. Once structure exists, it acts to constrain further human actions. Thus agency and structure have a dialectic relationship. When learning is viewed as the tension between reproducing or changing structure we might consider this a sign of *conceptual change,* a special category of learning we will elaborate on shortly.

Erving Goffman (1967) writes about the notion of interaction rituals and their dependence on establishing a common focus of attention and arousing a common mood, emotion, among participants. Such interactions are situated within what Goffman (1981, 1983) refers to as interactional frames.

Toulmin, in writing about the notion of creating shared meaning though the use of language, including the types that relate to specific communities and references the work of Wittgenstein and Vygotsky, independently. Referencing Wittgenstein, Toulmin writes, "All such units of understanding obtain their meaning by entering language not via the minds of single individuals but within "forms of life" (*Lebensformen*) that are essentially collective" (p. 55).

Using the lens of Vygotskian thinking, Toulmin reminds us that language is the means for enculturation and socialization as well as the mastery of our disciplines. "In any professional work, we master the relevant knowledge by making our own the *Wissensstand* of the discipline involved – the procedures that constitute the collective state of understanding in that field at present" (p.60). Learning physics is more than mere concepts, it is also learning about the discipline's practices and the epistemology embedded in its inscriptions and tools. To understand the processes involved in learning and conceptual change we need to look closely at the ways students use language as they create their own meanings of physics out of collective uses of concepts, knowledge and procedures. This tension between collective doing and individual knowing is one that we will focus on in this analysis.

Sfard (2002) states that "if we regard thinking as communicating, the term *discourse* may become a substitute for *knowledge*, and the notion of learning can be redefined to denote the activity of *becoming a skillful participant of a certain specialized type of discourse*" (p. 323). Thus, school learning becomes an initiation into the special discursive practices of a discipline of study. This might be equated to Gee's (1992) notion of big "D" discourses or Bakhtin's talk of "speech genres."

For this we need to look at the activity systems and the structures created by the interactions of individuals (students, teacher, community), the ways they use mediating artifacts, and the resources and rules they produce (both those made available by the environment and those created by the individuals involved). Giddens (1997) places rules in a privileged position when it comes to the creation of structure. Rules are the means through which patterns of social interaction emerge. Those interactions, in turn, redefine the rules in a dynamic and dialect fashion. Rules also generate resources.

There are rules and meta-level rules – outlining the acceptability criteria, adequacy, equivalence and normative uses of words and concepts. Sfard (2002), talks about *metadiscursive rules*, which are another feature that is distinctive of discourses. She defines them as "mostly tacit navigational principles that seem to underlie any discursive decision of the interlocutors. It is thanks to these rules that the speakers know "*when* to do what and *how* to do it" (Bauersfeld, 1993; cf. Cazden, 1988)" (Sfard, p. 324). These rules are what distinguish the discourse of physicists from mathematicians. These rules are more exact and rigorous than in normal everyday language. To become expert, students need to understand these rules and learn how to use them effectively. It is this aspect of learning within disciplinary fields, which is very difficult and requires substantial practice.

Conceptual Change

The literature of schema-based learning theories describes three types of learning: accretion, tuning and cognitive restructuring (Rumelhart & Norman, 1976). By and large, much of the content that CÉGEP students are required to learn can be described as conceptual knowledge and falls under the umbrella of cognitive restructuring. Keil (1989) suggests that concepts live in a network of other concepts and are not arbitrary isolated entities. The relationships between concepts relate to features frequencies and correlations, as well as provide explanations of those frequencies and correlations that are often causal. The implications of this supposition are that conceptual knowledge building requires the reorganization of these networks of relationships. This is generally referred to as *conceptual change* – a process by which learners build new ideas in the context of their existing understanding (diSessa, 2006).

Conceptual change and collaboration.

It has been shown that conceptual change can be promoted through opportunities for discourse and reflection whether as self-explanation (Chi, 2000) or through collaboration with peers (Crook, 1994). The latter showing decidedly greater positive results.

Social constructivists, posit that authentic tasks, and contexts, afford the types of discourse that promotes learning (Rogoff, 1990). In the effort to solve authentic problems, peers have opportunities for articulation, conflict and co-construction (e.g., Chan, Burtis & Bereiter, 1997). Furthermore, peer interaction and collaboration provides a rich environment for mutual discovery, reciprocal feedback, and frequent sharing of ideas and may lead students to restructure their existing knowledge (Roschelle, 1992).

Collaborative Learning & Instruction

Social interactions can be design to elicit collaboration or cooperation among participants. We define collaboration as the mutually coordinated engagement of individuals working together to on specific task (Roschelle & Teasley, 1995). Some draw distinctions between it and cooperative learning, which involves a division of labour (Dillenbourg, Baker, Blaye & O'Malley, 1996). Though important at the theoretical level, we do not emphasize these distinctions in our definition of collaboration. What is known from the cooperative learning literature is that when students are given the opportunity to work together face-to-face, with particular supports and group organization, their learning outcomes are increased and the quality of that learning is richer (Johnson, Johnson & Smith, 1998).

Kirscher (2002) describe seven key factors that make up collaboration or cooperation:

- Learning is active
- Teacher as facilitator instead of a "sage on the stage"
- Teaching and learning are shared experiences
- Students participate in small-group activities
- Students take responsibility for learning
- Students reflect on their own assumptions and thought processes
- Social and team skills are developed through the give-and-take of consensus-building

In other words, collaboration relies on *grounding activities* such as negotiation of meaning and mutual agreement among participants in the production of an emergent outcome that meets a shared goal. This emergent outcome is something that any one participant could not do by himself or herself.

Collaborative learning research tells us that collaboration is particularly sensitive to initial conditions. What we need to better understand are those conditions and how we might mediate the environment and context to support collaboration and learning.

Peer-to-peer collaboration

The peer instruction approach calls for students to work together in small groups to answer conceptual questions posed by the teacher. The traditional method of peer instruction requires students to first commit to an answer by voting individually then, in small groups, they are asked to explain and account for their choice. Then they are asked to revote individually. Along the way, students express their understanding about a concept and reasoning for choosing an answer or changing their answer. It is posited that in following this process students can experience conceptual change.

While several studies show learning gains of the peer instruction method little work has been done to understand the collaborative processes involved. Furthermore, no other study to date has examined whether changes to the social interaction can affect peer instruction, positively or negatively.

Peer Instruction Approach

Peer instruction (Mazur, 1997) is an example of an instructional activity focused around concept-learning tasks. It emphasizes the development of specific conceptual knowledge that is known to be particularly difficult for students to understand because it calls for *conceptual change* – a process that many believe can be facilitated by confronting wrong answers and misunderstandings through discussion (Strike & Posner, 1992).

At another point on the collaborative learning continuum we have project such as Peer Instruction (PI; Mazur, 1997), which also promotes collaboration, this time in large lecture settings. Its' emphasis is on the development of specific conceptual knowledge that is prone to misconceptions and easily left unidentified in traditional classroom assessments. This approach calls for students to work together in short spurts (what we refer to as collaboration *on-the-fly*) as they attempt to account for their answers and convince others by reasoning about the selected concepts. Though this approach uses less structured forms of community building it engages students in working with each other, nonetheless. And, it may also be an example of Rogoff's (2003) notion of active observation.

We will elaborate on both these methods shortly, but first let us briefly clarify some of the ideas we base our assumptions on. To start we describe what is conceptual knowledge and why it may be difficult to construct. We then discuss how this understanding may be fostered by collaborative activities, specifically those related to deep and meaningful learning (i.e., knowledge building and peer instruction approaches). Lastly, we emphasize why the affordances of technology may be key to promoting learning in these environments.

Collaborative Knowledge Building

Knowledge Building (KB) is viewed as distinct from learning in that the former involves the construction and modification of knowledge in a public setting (Bereiter & Scardamalia, 1993). KB involves learning as a social process guided by certain principles relating to the design of the environment (generally computer supported) and the scaffolds to support knowledge construction. As defined, KB is specific to these ideas put forward by Scardamalia and Bereiter, but more recently, others have begun to adapt their ideas to create a more generic take on this public process of knowledge construction and learning. Resta and Laferriere (2007) refer to knowledge building as idea improvement. They suggests social interaction in the online collaborative environments can be seen as a “source of cognitive advancement, and may play an important role in academic achievement.” (p. 70). In our study we adapted some elements of KB in one of the instances of collaborative learning.

KB is a structured way of thinking about how students should work together. Scardamalia (2002) defines KB as an intentional collective activity consisting of twelve principles:

- **Real ideas and authentic problems.** The driving force for students in a KB community is understanding real problems in the real world.
- **Improvable ideas.** Students' ideas are regarded as improvable objects.
- **Idea diversity.** Diversity of ideas is a necessary component of this system.
- **Rise above.** Higher-level concepts and ideas are created through the sustained improvement of ideas and understanding.
- **Epistemic agency.** Motivation to act and sustain the pursuit of knowledge comes from the students themselves.
- **Community knowledge, collective responsibility.** The primary purpose of the KB activity is the improvement of collective knowledge.

- **Democratizing knowledge.** An open playing field where all are welcomed to contribute.
- **Symmetric knowledge advancement.** Reciprocal advance of knowledge comes from students and the community at large.
- **Pervasive Knowledge building.** Willingness to engage in collective KB becomes an attitude.
- **Constructive uses of authoritative sources.** Advanced epistemic beliefs about knowledge and how a community constructs it.
- **Knowledge building discourse.** Students learn to use the language of the discipline as they share and improve their ideas
- **Concurrent, embedded, and transformative assessment.** Students participate in how they will be assessed and take a global view of their understanding.

Of these ideas the most salient for our purposes are epistemic agency and development of collective responsibility. We will discuss these in more detail later on.

Technology and Collaboration

Opportunities for collaborative activity alone are not enough, and do not guarantee successful learning (Dillenbourg, 1999; O'Donnell, & O'Kelly, 1994). To take full advantage of these socio-cognitive learning approaches, appropriate tools and methods must be designed and implemented. Technology and computer supported collaboration has been shown to be very effective. Hmelo (2006) states that, in general, computers have been used to promote collaborative learning in two ways: (1) simulation and modeling tools afford the creation of a context for testing ideas, which engages students in negotiation of meaning; (2) creation of discussion spaces can scaffold students' reasoning and collaboration and affords the articulation of deeper and meaningful learning.

The Effectiveness of Clickers

The effectiveness of Information and Communication Technologies (ICT) is a critical issue to address (Fluck, 2003) as meta-analyses on the effectiveness of ICTs as a whole show relatively small effect sizes[2] (Parr, 2000), comparable to other approaches such as homework or parent questioning (Sinko & Lehtinen, 1999). Given that information technologies are powerful tools, this data suggests that ICTs can very effectively enhance learning or may effectively impede it (Lawless & Brown, 1997). Since technology in itself is not a substitute for good pedagogy, it is essential to focus on those technological applications that have demonstrated effectiveness such as Peer Instruction.

One should not loose focus of the pedagogy when seeking to implement a technology. Some techno-pedagogical approaches such as Peer Instruction have been widely adopted because of instructors' interest in "clickers" (Burnstein & Lederman, 2001, 2003). Although recent reports confirm that "A 'Strong Case' Exists for Classroom Clickers" (Scriven, Chasteen, & Duncan, 2009), it is important to reiterate that clickers are not magic bullets (Lasry, 2008a). They are effective if properly implemented with approaches such as Peer Instruction.

The purpose of the present study is to disseminate effective techno-pedagogies such as Peer Instruction while minimizing the financial and technological burden involved with the use of clickers. What are the current barriers to widespread adoptions of clickers in CÉGEPs?

To some institutions (such as some rural CÉGEPs), the cost of purchasing clickers may be prohibitive. To others, keeping up with privately held clicker companies may be a challenge with issues such as hardware half-life (Radio-Frequency devices replacing older Infra-Red clickers) and software incompatibilities (some newer clicker software can no longer mesh with PowerPoint 2007 because it no longer has Visual Basic). In a recent informal poll of more than 120 students at John Abbott College, approximately 97% had a cellular phone with them and all but one had access to one if they needed it. Our basic proposal is: can a cell phone be used as a clicker? Does the cell phone provide all the functionality of a clicker? Does it provide additional features?

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[2] Parr (2000) reported effect sizes of 0.4 and Sinko & Lehtinen (1999) reported effect sizes ranging from 0.28 to 0.5. Both findings suggest small to moderate effects of ICTs as a whole on instruction, but say nothing about the effectiveness of individual ICT approaches such as Peer Instruction. These finding suggests that given the number of effective ICT approaches, there may be a countering number of detrimental ICT uses.

CHAPTER 2

Research Methodology

Research Objectives

Though such learning environments may be the gold standard for education (particularly in science, technology, engineering and math – STEM), achieving well functioning classrooms with participant communities and the requisite collaboration focused on building knowledge and producing deep understanding is not an easy task. Many teachers abandon the idea early on, while others make attempts but fall short of their goals (e.g., Messina, Reeve & Scardamalia, 2003; Moreau, 2001).

If we are to devote time and effort to designing learning environments that foster communities of learners and practitioners we need to better understand the role of socio-cognitive and socio-cultural developments in learning – i.e., collaboration. We need to better design and develop tools and methods to take full advantage of the "minds on" actions and discourse produced while individuals and collectives are engaged in such inquiry knowledge building and sharing. As well, we need to focus on assessment tools and guidelines for using collaborative activities, which reflect the production of individual as well as collective knowledge as well as the reality of the CÉGEP students and teachers. In particular, we need to consider the many theoretical and practical issues related to assessment of collaborative activities also needs to be resolved if we are to use such methods at the college level. Particularly as we prepare students to go onto university and/or to go on to demanding careers where accreditation boards require that they must demonstrate discipline competencies as individuals.

Research Questions & Design of the Research

The global research questions were as follows:

1. Does a change in the structure or model of social interaction (classroom participation) in Peer Instruction (PI) affect the learning outcome?
2. Does student participation change according to these differential structures or models of social interaction?
3. How does the collaboration or participation (activity systems) develop in such PI classrooms?
4. How does participations (activity systems) develop in online collaborative tasks?

From these global questions we developed more specific questions that were answered by conducting four specific studies. These four studies are as follows:

Study 1. A quasi-experimental design (data FCI)

Research Question 1a: Do various forms of classroom participation, including Peer Instruction and online collaboration, affect conceptual change and students' expectations compared to traditional teaching?

Study 2. A quasi-experimental design (data TPZ)

Research Question 1b: 1. How effective are in-class peer-discussions? Do other factors such as self-reflection (metacognition) mediate the changes observed in the Peer Instruction activity?

Study 3. A quasi-experimental design (data TPZ) & an ethnographic design (classroom data)

Research Question 2: Are there differences in the participation structures of the two classes?

Research Question 3: How do the participation structures (activity systems) mediate the ways that conceptual understanding is constructed among students?

Study 4. An ethnographic (online communities data)

Research Question 4: What types of learning practices develop within the settings of classroom wiki when the activity is designed to promote intentional knowledge building?

Overall we use quantitative and qualitative methods of data collection and analysis. This is consistent with our socio-cognitive and socio-cultural theoretical assumptions of learning. Each study produced results that elaborated on the principle research question in the aim of unpacking the phenomenon of collaborative learning with technology.

Organization of the Report

This report is divided into the four research studies that investigated different aspects of collaboration supported by the use of technology. Each study is presented in the separate chapters in the following manner:

- Chapter 3: presents Study 1
- Chapter 4: presents Study 2
- Chapter 5: presents Study 3 (three parts)
    - Section I – Study 3A
    - Section II – Study 3B
    - Section III – Study 3C
- Chapter 6: presents Study 4
- Chapter 7: presents our conclusions

CHAPTER 3

STUDY 1

Conceptual Change and Students' Expectations

Study 1 Research Question

1. Does various forms of classroom participation affect conceptual change and students' expectations?

Study 1 Background

Informed by a body of work on *situated cognition* (Brown, Collins & Duguid, 1989; Lave & Wenger, 1991), *distributed cognition* (Cole & Engeström, 1993; Hollan, Hutchins, & Kirsch, 2000; Salomon, 1993), and *situated action* (Theureau, 2004), a paradigm shift toward pedagogy informed by social constructivist theories of learning are quickly becoming an established part of primary and secondary schooling in Québec. Yet, some basic questions remain. How do we design social learning environments to promote deep and meaningful learning? What are the essential and sufficient features of such environments?

To address these questions, we designed a quasi-experiment with five different forms of classroom participations to test if they have different modes of participation affect students' learning through conceptual change and students' expectations towards physics.

Whereas one group was comprised of a control section with teacher-centered lecture-based traditional instruction, all four treatment groups consisted of variations of Peer Instruction (PI). PI is a student-centered instructional approach developed at Harvard University by physicist Eric Mazur (1997). A recent survey of new physics and astronomy faculty members in the US showed that PI is currently the student-centered pedagogy that new physics faculty members know best and are most willing to experiment with (Henderson, 2008). As a whole PI has been welcomed by the science community and adopted by a large number of colleges and universities due, among other reasons, to its common sense approach and its documented effectiveness (Crouch & Mazur, 2001; Fagen, 2003; Fagen, Crouch, & Mazur, 2002; Hake, 1998; Lasry, Mazur, & Watkins, 2008; Mazur, 1997). A commonly used schematic description of the PI method (Lasry, 2008) is reproduced in Figure 3.1.

In PI, students are presented with a brief lecture (7-10 minutes), the content of these lectures being similar to traditional curriculum differing only by an increased emphasis on concepts. After the brief lecture, students are presented with a *ConcepTest*: a multiple-choice conceptual question designed to have answers reflecting well-documented misconceptions, alongside the correct answer. The progression of any given class depends on the outcome of real-time student feedback to ConcepTests.

Students individually choose their preferred answer and communicate it to the instructor using a clicker or, equivalently, a flashcard or a raised hand (Lasry, 2008; Mazur & Lasry, 2009). Instructors are then able to determine the distribution of students holding each alternative conception. If too few students (<30%) hold the correct conception, the instructor reverts to lecturing on the concept in question. If a large majority of students hold the correct conception (>80%), the instructor proceeds to explain the remaining misconception(s) (held by the <20% of students) and proceeds to the next concept. Most often however, neither too few nor too many (between 30-80%) choose the correct conception. At this point, the instructor asks the students: "turn to either side and find someone with a different answer. Then try to convince them of your answer." This form of classroom collaboration constitutes the *peer* instruction *per se*.

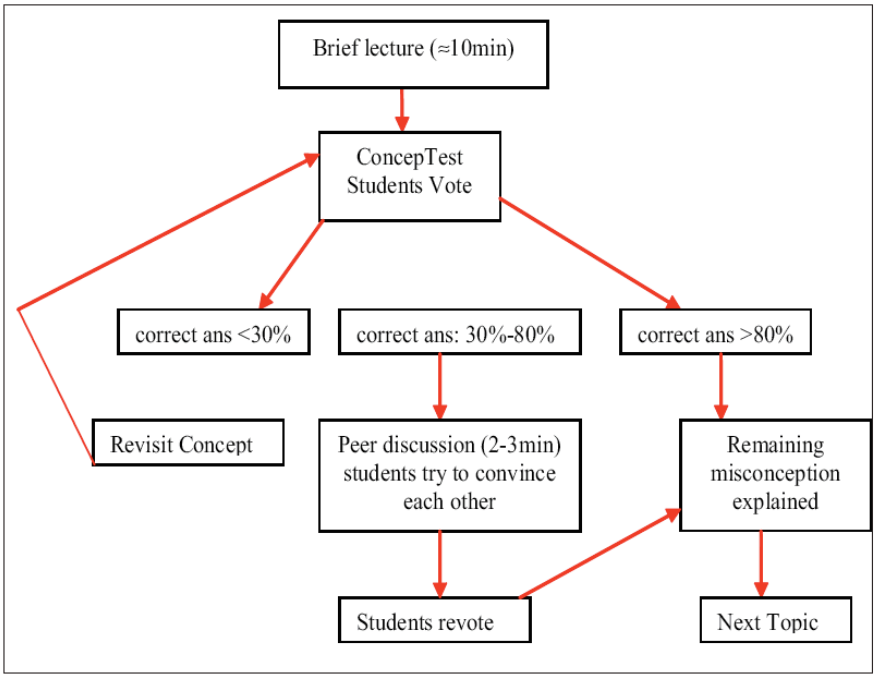


Figure 3.1. The Peer Instruction process.

Reproduced with consent from Lasry (2008).

Although the PI approach has been widely adopted, its implementation has not been uniform between instructors (Turpen & Finkelstein, 2007). The sole common denominator is possibly the use of in-class multiple-choice ConcepTests. Many instructors follow the process as described by Mazur (see Fig3.1) by having students vote individually, discuss between peers and revote. However, a second group of instructors have opted to take the 'peer' out of Peer Instruction by simply surveying students on ConcepTests without asking them to talk to each other after the initial survey (Fagen, 2003). To save the cost of purchasing clickers for all students, a third group of instructors have provided students with one clicker per group of 2-4 students. These instructors present ConcepTests and ask students to provide a group vote only after having discussed the concept collectively. This approach presumes that meaning will be negotiated collectively until a consensus arises and a group vote can be expressed. However, it also implies that students do not first commit to an answer before discussing it. Committing to a conception has been shown to have a profound impact on learning (Crouch, Fagen, Callan, & Mazur, 2004). In this section we report findings on the impact these different forms of in-class collaboration on students' conceptual change and epistemological expectations towards physics.

Study 1 Methods

A quasi-experimental design (see Table 1) was used to answer the basic question of whether or not different forms of classroom participation affect students' learning through conceptual change, as measured by the Force Concept Inventory (FCI) (Hestenes, Wells, & Swackhamer, 1992), and affect students' expectations about physics, as measured by the Maryland Physics Expectations survey (MPEX) (Redish, Saul, & Steinberg, 1998).

Participants

Students in five different physics mechanics courses (203-NYA) were taught by four teachers in two different colleges (2 teachers at Dawson and 2 teachers at John Abbott). All groups were intact classes of students enrolled in algebra-based introductory physics courses either as part of the pre-university Science Program or as one of the physical or medical technology programs at Dawson College. The student population reflects the diversity of the respective campuses, urban and suburban, in true representation of our province. Generally, classes were made up of students between the ages of 17 – 19 years; and consisted of a close to even split of male and female students. Complete data was obtained for n=101 students (M=51, F=50) in four treatment groups. Data from the fifth group (n=22; M=18, F=4), consisting of a teacher-centered lecture-based control section, was collected in a previous study (Lasry, 2006). All five groups are described in greater detail below.

Group1: ***Individual Pre, Discussion, Individual Post*** (n=24 ; M=14 , F=10)

In this group, students were given ConcepTests and asked to choose their preferred answer individually. They were then asked to turn to a peer (or peers) that has a different answer and try to convince them. After this small group small group (2-4 students) discussion, students were asked to revote individually. That is, each student entered a vote after the peer discussion.

Group2: ***Individual Pre, Discussion, Group Post*** (n=30 ; M=13 , F=17)

As in the previous group, students were asked to vote individually on a ConcepTests and were then asked to peer-discuss the question in small groups (2-4 students). However, after the discussion, students were asked to revote as a group. That is, students had to arrive at a consensus vote after the peer discussion.

Group3: ***NoPre, Discussion, Group Post*** (n= 32; M= 16, F=16)

Students were given a ConcepTests and were immediately asked to discuss the question in a small group (2-4 students). After the discussion, students were asked to revote as a group, that is, to arrive at a consensus vote after the discussion.

Group4: ***Individual Pre, No Discussion*** (n=15 ; M=8 , F=7)

Students were given a ConcepTests and were asked to choose their preferred answer. Students were not instructed to discuss their choice with a neighbor. Using the real-time feedback from students, the instructor discussed the prevalent misconceptions and explained the correct conception engaging as many students as possible in a class-wide teacher-led discussion. Although there were no in-class peer-to-peer collaborations, the instructor did make use of asynchronous online collaborative tasks. This gave us a point of comparison to determine whether asynchronous peer-interaction produces a differential effect compared to real-time collaborative activities.

Control: ***Traditional, lecture-based, didactic instruction*** (n=22 ; M=18 , F=4)

This section was comprised of a traditional teacher-led class. No special attention was given to collaboration and no systematic efforts were made to engage students in active learning.

Table 3.1. Quasi-Experimental research design

	ConcepTests (Y/N)	First Poll (Ind/Grp/None)	Peer-Discussion (Y/N)	Second Poll (Ind/Grp/None)
Group1: Peer Instruction	**Y**	**Ind**	**Y**	**Ind**
Group2: IndPre/Disc/GrpPost	**Y**	**Ind**	**Y**	**Grp**
Group3: NoPre/Disc/GrpPost	**Y**	**N**	**Y**	**Grp**
Group4: IndPre/NoPeerDisc	**Y**	**Ind**	**N**	**N**
Group5: Trad Control	**N**	**N**	**N**	**N**

Measures Taken at the Beginning-End of Semester

<u>*Traditional Problem Solving Skills*</u>

Physics knowledge is traditionally measured through quantitative problem solving. Teachers involved in each college consulted each other on the construction of in class assessments and exams. Tests and exams were designed to assess similar content and were deemed of equivalent difficulty by teachers in both institutions.

<u>*Conceptual Change: The Force Concept Inventory (FCI)*</u>

In physics, students may know how to solve algorithmic problems without having a complete conceptual understanding of the physics involved (Kim & Pak, 2002). Therefore, conceptual understanding was measured the first and last week of the semester with the Force Concept Inventory (e.g., Hestenes et al., 1992). To avoid ceiling and floor effects, *normalized gains* (Hake scores) in the FCI will be compared. Normalized gains are defined as:

$$g = (\text{Post T} - \text{Pre T}) / (\text{max T} - \text{Pre T})$$

These gains can be calculated by student or by class. We will exclusively use student gain scores because they provide data points for each student and hence increase the power required to find statistically significant differences.

<u>*Students' Epistemologies & Expectations: Maryland Physics Expectations survey (MPEX)*</u>

Students may know how to solve problems, understand basic concepts yet fail to grasp the nature of physics as a discipline and the processes involved in its practice. The MPEX is a 34-item survey that probes student attitudes, beliefs, and assumptions about physics on a 5-point Likert-scale (agree-disagree). We added the following six questions, five of which were intended to identify the students' "sense of membership" factor. The sixth item was inserted to gauge attention (see Appendix A).

Table 3.2. Six questions added to the MPEX survey.

1:StronglyDisagree	2: Disagree	3: Neutral	4: Agree	5: Strongly Agree

22	We use this statement to check that people are reading the questions. Please choose number 4 (Agree) as your answer.	
33	Really understanding science is only for those who want to be scientists.	
34	Working with others on problems is important because we can share our understanding and knowledge.	
38	A scientist is someone who seeks knowledge because s/he does not have all the answers.	
39	Scientists belong to a community of people attempting to understand the world (knowledge seekers), as such, doctors, engineers, geologists, psychologists, sociologists, etc., can all be described as scientists.	
40	By attempting to understand the world, I become a member of the knowledge seekers community.	

Learning Outcomes Data

The FCI was administered to students in all groups at the beginning and at the end of the semester so as to measure their level of conceptual change after a semester of instruction. Data was also obtained for all groups on a final exam that was comprised in large part of traditional numerical algorithmic problems. The MPEX with additional six questions (Table 3.2) was administered in Groups 1,2,3 and 4 at the beginning and at the end of the term to determine the effect of different forms of participation on students' expectations and beliefs.

Study 1 Results

Conceptual Change: ALL Treatment Groups vs Control Group

Using the Force Concept Inventory (FCI), we compare the differences in learning through conceptual change between all treatment groups and the teacher-centered lecture-based control group. The table below shows the average FCI scores at the beginning of the semester (Pre-FCI) with the average FCI score at the end of a whole semester of instruction (Post-FCI) as well as the normalized Hake gain. We find that our taken together the collaborative treatment groups provide significantly better conceptual learning than traditional forms of instruction (p=0.035).

Table 3.3. Change in FCI scores between Treatment groups and Control.

	All Tx Gps (gp1-4)	Control	p-value
Pre FCI	10.2	13.8	
Post FCI	19.0	19.0	
Hake <g>	**0.46**	**0.33**	**0.035**

As the groups differed markedly in pretest score, we also conducted a complementary ANCOVA analysis to test the difference in FCI post-test scores (between treatment groups and control) using the pre-test score as a covariate. Results show that our treatment groups achieved statistically higher FCI post-test scores when controlling for FCI pre-test scores (p<0.0001).

Comparing Conceptual Change Between Treatment Groups

We compared the differences between all treatment groups in learning through conceptual change. The table below shows the average FCI scores at the beginning of the semester (Pre-FCI) with the average FCI score at the end of a whole semester of instruction (Post-FCI) as well as the normalized Hake gain. An ANOVA comparing the Hake gains between groups yielded no significant differences (p=0.65) suggesting that all treatments were equivalent in effectively enabling conceptual change.

Table 3.4. Comparing FCI gains between treatment groups.

	Gp1	Gp2	Gp3	Gp4
Pre FCI	9.8	9.1	11.5	10.3
Post FCI	18.9	19.3	19.6	18.2
Hake <g>	**0.43**	**0.46**	**0.50**	**0.43**

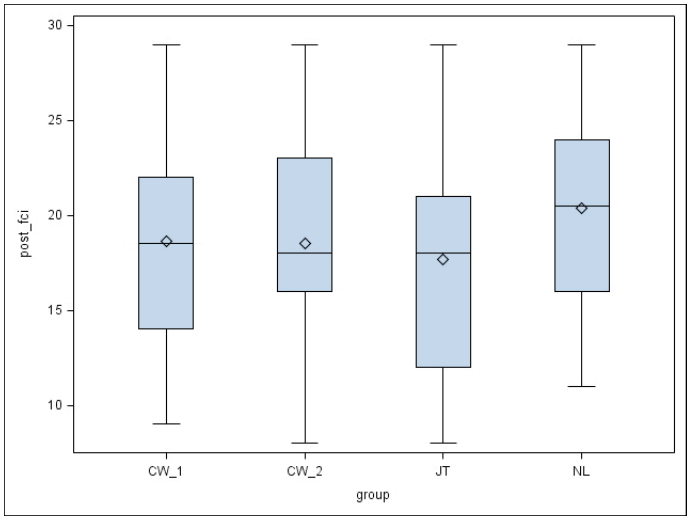


Figure 3.2. Similarity in post FCI scores between four treatment groups.

Comparing Attitudes and Beliefs Between Treatment Groups

We measured students' attitudes and beliefs with respect to physics using the MPEX at the beginning and at the end of the semester. MPEX answers can be used to categorize attitudes and beliefs as either Novice (NOV) or expert (EXP). Average expert MPEX scores at the beginning and at the end of the semester are shown below, for expert responses in Table 3.5 and for Novice responses in Table 3.6.

Table 3.5. Comparing MPEX changes in EXPERT scores between treatment groups.

	Gp1	Gp2	Gp3	Gp4
Pre	18.9	17.3	20.2	19.6
Post	18.7	18.5	18.0	19.1
<post-pre>	-0.2	+1.2	-2.2	-0.5
p-value (pre)	0.0075			
p-value (post)	0.0967			

Table 3.6. Comparing MPEX changes in NOVICE scores between treatment groups.

	Gp1	Gp2	Gp3	Gp4
Pre	8.5	7.5	7.5	7.1
Post	8.6	8.1	9.1	7.8
<post-pre>	0.1	0.6	1.6	0.7
p-value (pre)	<0.0001			
p-value (post)	0.0005 ANCOVA			

MPEX results show that treatment groups differed at the beginning of the semester, and at the end. Given the differences present at the beginning of the semester, caution must be used in comparing end of semester scores. To determine whether any difference between the groups exist, we conducted an ANCOVA of the end of semester MPEX score while using the beginning of semester MPEX score as a covariate. Results of the ANCOVA show no significant differences in post MPEX Expert scores when controlling for beginning of semester Expert scores. One can infer from the MPEX expert data, that a semester of instruction has students converge to a score of roughly 18, regardless of whether these students started above or below this score.

Given that MPEX Novice scores at the beginning of the semester were also significantly different, another ANCOVA was conducted on MPEX Novice score at the end of the semester using the beginning of semester MPEX Novice score as the covariate. This analysis revealed a significant difference with the group 3 differing from other treatment groups ($p<0.01$). Recall that students in group3 did not commit to an answer but first discussed in groups before providing a group choice. Group3 differed significantly from other treatment groups with end of semester MPEX Novice scores being significantly higher, suggesting than not committing to an answer before instruction may have deleterious effects on students' expectations.

Given that experts are defined not only by their conceptual understanding but also by their attitudes and expectations, we charted the MPEX expert score at the end of the semester for each student with their post-test FCI score. We find no significant correlation between both measures in college students (Figure 3.3).

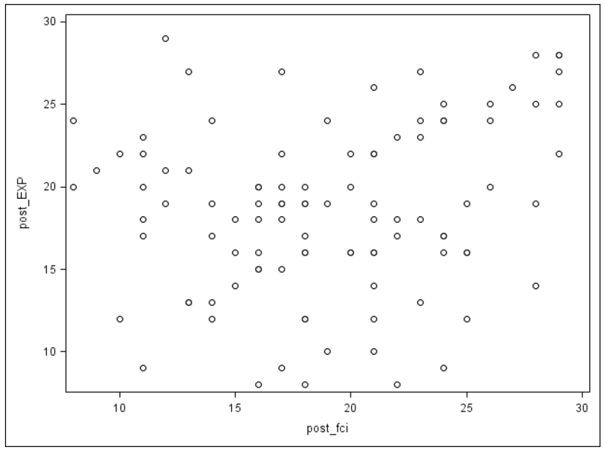


Figure 3.3. Relationship Between Expert MPEX Score and Post FCI score.

Comparing Traditional Exam Results Between Treatment Groups

Having measured conceptual change and attitudes and beliefs a remaining concern is whether students in collaborative groups are able to perform well on traditional problem solving exercises such as those found in common class tests and term exams. We compared the final exam grades between the control group and all treatment groups pooled together. Although students in our treatment sections were exposed to less traditional problem solving, these students obtained significantly better grades on traditional exams when compared to students in the teacher-led control section.

Table 3.7. Difference between Treatment groups and Control in exam grade.

	Gp1-4	Control
Avg Exam Grade	75.1	63.0
p-value	<0.0001	

Having sought differences with the control section we compared all treatment groups to each other and found no significant difference in traditional problem solving skills as measured by final exam grades.

Table 3.8. Lack of significant difference across Treatment groups in exam grade.

	Gp1	Gp2	Gp3	Gp4
Grades	76.0	75.6	70.6	76.56
p-value	0.1670			

MANOVA Results: Pooling Variables

Although individual analyses may reveal little differences between treatment groups, taking all variables together in a multivariate analysis of variance may detect overall differences between groups. We determined whether our learning outcome variables (Post FCI score, MPEX expert score and Exam score) depended on the incoming MPEX and FCI scores or on the treatment group. No significant differences were found (p=0.5), suggesting that all collaborative treatment groups performed equally well in promoting conceptual change, in traditional problem solving skills and in relation to students attitudes and beliefs.

Learning Gap Between Hi and Lo Background Knowledge.

As the constructivist mantra holds: "new knowledge is constructed from prior knowledge". One consequence is that students with more prior knowledge learn more than students with less prior knowledge. Indeed, a number of studies in physics have found more learning in students with more background knowledge (Coletta & Phillips, 2005; Lasry, et al., 2008).

This 'Matthew Effect' -where the rich get richer and the poor get poorer- poses an interesting challenge. Arguably, students with lower background knowledge need to learn at least as much as students with higher background knowledge. We sought to determine the size of the learning gap present between our students of higher ability as compared to those of lower ability. To achieve this goal, we determined the median FCI score for all students (9/30). We then split all students in two groups depending on whether they had 9/30 or less or whether they had more than 9/30. We then compared the Hake gains of the higher background knowledge students (preFCI >9/30) with those of the lower background knowledge students.

Surprisingly, we found no differences in average Hake gains between students that had low incoming background knowledge and those of higher background knowledge (Low_FCI g= 0.45 Hi_FCI g=0.47). The scatter plot below shows the lack of correlation between incoming knowledge level (as measure by the beginning of the semester FCI score) and normalized learning gain <g>. Indeed, with a Pearson r=0.26, less than 7% of the variance in normalized gain is attributable to incoming PreFCI score. This suggests that our collaborative approaches may have eliminated the learning differences due to background knowledge.

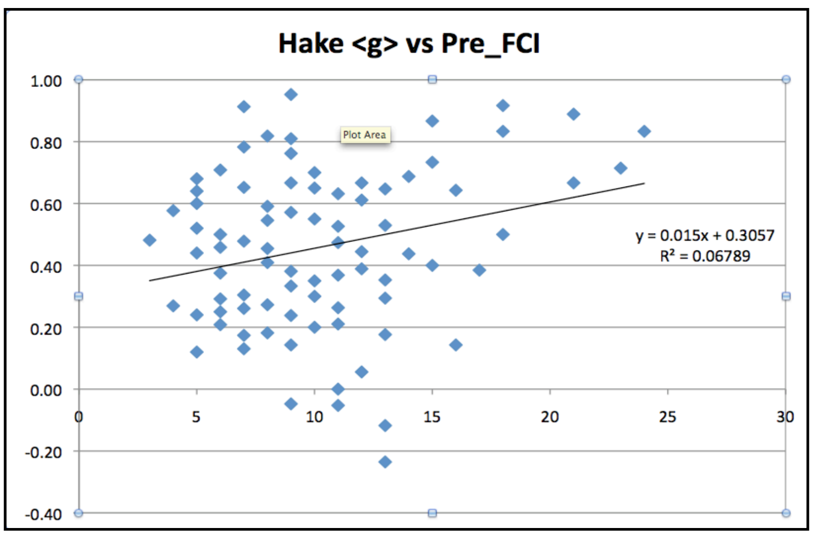


Figure 3.4. Correlation between normalized gain and background knowledge (Pre FCI score).

Difference Between Groups in Learning Gap

Having found almost no learning gap in average gains in our treatment groups, we ask whether the different groups were equally effective in eliminating this gap.

Table 3.9. Difference in gains between Hi and Lo background knowledge across groups.

	Gp1 Lo	Gp1Hi		Gp2Lo	Gp2Hi		Gp3Lo	Gp3Hi		Gp4Lo	Gp4Hi
<g>	0.49	0.33		0.44	0.48		0.47	0.53		0.32	0.51
n (N)	14 (24)	10 (24)		16 (30)	14 (30)		15 (32)	17 (32)		8 (15)	7 (15)

We find a range of gaps with one group replicating the traditional gap in favor of higher background knowledge, on group inverting the gap in favor of lower background knowledge and two groups roughly eliminating the gap. Figure 3.5 below illustrates the size of the difference in normalized gains between higher and lower (difference in gain: GpX_Hi- GpX_Lo) background knowledge students. Thus, positive differences indicate that students with higher background knowledge had larger gains.

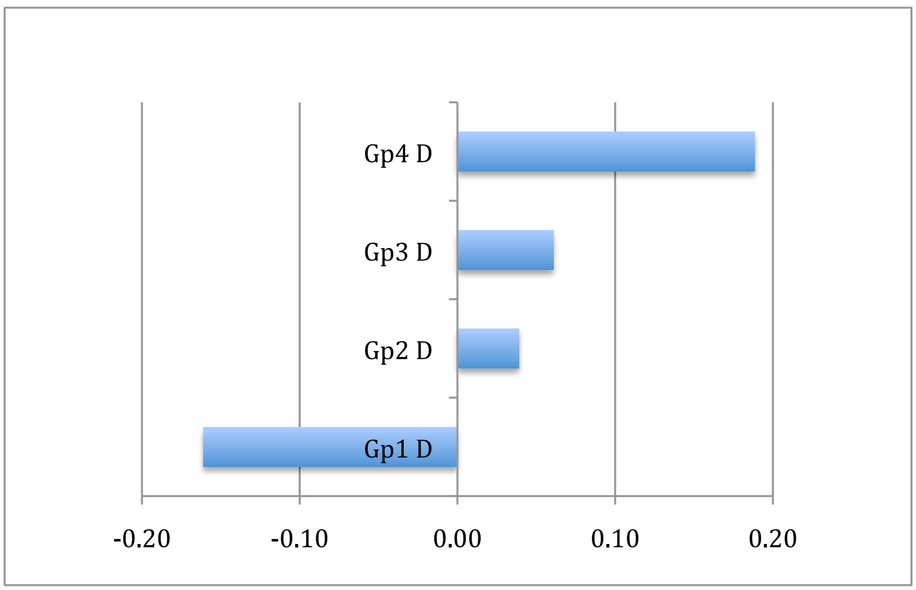


Figure 3.5. Difference in Hake <g> for Hi and Lo background knowledge across groups.

Positive differences show how much more gain students with high background knowledge had. Conversely, negative differences show how much more gains students with Lo background knowledge had. This finding suggests that treatment groups differed markedly in the way they catered to students with various background knowledge levels. Group4 (no in-class peer discussions) replicated the expected gap in favor of students with high background knowledge.

On the other end, Group1 (individual vote, peer-discussion, individual vote) inverted the gap in favor of students with lower background knowledge. Finally, the two remaining groups (group vote after peer discussions) showed no sizeable gap between higher and lower background knowledge students.

Study 1 Discussion

While all treatment groups enable significantly more conceptual change than the teacher-centered control section (p=0.035), we find that our collaborative treatment groups do not differ between themselves in average conceptual learning gains (p=0.65).

Students in all treatment groups were exposed to more conceptual qualitative discussions and less quantitative algorithmic problem solving in class. However, these students far outperformed students in the control group on traditional problem solving tasks (p<0001). No significant difference was found between treatment groups in average exam grade (p=0.16).

We also find no significant difference between treatment groups with respect to Expert attitudes and beliefs after instruction (p=0.1). Interestingly, we found that in Group3 (where students had not committed to a conception before peer-discussion and the subsequent group vote) students had a significant increase in Novice beliefs after instruction. Since the main difference between this group and the others is that students were not asked to commit to a conception before discussion, this result supports the finding that it is important to commit to a conception prior to any critical thinking or peer-discussion (Crouch, et al., 2004).

A multivariate analysis pooling all learning outcomes revealed no significant differences between our treatment groups. But is there really no measurable difference between these forms of in-class participation?

Based on the literature (Coletta & Phillips, 2005) and one of our previous studies (Lasry, 2006; Lasry, et al., 2008), we expected a learning gap where students with higher background knowledge would display markedly greater normalized gains than students with lower background knowledge. Averaging across all treatment groups we found no significant gap in normalized gains between students with higher and lower background knowledge ($\langle g \rangle_{HI} = 0.47$; $\langle g \rangle_{LO} = 0.45$).

Interestingly, this learning gap was not eliminated in all treatment groups. The average across all groups showed no learning gap because one group had a strong learning gap in favor of higher background knowledge whereas another had a sizeable gap in favor of lower background knowledge. The two remaining groups had no sizeable gap between students with higher and lower background knowledge. A closer look at these groups is quite informative. In Group4 where no in-class discussion was fostered, our treatment group most like traditional instruction, this learning gap in favor of students with higher background knowledge was found. Interestingly, in Group1 where students followed the classical Peer Instruction format (individual vote committing, peer-discussion, individual revote), a gap in favor of students with lower background knowledge was found. This is particularly intriguing given that Peer Instruction was developed at Harvard University where students have strong background knowledge.

If one seeks to eliminate learning gaps altogether, both treatment groups2,3 with peer-discussions in class and a group revote (built from consensus) showed minimal differences between students with higher and lower background knowledge. The difference between both groups is that group 3 did not give students a chance to commit to an answer before instruction. Recall that this group was found to have the greatest increase in Novice attitudes and beliefs after instruction.

Our findings therefore suggest that the optimal configuration for in-class collaboration is having students commit to an answer, ask them to discuss between peers and then provide a consensus group vote after the peer discussion. We look forward to more studies replicating the superiority of this instructional design.

CHAPTER 4

STUDY 2

In-Class Peer-Discussions

Study 2 Research Question

1. How effective are in-class peer-discussions? Do other factors such as self-reflection (metacognition) mediate the changes observed in the Peer Instruction activity?

Study 2 Background

In the previous chapter we designed various forms of PI where the instructor lectures briefly and then presents students with a multiple-choice conceptual question (Crouch & Mazur, 2001; Mazur, 1997). Having committed to an answer, students are typically asked to turn to their neighbor and try to convince them of their answer: the *peer* instruction *per se*. Arguably, peer discussions are useful because rates of correct answers typically increase after discussions. Although this learning gain is implicitly ascribed to peer discussions, it is possible that students arrive more frequently at a correct answer after discussion because they are given more time to work on the concept or because of their own individual reflective process, independently of the peer with whom they discuss.

It has also been shown that testing is not a 'read-only' procedure. Repeated testing increases learning and retention, a process that has been termed the 'testing-effect' (Karpicke & Roediger III, 2008). Through the 'testing-effect', one would expect students tested twice to migrate towards the correct answer.

In the previous chapter we looked at various learning gains and inferred that 1-3 minute peer-discussions were important from data collected at the beginning and the end of a 15-week semester. In this chapter, we take a finer grain-size look at classroom processes by analyzing peer discussions within a single 90min class. We investigate whether instructions requesting different cognitive tasks between polls on a conceptual question might influence learning and determine the added value of peer discussions within a single class period.

Study 2 Design

An identical sequence of 9 conceptual questions was given to three groups in a 90-minute class during the first week of the semester as part of an introduction to using clickers. All groups were polled twice on each question. Different tasks were assigned to the respective groups between the first and second poll - students were either asked to discuss, reflect or were distracted (e.g., distracted by the display of a sequence of science-inspired cartoons). Given that the questions were related, feedback on the right answer was provided only at the end of the nine-question sequence.

Group 1: Peer Instruction

In the first treatment group students were given nine multiple-choice conceptual questions. For each question they were asked to record their answer by using individually assigned clickers. Once the vote was recorded, students were asked to turn to their neighbor and discuss their answers to the assigned multiple-choice question, (i.e., peer-to-peer discussion between polls). In each case, the discussion was allotted approximately a minute and students were the given another 60 seconds to re-enter a vote. This treatment followed the traditional Peer Instruction format with an initial poll followed by a peer discussion and then another poll (Crouch & Mazur, 2001; Mazur, 1997).

Group 2: Reflection-Distraction

In the second treatment group, students were given the same sequence of 9 multiple-choice questions as the first group. On 5 of these questions, after students were asked to vote, they were instructed to reflect individually on their answer for 60 seconds (i.e., not turn and discuss). At the end of the minute, students were given 60 seconds to re-enter a vote on the same question. For the remaining 4 questions, these students were asked to choose their answer, however, instead of reflecting on their answer during the 60-second interval between votes, they were given a distraction task (e.g., sequence of ‘funny’ science cartoons). Students were then re-polled on the same question and had 60 seconds to re-enter a choice. The possibility of reflecting on the concepts was reduced by the distraction task given to students between polls although students were given the same amount of time as when they had been asked to reflect.

Group 3: Distraction-Reflection

Students in the third treatment group were given the same set of 9 conceptual questions as the two other groups. The treatment was identical to group 2 except for the fact that the order of reflect and distract were reversed – i.e., students were distracted on the first 5 questions and reflected on the last 4. In doing so, this group was asked to reflect on the half of questions that treatment group 2 was distracted on. This cross design allowed us to control for differences in the change in correct answers which would be due to the difficulty of specific question.

Note that the treatment group 1 used regular Peer Instruction and was *not* distracted or asked to reflect on a portion of the questions. This methodological gap is due to the fact that in classroom settings, when students are given the possibility to discuss, it is excessively difficult to prevent them from discussing afterwards. Hence, no distraction or reflection tasks were assigned to this group that was initially asked to discuss.

Study 2 Results

Interestingly, all three groups displayed gains between the first and second poll. Figure 4.1 shows the average increase in the frequency of correct answers for all questions where students were asked to Discuss (labeled ‘Discuss’), or were asked to Reflect (labeled ‘Reflect’) or were distracted (labeled ‘Distract’). Students distracted between polls had the smallest increase (3.4%)

in correct answers, although the data do show a positive non-zero increase (standard-error bars above 0). Although the 'Reflect' group had larger increase in correct answers (9.7%), the 'Discuss' group had the greatest increase (21.0%).

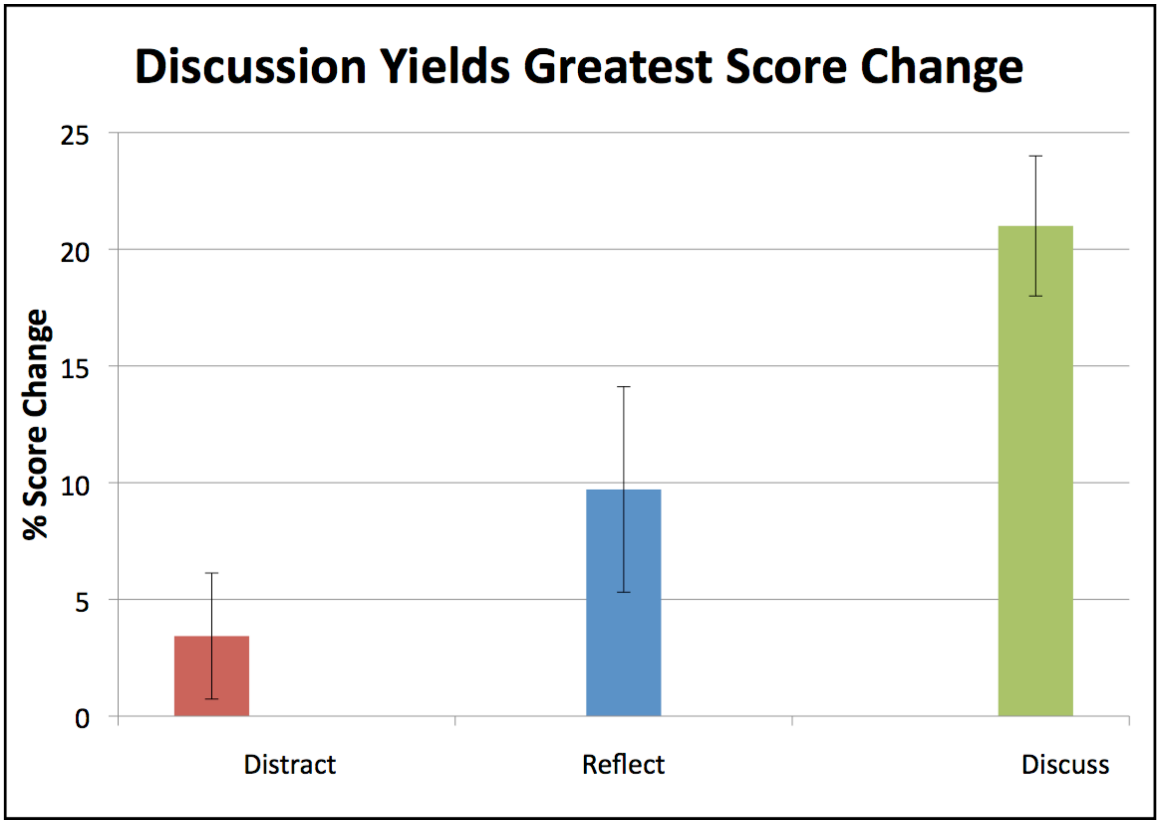


Figure 4.1. Average change in relative frequency of correct answers between consecutive polls on conceptual questions.

Between polls, students were either asked to 'Discuss' their choice of answer with their peers or were asked to 'Reflect' individually (no discussion) or were given a 'Distraction' task (no discussion and no reflection). All conditions increased in rates of correct answers when re-polled with the 'Discuss' condition increasing the most.

Study 2 Discussion

Looking at learning processes within single-class time-scales reveals a complementary picture to data collected at the beginning and the end of an entire semester. In this study, all conditions had increases in rates of correct answers, including increased rates of correct answers on questions where students had been distracted between polls. Such increases may be due to the 'testing-effect' recently published in Science (Karpicke & Roediger III, 2008). Tests are conventionally used to 'read' students' knowledge. Yet, testing is not a read-only procedure because testing itself can aid learning; an effect that could be attributed to neural mechanisms such as memory reconsolidation (Nader, Schafe, & Le Doux, 2000) and the impact of reconsolidation on providing multiple traces into memory to maximize retrieval (Lasry, Levy, & Tremblay, 2008). Testing effects suggest that instructors should rethink the use of tests in general and concept tests in particular so as to view these as important pedagogical tools, not just passive assessments of students' knowledge. Although simply re-polling students in-class on conceptual questions yields increases, self-reflection and peer-discussions further increase the rates of correct answers.

Increased rates of correct answers observed with individual reflection can be linked to previous work on the effectiveness of self-explanations (Hausmann, Chi, & Roy, 2004). This study helps to rule out the possibility that other cognitive processes alone promote change in conceptual understanding during Peer Instruction and that there is genuine added value to peer-discussions. Finally, previous work has shown a large variability in ways that Peer Instruction has been implemented (Turpen & Finkelstein, 2007), with some instructors using conceptual questions to poll students without any peer discussions (Fagen, 2003). The sizeable increase in correct answers after discussion, confirms the importance of peer-discussions in engaging students within active participatory classroom frameworks.

CHAPTER 5

STUDY 3

Participation Structures in Peer Instruction Classrooms

Study 3 Research Question

1. Does a change to the organizational structure of peer interactions affect the outcomes of Peer Instruction? In other words, does a change to possible social interactions produce differences in the patterns of students' answers? And, does it affect the patterns of students' interactions?

2. How do these different collaboration structures mediate the ways that conceptual understanding is constructed among students?

Study 3 Methods

Study 3 – Overview of the Research Designs

In our investigation of the participation structures of these two Peer Instruction classes we collected several types of data and designed three studies to answer several different research questions. We identify each study by the type of data collected and will explain the methodology involved in the analyses. For clarity we have separated these studies and report on them in separate headings in this chapter. Table 5.1 provides an overview of Study 3.

Table 5.1. Design of the three investigations that make up Study 3.

Sections Study 3	Focus	Research Question	Data Collected	Analysis
Study 3A	Between Class Responses to Concept Questions (Turning Point Questions)	1. Does a change to the organizational structure of peer interactions affect the outcomes of Peer Instruction? In other words, are there differences between the two treatment conditions? 2. What are these differences in terms of the change from the first vote to the revote? In other words, the percentage of wrong answers in the first vote to right answers in the re-vote, or right answers in first vote to right answers in revote, and so on?	Turning Point data	Quantitative analysis of data produced by Turning Point software.
Study 3B	Between-class participation structure -	Are there differences in the participation structures of the two classes?	Ethnographic observation • field notes • audio recording	• Content analysis of field notes • Analysis of sound recordings
Study 3C	Student/Group participation during concept questions	How do the different collaborative structures (activity systems) mediate the ways that conceptual understanding is constructed among students?	• audio recording • transcripts of recordings • Online conference	Discourse analysis of group conversations during peer instruction. Use of theoretical framework of Activity Theory & Bakhtin's communication model

1) Study 3A – Between Class Responses to Concept Questions

This is a report on the two classes' responses to the conceptual physics questions – *an analysis of conceptual question responses*. This study is a subset of Study 1 therefore it is based on the same quasi-experimental design (see Table 5.2). It reports on the data collected from responses to the

50 conceptual questions answered by the students during their Peer Instruction classes using *Turning Point*™ software (more on this later). We examine these data using simple descriptive statistics.

Table 5.2. Quasi-Experimental research design for Study 3.

	Treatment 1 = CW1 (Traditional PI)	**Treatment 2 = CW2 (Consensus PI)**
Individual vote & Group discussion	**Y**	**Y**
Individual revote	**Y**	
Group consensus revote		Y

2) Study 3B – Between Class Participation

The second study designed from this classroom data was a comparison of the participation structures of the students in two different treatment conditions – *an analysis of the structures of students' participation during peer instruction*. For this we used the field notes created during the in-class observations of the principal investigator of the project. These field notes were written up after each classroom session and checked for accuracy against the audio recordings taken of focus groups (these will be described in the next section).

3) Study 3C – Between Group Participation on Concept Questions

The third study analyzed audio recordings of students in small groups – *an analysis of group discourse during peer instruction*. For this study we collected data from two groups in both of CW's classes. Recall that the Traditional PI was called CW1, and the Consensus PI was called CW2. In each class we selected two groups (e.g., CW1G1, CW1G2). The composition of all four groups was based on their self-selection. Not surprisingly groups tended to be made up of similar ability students. In each class our Group 1 (CW1G1, CW2G1) consisted of medium ability students, and group 2 (CW1G2, CW2G2) consisted of high ability students[3]. For simplicity we

[3] Note that all these students were in their first year of the 2-year pre-university science program, which requires that students have a minimum of 75% in their high school physics course (NUMBER). Also note that these classes were considered part of the

have provided a table that gives an overview of the classes and groups (see Table 5.3) and refer to the four groups by an assigned name rather than number. We will also refer to the students by pseudonyms.

Table 5.3. Overview of design of Treatment groups and classroom conditions.

Class	CW1		CW2	
Treatment	Traditional PI		Consensus PI	
Groups	G1CW1	G2CW1	G1CW2	G2CW2
Assigned name	Alpha	Beta	Chi	Epsilon
Composition	3 girls	3 boys	2 girls 1 boy	2 boys

We designed two case studies to understand the types of activity structures produced by the students' participation. Case study 1 looked at the two groups within class CW2 (see Table 5.4).

Table 5.4. Case study 1 – Within-Class comparison of ability groups.

Class	CW2	
Treatment	Consensus PI	
Groups	G1CW2	G2CW2
Assigned name	Chi	Epsilon
Composition	2 girls 1 boy	2 boys

Case study 2 looked at differences between the two classes and how equivalent ability groups participated, and what those differences might tell us about the original questions investigated in Study 1 and Study 3A & 3B (see Table 5.5).

regular program and not an honours class. Also note that this college has a special cohort of honours students who are enrolled in an honours program called "First Choice" in which all students must have over 90% in their high school science courses.

Table 5.5. Case study 2 – Between-Class comparison of ability groups.

Class	CW1	
Treatment	Traditional PI	
Groups	G1CW1	G2CW1
Assigned name	Alpha	Beta
Composition	3 girls	3 boys

Please note that in the remainder of this chapter we elaborate on these studies. In doing so we the remainder of the chapter is divided into sections. Additionally, each study can stand on it's own therefore you do not need to read them in sequence.

Settings of Study 3

The data we report on was collected from the classrooms of one of the two teachers who engaged their students in the Peer Instruction approach. We call this teacher "CW", who was also part of the research team. CW taught two of the treatment classes of introductory physics using two versions of the Peer Instruction (Treatment 1 & 2 in the previous data set). Recall that Peer Instruction (PI) is said to promote learning in physics by focusing students' attention on specific concepts using polling on multiple-choice questions during class time. These questions are initially answered and voted on individually (commitment to an answer) and, if necessary, discussed in small groups then voted on again. This method is designed to engage students in collaborative activity including debate (logical arguments – scientific reasoning) leading to concept revision – i.e., conceptual change. In the traditional form of PI, the revote is based on an individual's decision to hold on to their initial choice or not. In this study we examined both the traditional method of PI (we call this class, CW1) as well as a version that required the small groups to come to consensus on their revote (we call this class, CW2). For those who wish to compare across studies, CW1 produced the data labeled Treatment 1 in Study 1 & 2; meanwhile, CW2 produced the data labeled Treatment 2 in Study 1 & 2.

SECTION I

Between Class Responses to Concept Questions

Study 3A Research Questions

Research Question 1a: Does a change to the organizational structure of peer interactions affect the outcomes of Peer Instruction (PI)? In other words, are there differences between the two treatment conditions?

Research Question 1b: What are these differences in terms of the change from the first vote to the revote? In other words, the percentage of wrong answers in the first vote to right answers in the re-vote, or right answers in first vote to right answers in revote, and so on?

Study 3A Methods

Treatment Instruments

Data for this study was collected using Turning Point™ software. Turning Point is an audience response system that allows students to participate in presentations or lectures by submitting responses to interactive multiple-choice questions using hand-held devices (clickers). It is fully integrated into Microsoft® PowerPoint® therefore is part of regular PowerPoint presentation. Each time a question is answered using an individual clicker Turning Point records the answer as a separate piece of data. Responses statistics can be made visible and reported on the same PowerPoint slide (see Figure 5.1).

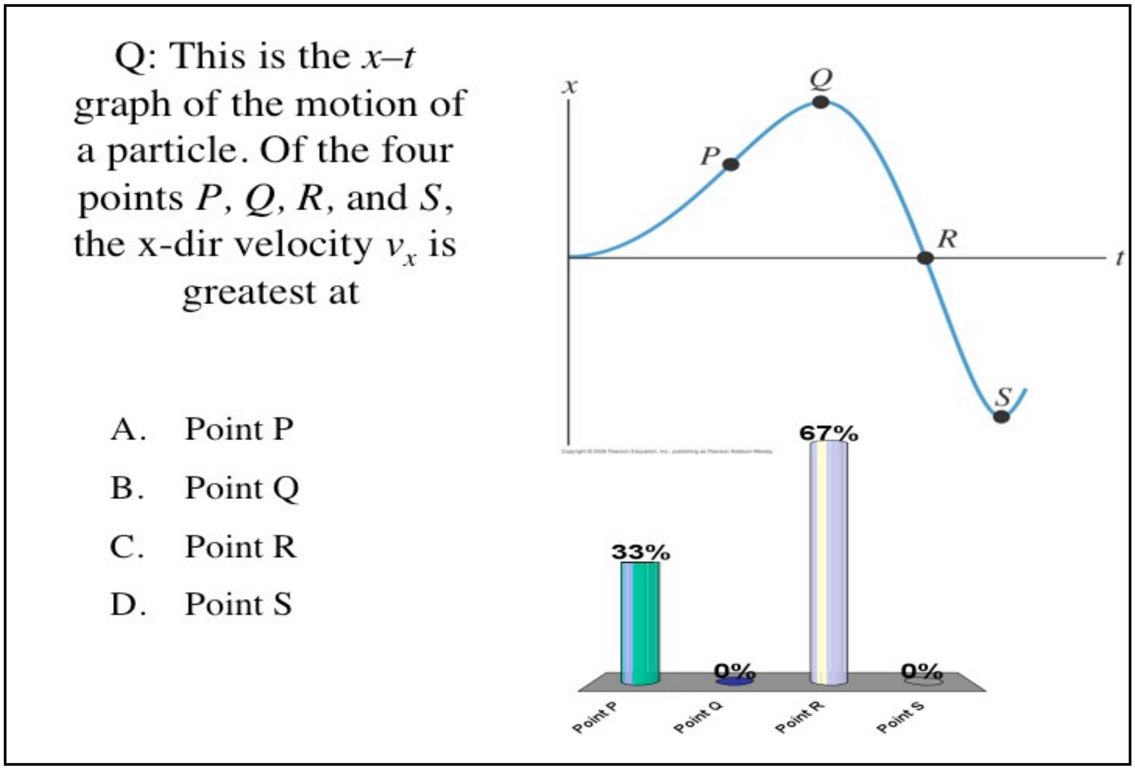
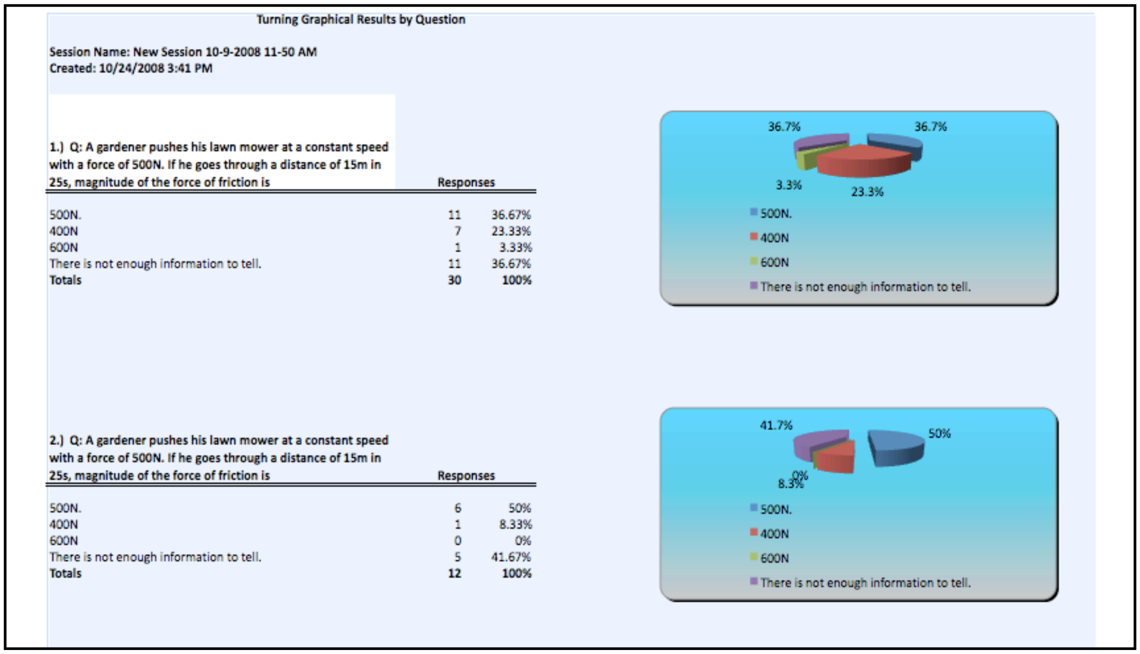


Figure 5.1. Example of Turning Point™ output graph on a PowerPoint® slide.

Additionally, these data are archived within the software and can later generate a variety of report statistics. These reports are generated as Microsoft® Excel® or Word® documents. Results can be generated as tables or figures and shown by question or by participant (i.e., clicker). For example: results by question, graphical results by question, demographic comparison, and participant results.

For this study we generated our results by question and used both the tables as well as figures (e.g., Figure 5.2). These were somewhat redundant but allowed use to compare across the large pool of data these 100 plus data points produces across two classes.


Turning Graphical Results by Question

Session Name: New Session 10-9-2008 11-50 AM
Created: 10/24/2008 3:41 PM

1.) Q: A gardener pushes his lawn mower at a constant speed with a force of 500N. If he goes through a distance of 15m in 25s, magnitude of the force of friction is	Responses	
500N.	11	36.67%
400N	7	23.33%
600N	1	3.33%
There is not enough information to tell.	11	36.67%
Totals	**30**	**100%**

2.) Q: A gardener pushes his lawn mower at a constant speed with a force of 500N. If he goes through a distance of 15m in 25s, magnitude of the force of friction is	Responses	
500N.	6	50%
400N	1	8.33%
600N	0	0%
There is not enough information to tell.	5	41.67%
Totals	**12**	**100%**

Figure 5.2. Example of Excel® generated graphical report from Turning Point™.

Conceptual Question Assessment Instruments

Of course Turning Point is only a presentation software and the real substance of the study are the questions that allow students to express their knowledge and ideas, hopefully leading to conceptual change. For this study the teacher, CW, selected the majority of the 50 plus questions (see example in Figure 5.3) from a bank of conceptual questions available from *University Physics with Modern Physics with Mastering Physics™, 12th Edition* (Young & Freedman), the remainder were from other sources. Note these questions make up the items discussed in all the Peer Instruction approach used in Study 1.

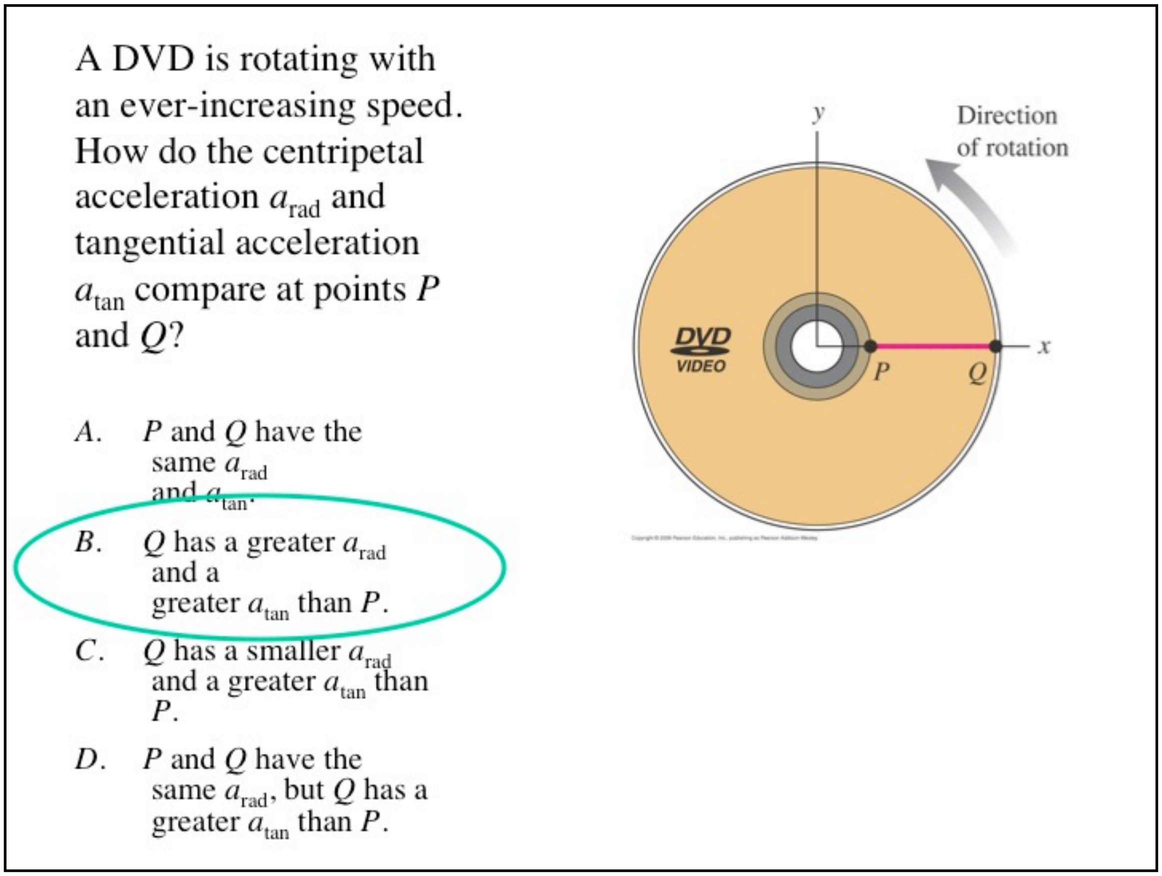


Figure 5.3. Example of conceptual question presented in PowerPoint® and voted on using Turning Point™.

Transition Assessment Instrument

In addition to the conceptual questions collected by the Turning Point software we also designed an instrument to collect information on how students changed their votes between the two polls. We call this instrument the *Transition Slide* (see Figure 5.4), which gave students a chance to self-identify whether and how they changed their answers. It was administered only in the event of a revote and after the teacher had shown and explained the correct answer to students.

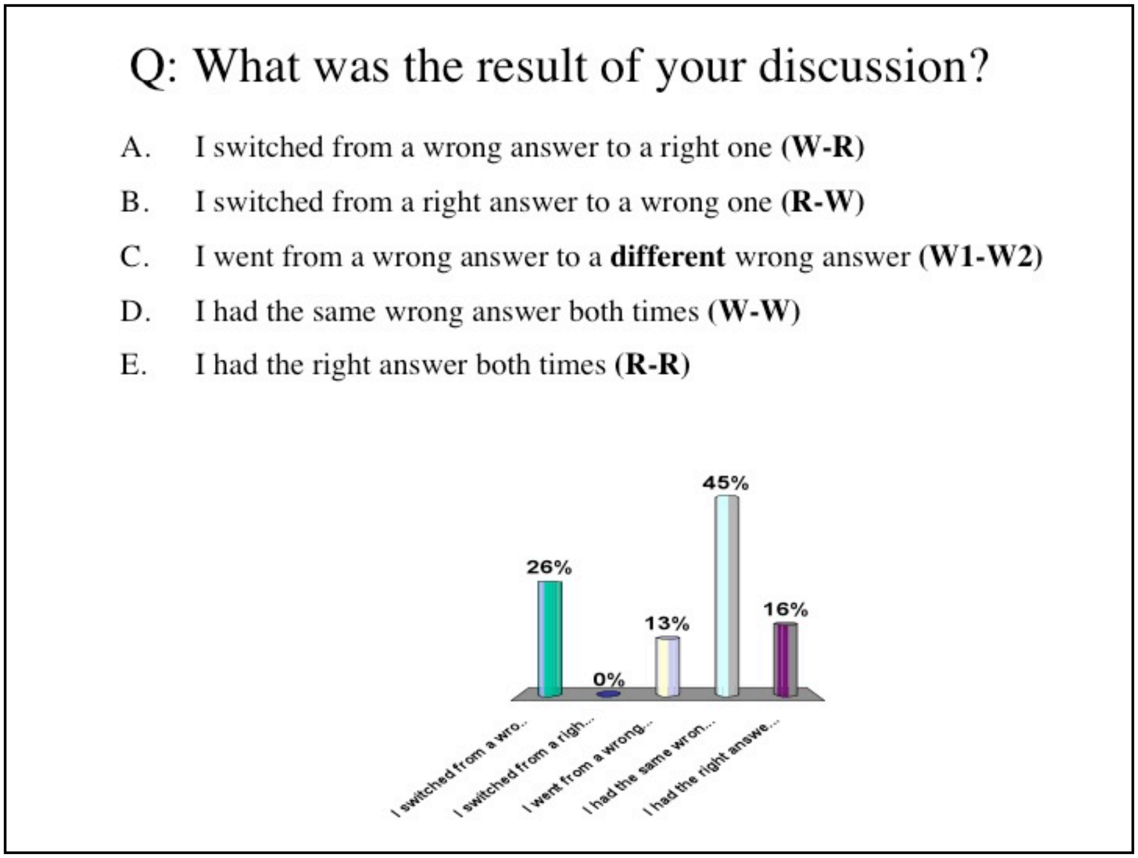


Figure 5.4. Example of a Transition slide showing the change between the Vote and Revote.

Study 3A Data Collection

The same set of 50 plus Turning Point questions were administered to both of CW's classes (i.e., CW1 & CW2). They were delivered in the same order and, generally, within the equivalent class or lab scheduled for the week (see Appendix B for schedule of questions and dates they were administered). These 50 plus data points for each class are considered the TPZ data and span approximately 12 of the 15-week semester. Each data point is recorded as raw numbers of students and percentages of the total students voting on a single question.

The decision to hold a revote was based on whether or not the larger percentage of the voting students got the right answer. This cut off number was approximately 65% and higher. In those cases, there was no call for a revote and the teacher moved forward with the explanation of the answer. On the other hand, if the percentage of students entering a wrong answer was higher than 40% (approximately) the teacher asked students to revote. After the revote he revealed the correct choice and then explained the answer. In the latter case, the Transition Slide was administered.

Note that because of our design for CW2 (Consensus PI) where students voted as individuals in the first poll and groups in the second, we compared percentages rather than raw numbers. Generally speaking, students were mainly compliant and participated in both the vote and revote. There are some instances, however, where there are discrepancies between the total votes. In no case are these differences large enough to warrant removal of the data.

Transition data

The Transition Slide data was also recorded in Turning Point software and generated the same Excel files. In all cases students voted as individuals and entered how their answers changed between polling. These data were recorded as raw numbers of students and percentages of the total votes. Interestingly, in some cases more students participated in this voting compared to the TPZ voting.

Study 3A Results

TPZ Data

There are no differences between the numbers of correct answers generated by CW1 compared to CW2. Additionally, there is no definite pattern emerging from the TPZ data that suggests a relationship between the number of students arriving at the correct answer and the treatment condition.

Transition Slide Results

The Transition Slide was required approximately fifty percent of the time for both classes: CW1 = 51% of the questions, CW2 = 54% of the questions (NB. that it was not used in the first 6 questions). In other words, the majority of students in CW1 got 23 questions right, therefore no revote was required. Meanwhile, the majority of students in CW2 got 22 questions right, therefore no revote was required.

What we see with the Transition Slides is a slightly more revealing picture. Figure 5.5 shows that if we aggregate questions by the period within the semester, i.e., early semester (20 questions) and late semester (18 questions), and take the average percentage of students changing from wrong to right answers, then more students in CW2 change to the right answer even early on. But later in the semester this difference becomes substantially larger.

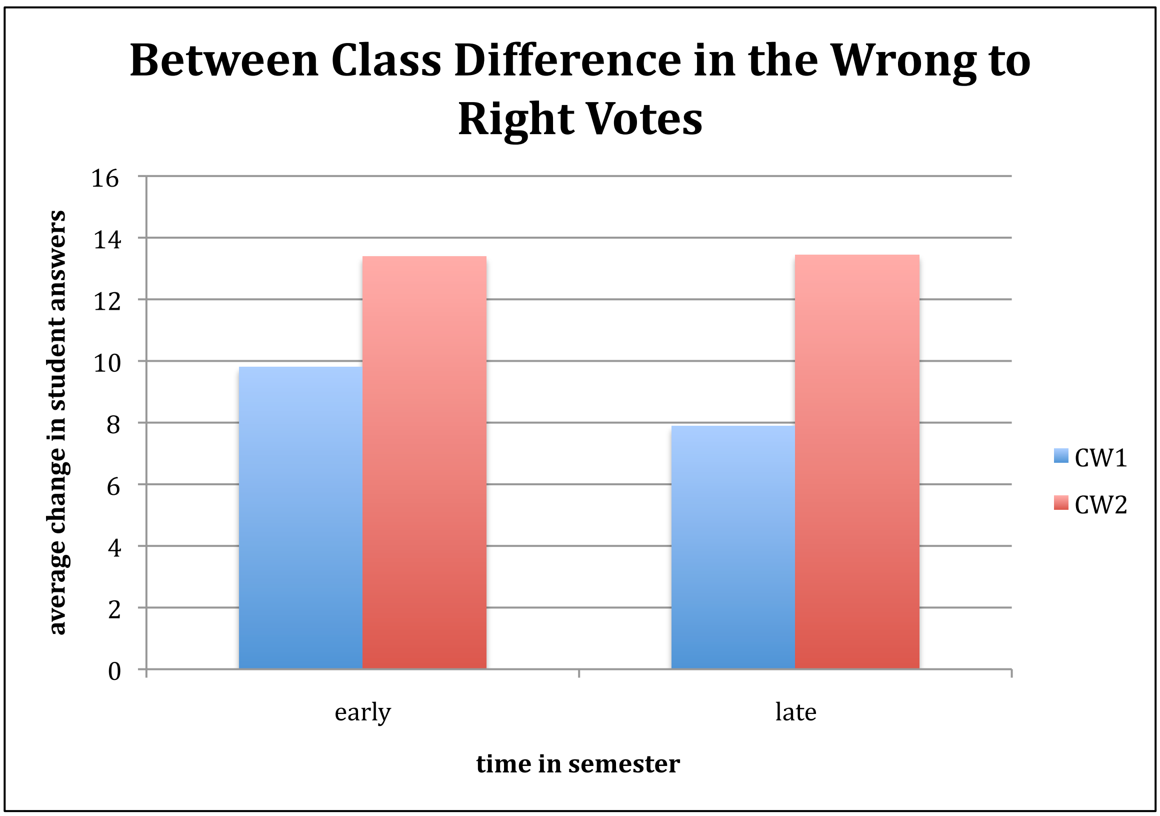


Figure 5.5. Between-Class differences in the Wrong to Right Vote.

If we do the same and divide the semester into early and late using data from the other options available in the Transition Slide, namely, right to wrong, wrong to wrong, and so forth, there is no difference between classes, but there is a small difference for early or late in the semester (see

Figures 5.6 & 5.7). In this case there is a small decrease in the percentage of students getting the answer right both times. More interestingly, there is a small increase in the number of students sticking with their original answers, going from wrong to the same wrong answer. In no instance is there any statistical difference between classes, or between early and late within the class.

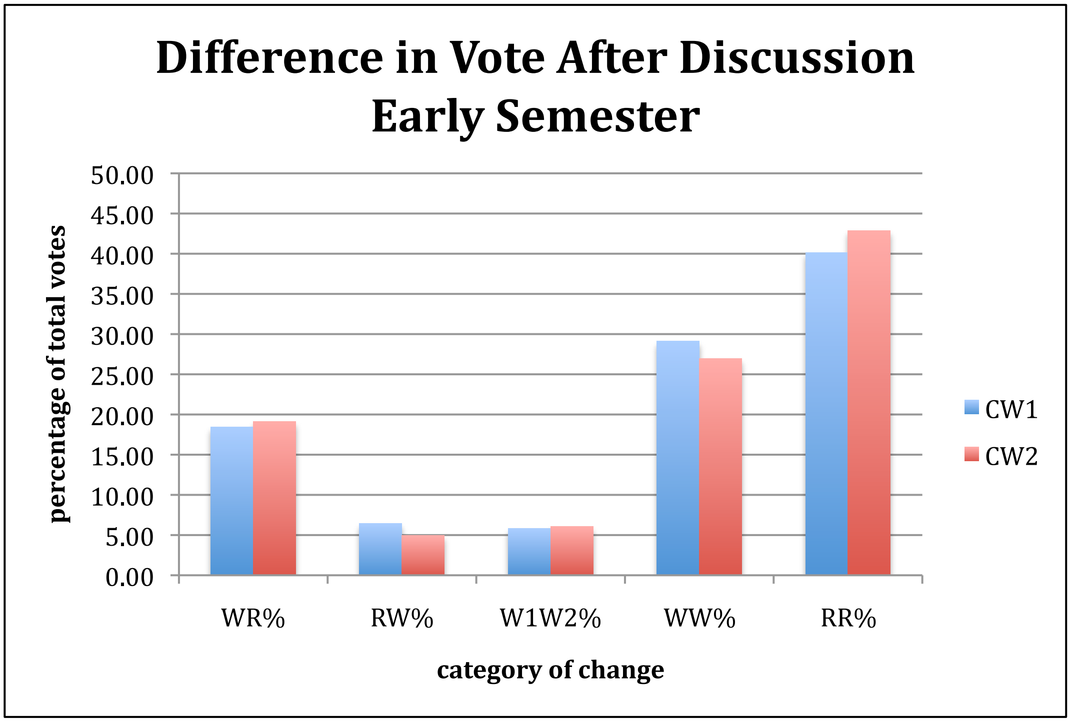


Figure 5.6. Early Semester differences on the Transition Slide between CW1 & CW2.

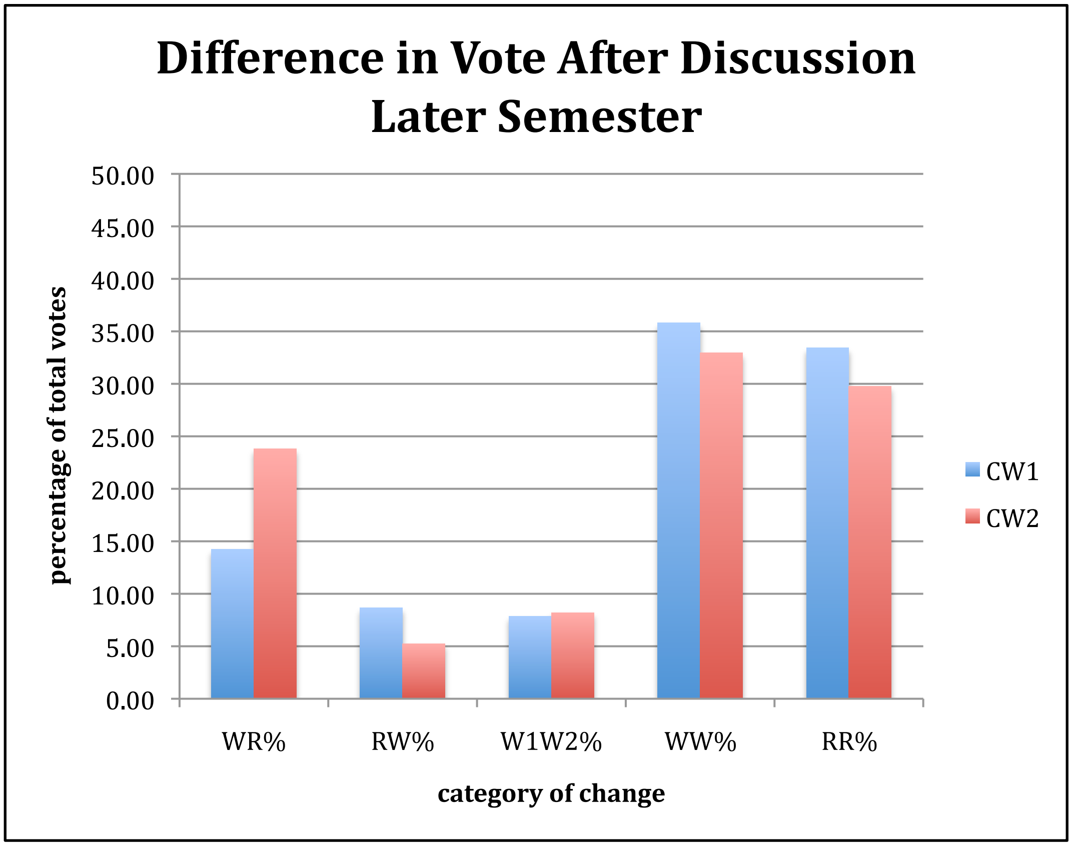


Figure 5.7. Late Semester differences on the Transition Slide between CW1 & CW2.

Variance between CW1 and CW2's voting

If we look only at the differences between the two classes and compare how these change over time we get a slightly different perspective on the process of Peer Instruction, as enacted in these two cases. While Figure x8 confirms that the difference between the classes wrong to right answers continued to vary throughout the semester, with the later half favoring CW2, the other figures show another part of the story.

Figure 5.9 and 5.10 show that there is a lessening of the variance between the two classes on two of the variables in the Transition Slide, i.e., the wrong to wrong, and right to right. In other words, the students in both classes were becoming more similar when it came to these two ways of responding to the multiple-choice questions. We do not see the wild fluxtuations that are in evidence in the wrong to right or in the other options (not shown).

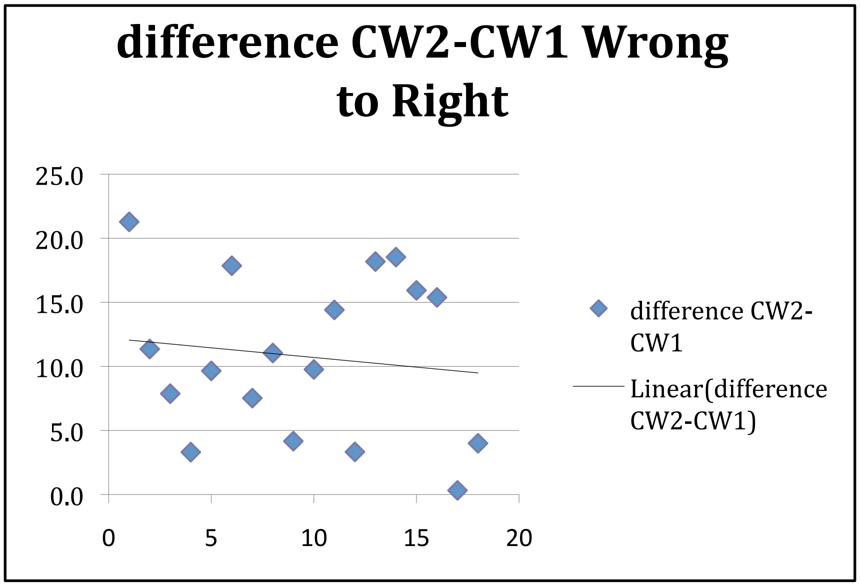


Figure 5.8. Continuing cariance between CW1 & CW2's Wrong to Right Vote.

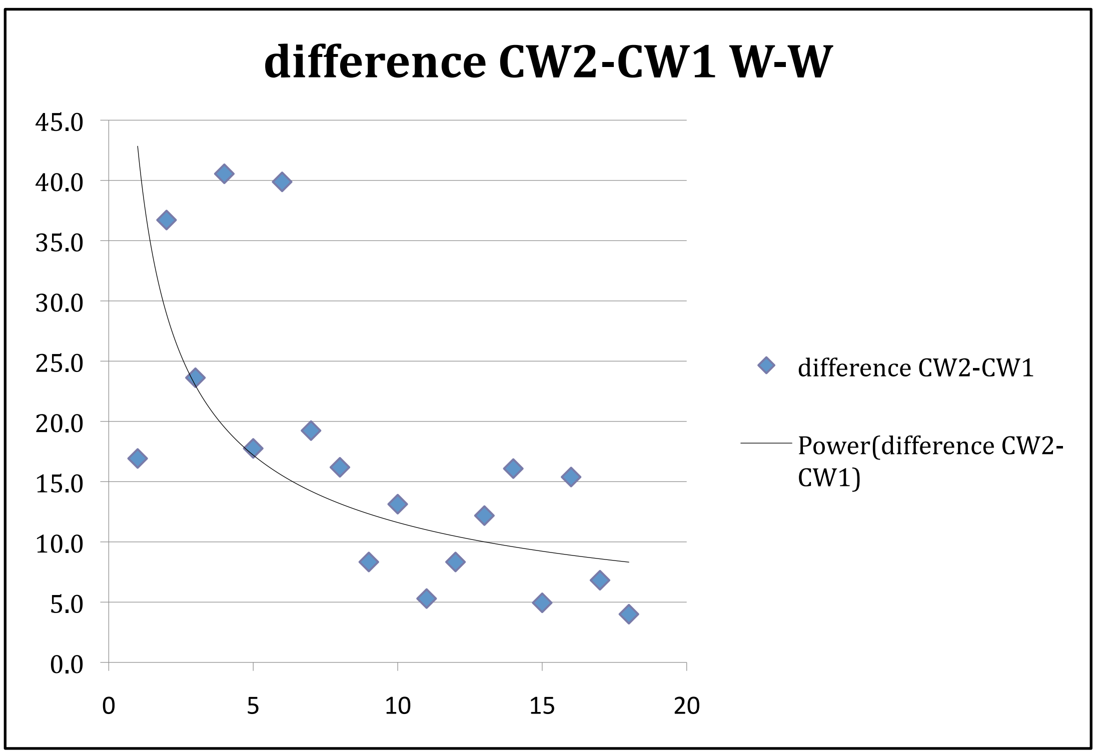


Figure 5.9. Lessening variance between CW1 & CW2's Wrong to Wrong Vote.

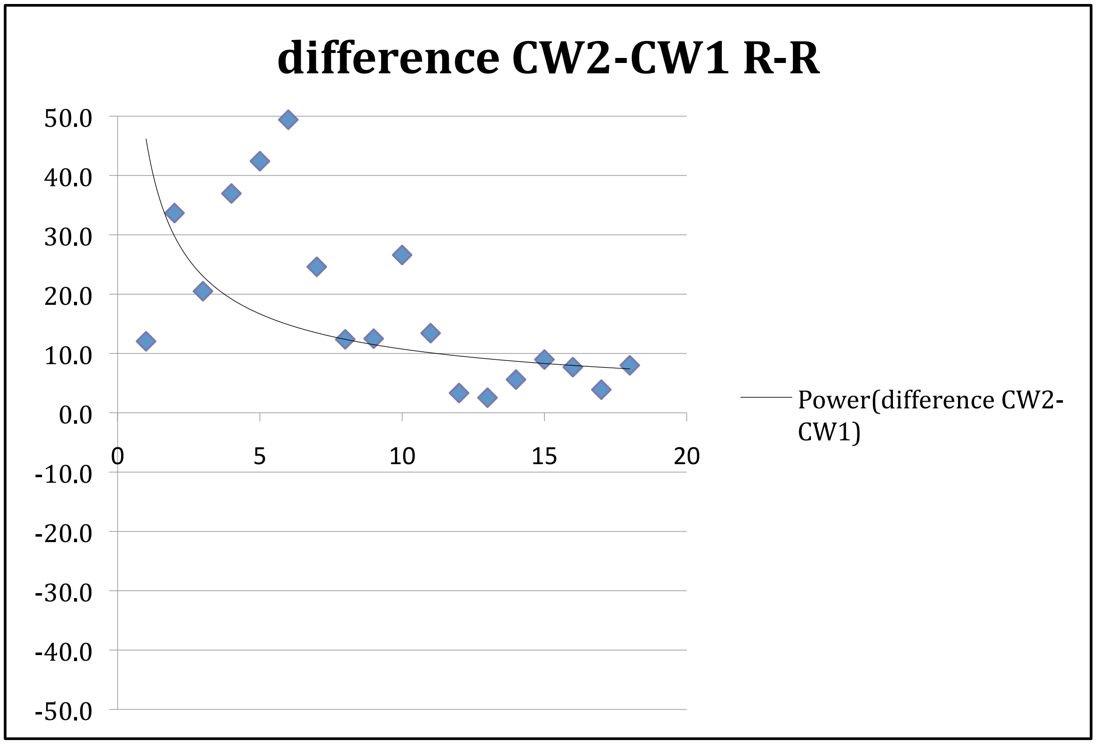


Figure 5.10. Lessening variance between CW1 & CW2's Right to Right Vote.

Study 3A Discussion

Our data show that the peer instruction method has a positive effect on students' conceptual learning gains compared to other traditional instruction data (as shown in Study 1 using the FCI). Changing the organization of the social interaction in peer instruction, however, does not produce a statistically difference between treatment conditions (also shown in Study 1).

The convergence of the variance between the two classes on the variables of Wrong to Wrong and Right to Right suggests a couple of possibilities. First, it may be the result of students in the two groups becoming more like their teacher and therefore more like each other. This could be explained from the cognitive view of mapping mental models or from the socio-cultural view of appropriating certain practices. Another possible explanation is that regardless of the class or treatment, over time students begin to sort out into those who understand the content (Right to Right) and those who do not (Wrong to Wrong). It is the latter that also reveal this conceptual "fixitivity" in the other representations showing a small increase in the number of wrong-to-wrong answers. On the other hand, these results also give some encouragement when it comes to the change we see over time with the small increase in the percentage of CW2 students who go from wrong to right answers. This suggest that something cumulative may be happening in

Regardless of the explanation, what our qualitative data shows is that there were differences between the two classes. What exactly these differences are we will investigate in the upcoming chapters that extends Study 3.

Reflections on What Has Been Learned to this Point

Before moving forward to Study 3B let us review what we have learned thus far. Recall that there were two classes of Peer Instruction being studied, CW1 (Traditional PI) and CW2 (Consensus PI). These were part of the first investigation, Study 1, which established a baseline understanding of whether different modes of participation affect students' learning through conceptual change and students' expectations towards physics. Study 1 showed us that there were not statistical differences between the 4 different modes of classroom participation. In short, designing opportunities for students to engage with each other around conceptual understanding promotes learning. But we also saw trends in the data suggest that some modes of participation were more effective.

The global design of Study 3 was to investigate certain elements of the Peer Instruction approach, namely the role of the discussion. For this we designed two conditions, CW1 (Traditional PI) and CW2 (Consensus PI). In doing so, Study 3 was planned as a way to allow us to further elaborate on whatever trends we might identify in Study 1. We did this by designing 3 levels of observation, each at different grain sizes. The first in Study 3A was at a gross level of granularity and showed whether or not there were differences between the two classes and how they came to the right answers on the conceptual multiple-choice questions that make up the Peer Instruction approach. The results of this investigation showed trends leaning toward differences in the percentage of right answers for CW2 as the semester progressed. It also showed that students in both classes also began to converge toward a normalizing trend when it came to knowing the answers from the start (right to right) or not knowing (wrong to same wrong).

SECTION II

Analysis of Participation Between Classes

Study 3B Research Questions

Research Question 1c: Are there differences in the participation structures of the two classes?

Research Question 1d: How might we account for those differences using a socio-cultural perspective?

Study 3B & 3C Methods

Study 3 – Part 2 & Part 3 were planned as a way to zoom to finer levels of granularity. In this way, Study 3 – Part 2 uses the classroom field notes to describe the classroom participation structures. As an advance organizer, Study 3 – Part 3 zooms into the conversations between the students in the small groups to give us a micro-level view of what happened between students engaged in Peer Instruction.

Study 3B Data Collection

Ethnographic methods were used to collect the data used in Study 3 – Part 2. These data were in the form of field notes made by the principal researcher during in-class observations: 18 classes in CW1 (Traditional PI) and 16 classes in CW2 (Consensus PI). The field notes were edited and transferred to electronic form after each class. At that point they were organized according to a template developed to facilitate future analysis. This organization considers of approximate times of notable activities, who initiated the activities (e.g., students or teacher), and descriptions of the activities (see Appendix B for example).

Additionally, audio recordings made during the discussion of the Turning Point conceptual multiple-choice questions were used to confirm the field note reporting. Audio recording software was used to produce histograms of the sound levels. These could then be compared across the treatment conditions, i.e., CW1 and CW2. The idea to use the sound levels produced during these discussions is based on both Eric Mazur's notion of creating an environment with sufficient ambient noise so that students are not inhibited to talk. Additionally, recent research conducted by Pierre Dillenbourg and his research team and presented at the CSCL conference, June 2009 (e.g., Jermann, Nüssli & Dillenbourg, 2009).

Study 3B Analytic Procedure

This participation was defined by the following indicators:

1. Engagement with peers. Participation was defined as signs of interest during the peer discussions. Indicators used were: (1) evidence of continuous talk, (2) engagement with other groups for the purpose of discussing answers (e.g., turning around to talk to other students), and (3) following the teacher's instructions in a timely fashion (e.g., no repeating of instructions). These were identified by field notes and the audio recordings of the respective classes.

2. Engagement with content. Participation was defined as engagement with the content as indicated by the interaction with the teacher. This interaction was identified as (1) question asking, and (2) comment making. Questions and questioning strategies are reported to be important in learning (e.g., Ram, 1991; van Zee & Minstrell, 1997). As such, we determined student-led questions would be good indicators of a certain type of student participation.

Study 3B Results

The field notes indicate that, overall, students in CW2 (Consensus PI) participated more actively with their peers than students in CW1 (Traditional PI). This was confirmed by the audio recording histograms that show that students in CW2 produced more continuous talk (Figures 5.11) compared to students in CW1 (Figure 5.12). The examples shown were made from excerpts during discussion on the 7th week of classes (i.e., Oct 9th for both groups discussing the same question).

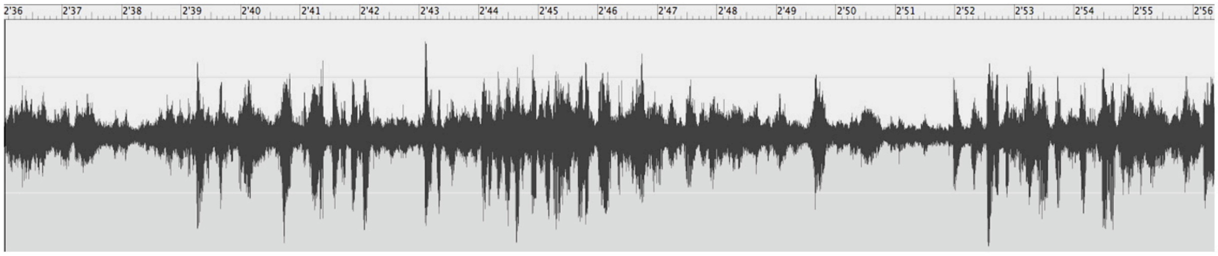


Figure 5.11. Histogram produced during student discussion period in CW1.

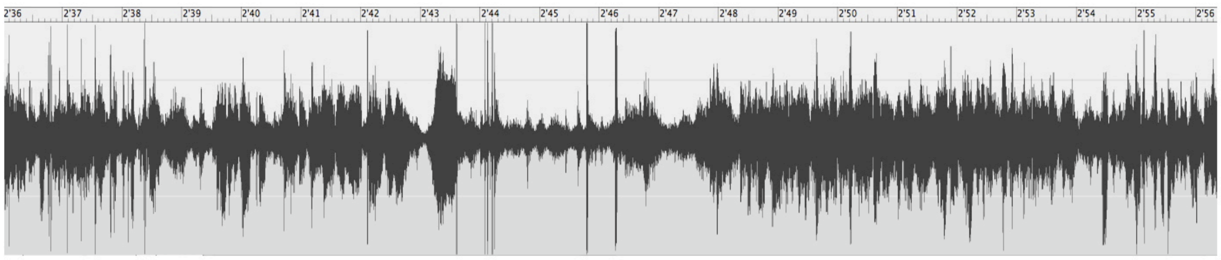


Figure 5.12. Histogram produced during student discussion period in CW2.

Student interest in the content. Additionally, we identified student comments as another form of participation. These two items were identified in the field note data, coded as such and tabulated for the respective classes (see Table 5.6).

Specifically, they were twice as likely to initiate questions directed at the teacher compared to their peers in CW1 (Traditional PI). Interestingly, the reverse was true for the student-led comments.

Table 5.6. Descriptive statistics of student participation in CW1 & CW2 over 15 classes each.

Student generated participation	CW1 (Traditional PI)	CW2 (Consensus PI)
Questions over 15 classes	M = 2.8	M = 6.6
Comments	M = 0.6	M = 0.2

Student question asking in CW1 was significantly less than in CW2. Graphical respresentations of thse results makes it clearly evident (see Figures 5.13 & 5.14).

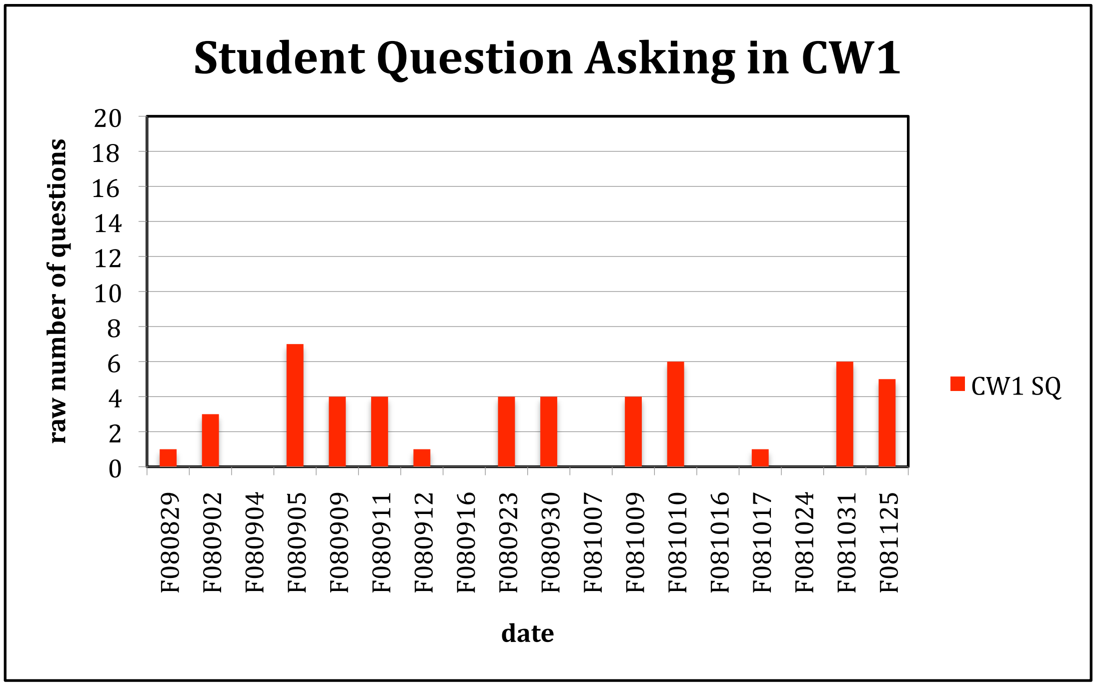


Figure 5.13. Student Questions Asking in CW1 (Traditional PI).

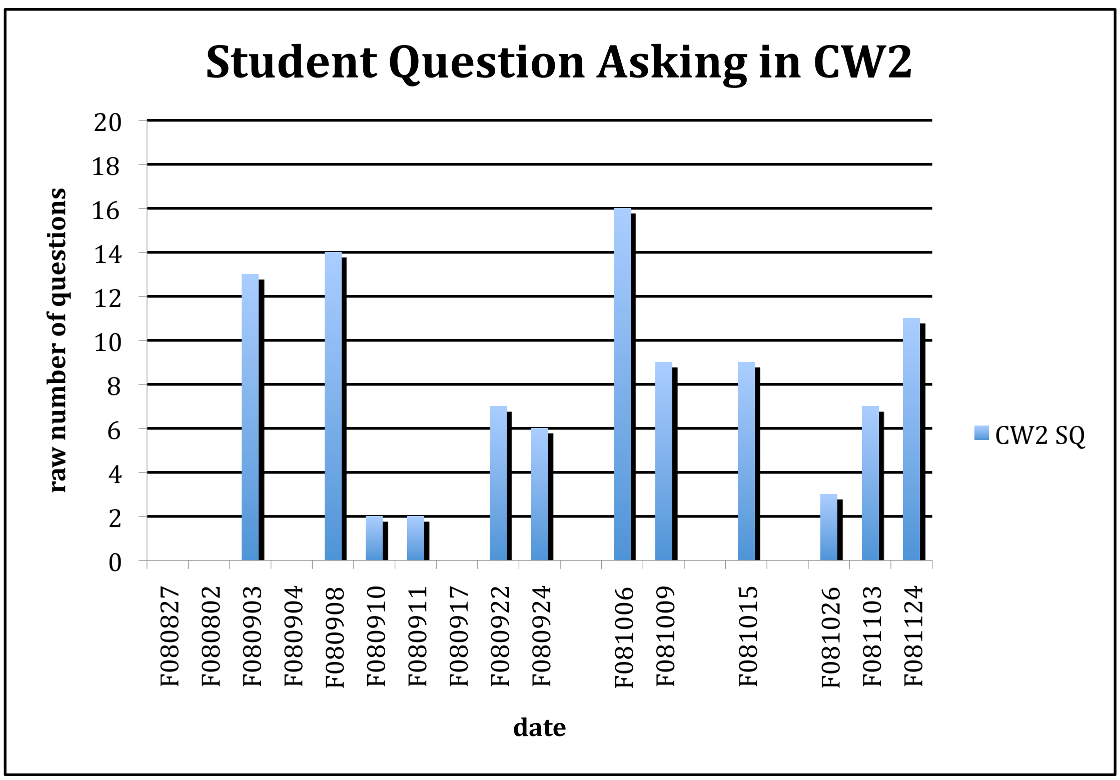


Figure 5.14. Student Question Asking in CW2 (Consensus PI).

SECTION III

Between Group Participation Concept Questions

In the following section we will describe the design and results of this third investigation that makes up Study 3. Before continuing, however, we will briefly describe the theoretical framework that guides this study and the analysis of the data.

Socio-Cultural Analytic Framework

Social interactions are often designed into activities that call for collaboration. Collaboration relies on collective actions and development of *common ground* (Clark & Schaefer, 1989). The process of *grounding*, helps to shape the collective purpose and establish shared goals (Clark & Brennan, 1991). Roschelle (1992) refers to this as "convergence of meaning," which promotes conceptual change. Shared meanings and patterns of thinking (epistemic frames) are created through the use of language, which, in turn, is colored by the culture and history of the discipline (Toulmin, 1999). It is related to what Sfard (2008) calls "commognition."

In this analysis we used the framework of Engeström's *Activity Theory* (Engeström, 1999) and Bakhtin's notion of communication (Bakhtin, 1986). We will discuss each of these in turn.

Activity Theory is a psychological theory that describes socially-based actions and the development of practice producing social outcomes. In doing so, it offers a way to account for individual and community level contributions to the activity system (see Engeström, 1987, 1993; Leont'ev, 1974, 1981, 1989; Nardi, 1996; Vygotsky, 1978). According to Barab, Barnett and Squire (2002), "(w)hen discussing activity, activity theorists are not simply concerned with "doing" as a disembodied action, but are referring to "doing in order to transform something," with the focus on the contextualized activity of the system as a whole (Barab, 2002; Engeström, 1987, 1993) (p.504)."

According to the theory, activity is comprised of four triangular relationships (see Figure 5.15). The original relationships are between the Subject, Tools & Artefacts, and Object. The lower half of the triangle accounts for the external factors that impact the activity of the individual(s), they are: rules, community and division of effort/labour. These components interact each with the other, in a dialect fashion. We will use this theory as the theoretical lens to understand the activity of the classes and the groups that operate within them.

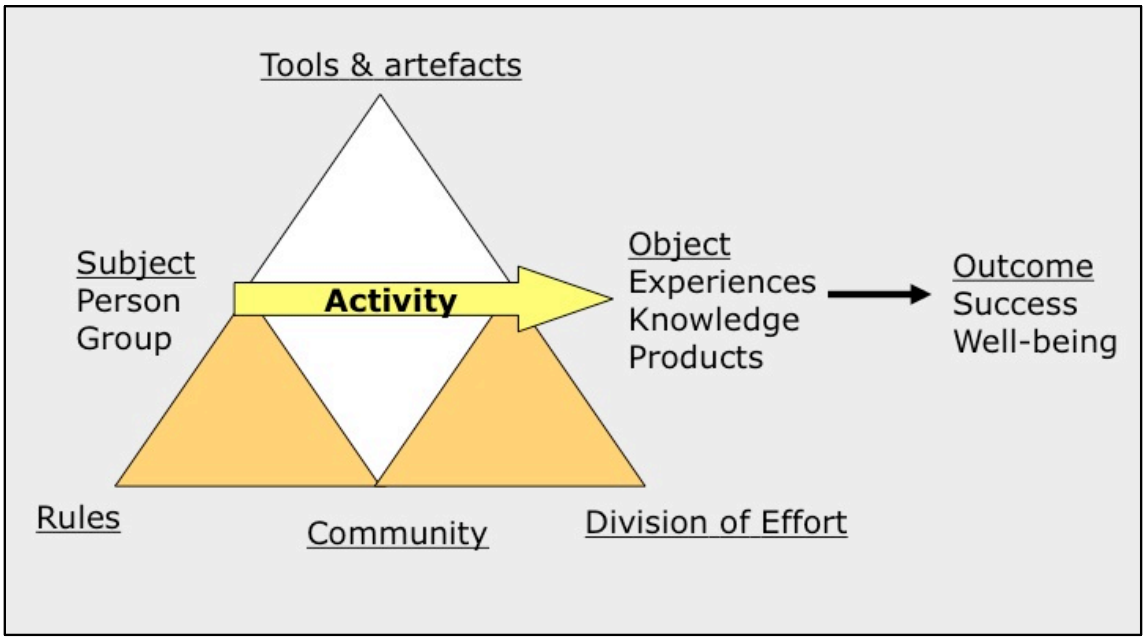


Figure 5.15. Engeström's Model of Activity Theory.

Bakhtin's Model of Communication

Mikhail Mikhailovici Bakhtin Russian philosopher and linguist, introduces the notion of dialogical communication to describe the socially rooted ongoing dialog with things that have been said, or written, and in anticipation of those that will be said in response. From this view even individual thinking/learning is dialogic because we interact with the external sources of the thing we are thinking or learning about (i.e., the externalized knowledge).

It might be said that Bakhtin's model views communication as collaboration, even if it is with oneself. He calls this process *polyphony* – the use of multiple voices for making sense of the real world. It is the multiplicity of thought that passes though the utterances of different individuals, in the process taking on different sounds and tones (Bakhtin, 1986). It is the process through which a specific community's discourse/language (*second genre*) is appropriated and becomes familiar – i.e., words, concepts, meanings and ability to use them to create social meaning and personal meaning.

Mechanisms of polyphony discourse include two types of utterances, *unity* and *difference*. Unity as half the process reflects moments of collaboration (joint creation of harmony, problem solutions from multiple voices). It is achieved through *repetition*s, *inter-animated utterances*, *socializing* and *negotiating segments*. Repetition as a mechanism help to build richness of meaning as words and utterances build on each other (Stahl, 2006). Furthermore, according to Zemel (2005), in face-to-face collaborative problem solving participants unconsciously imitate each others' gestures and sometimes move together in choreographed unison (Zemel, 2005). Trausan-Matu, Stahl and Zemel (2005) suggest that such actions are the manifestations of polyphony, a state of group flow, the collaborative moment of a successful discourse.

Inter-animation, on the other hand, as a process, also allows for richer and perhaps more productive instances of problem solving because of the interaction of multiple voices. It could be explained as internally scaffolded interactions of participants/interlocutors in a discourse. The results of this type, the product of discourse produces what looks for all intent and purpose as a single utterance (Bakhtin, 1986).

The *difference* feature is achieved through the *dissonance*, *contrast* and *critique* of ideas (Trausan-Matu, Stahl & Sarmiento (2006). Difference is similar to a rhetorical voice. Trausan-Matu, Stahl and Sarminento (2006) elaborate on this notion by stating:

> The possibility of contemplating (listening), from a critical position, the ideas (melodies) of other peoples and entering into an argumentation (polyphony of voices), enhance problem solving and enables learning through a trial-error process. Such processes appear also in individual problem solving (we can say that thinking is also including multiple inner voices) but the presence of multiple participants enhance both the possibility of developing multiple threads and, meanwhile, of differences identification. The

> interanimation of the multiple perspectives of the participants, the opposition as result of contemplation and the presence of a third opinion in case of conflict, and sometimes the synthesis it brings are a better asset to success than a multi-voiced discourse performed by an individual (as inner thinking), that is inherently much less critique. (p. 136)

Study 3C Research Question

Research Question 2: How do the different collaborative structures (activity systems) mediate the ways that conceptual understanding is constructed among students?

Study 3C Design and Data Collection

Research setting

The data we report on was collected from the classrooms of one teacher we call “CW”, who was also part of the research team. CW taught two classes of introductory physics using two versions of the Peer Instruction approach. Peer Instruction (PI) is said to promote learning in physics by focusing students’ attention on specific concepts using polling on multiple-choice questions during class time. These questions are initially answered and voted on individually (commitment to an answer) and, if necessary, discussed in small groups then voted on again. This method is designed to engage students in collaborative activity including debate (logical arguments – scientific reasoning) leading to concept revision – i.e., conceptual change. In the traditional form of PI, the revote is based on an individual’s decision to hold on to their initial choice or not.

Recall that in this research we examined both the traditional method of PI (treatment group CW1) as well as a version that required the small groups to come to consensus on their revote (treatment group CW2). As a reminder, we provide once again the break down of the two classes and the two ability groups we selected to study. The two classes were CW1 (Traditional PI) and CW2 (Consensus PI). In each we selected two groups of differing abilities in physics. In each class our Group 1 (CW1G1, CW2G1) consisted of medium ability students, and group 2 (CW1G2, CW2G2) consisted of high ability students. For simplicity we refer to the four groups by an assigned name rather than number. We also refer to the students by pseudonyms (see Table 5.7).

Table 5.7. Study 3C – Description of classes and groups studied.

Class	CW1		CW2	
Treatment	Traditional PI		Consensus PI	
Groups	G1CW1	G2CW1	G1CW2	G2CW2
Ability level	Mid	High	Mid	High
Assigned name	Alpha	Beta	Chi	Epsilon
Composition	3 girls	3 boys	2 girls 1 boy	2 boys
Week 7 (mid-semester)	Girl 1 = Maria Girl 2 = Therese Girl 3 = Tara	Boy 1 = Joe Boy 2 = Tom Boy 3 = Bob	Girl 1 = Gina Girl 2 = Daniella Boy 1 = Rico	Boy 1 = Jacques Boy 2 = Peter
Week 14 (late semester)	same	same	(- 1 girl) Phoebe	(+ 1 girl) Aurélie

Study 3C Design and Data Collection

Using an ethnographic approach we collected audio recordings from all four groups of 2-3 students during their discussions of 27 multiple-choice questions – approximately half of the 55 total number of questions administered over a ten week period during the 15 week Fall semester (first session in the 2-year pre-university science program). These audio recordings were transcribed producing a large corpus of data. From this corpus we selected several questions to analyze closely using interactional analysis techniques.

We designed two case studies to answer two different research questions. Case Study 1 answered the question: how did the different ability groups in treatment group 2 change their interactional structures with time? What are the implications? Case Study 2 answered the question: how did the different treatment conditions differ in terms of their interactional structures and how decisions were made?

We based our selection of questions to examine for Case Study 1 on the following criteria: (1) quality of the discussion; (2) differences between responses – e.g., correct answer in one group but not in the other, correct answer in both groups, wrong answer in both groups; and availability of examples from different periods in the 15 week semester. In this analysis we selected questions from mid-semester (week 7) and from end of semester (week 14).

The selection of questions to examine for Case Study 2 was based on the following criteria: discussion in a matched question – i.e., did the two classes both get to discuss the same question or did one class have a majority of right answers on the first polling therefore no discussion period ensued. Using these criteria we identified a small number of questions from early in the semester and later in the semester to analyze. For In the analysis below we describe

Study 3C – Case Study 1 (Within Class Comparison)

The students in CW2 were engaged and participated fully in the activity system of the classroom. What is interesting is that different structures emerged from the interactions of the separate groups working within the class. The interaction of these students created differential activity structures. In the upcoming section we will examine an early example (week 7) and a later example (week 14) of the group's structures for both the mid-ability group (Chi) and the high-ability group (Epsilon). In doing so, we hope to show how the group's activity structure emerged and how it changed with time. We start first with a description of the question and the voting results it generated then move on to the analysis of the groups starting with Group 2 (Epsilon).

Analysis of Group Discussion – Week 7 (Mid-Semester)

Question 23 (see Figure 5.16) required that students understand Newton's First and Second Laws. It also required that students would be able to interpret the photographic representation inserted into the question and recognize that important information was missing from the question. The correct response to this question is D. The first vote resulted in the class being evenly split between answer A and D (37% each). In the revote (shown in the figure above) the percentage of the class voting for A increased to 50% but a sizable number (42%) continued to vote for D.

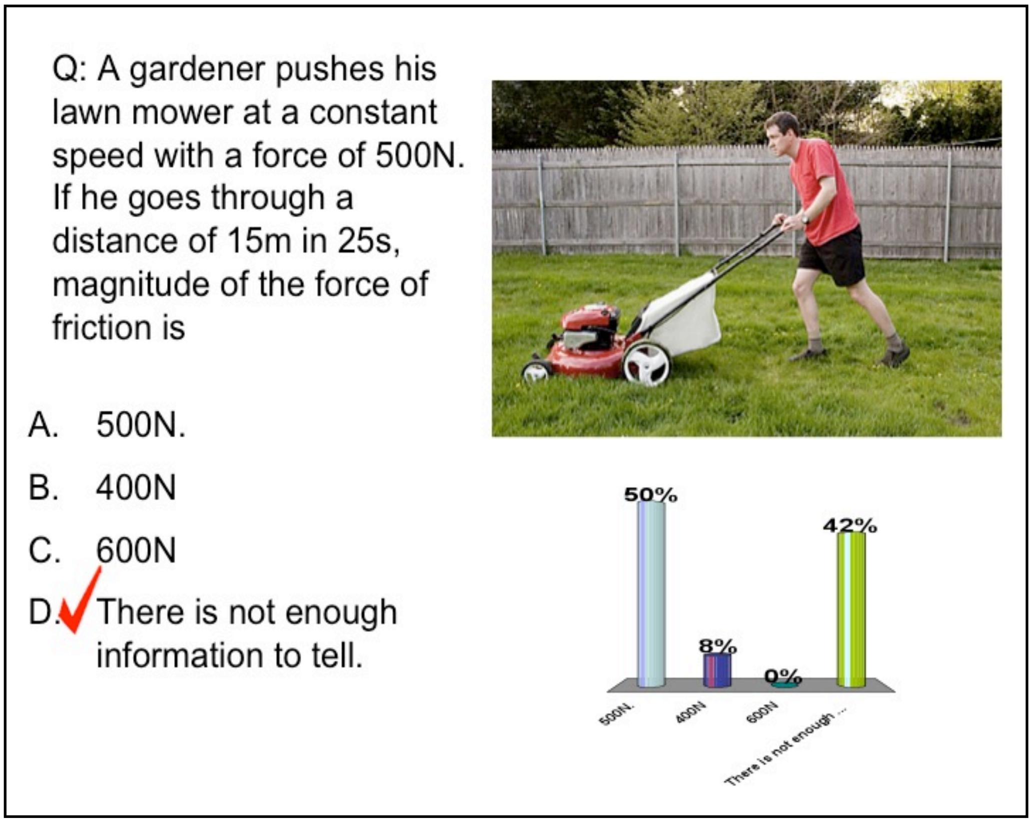


Figure 5.16. Slide of Question 23 presented with the results of the final TPZ vote.

This question is a great example of how the two groups in CW2 could both produce the same wrong answer yet work differently at solving the problem. Using Activity Theory as our analytic approach we start with the mediational tools (resources) produced and/or available within the activity systems of the two groups.

CW2 Group 2 (Epsilon) – 2 boys (Jacques & Peter)

The activity system created by the two students in Group 2 is a sophisticated system. It demonstrates their skill are reproducing and using basic scientific practices such as employing deductive & inductive reasoning to solve a problem. They start by defining concepts they believe are relevant to solve the problem. In this case they describe what they know about acceleration and how that relates to the lawnmower (lines 002-005). They then state the status of the system (lines 006-016) and then hypothesize on the answer using the information supplied in question (line 017-022). In accomplishing these actions, the boys produce synchronous talk (line 005) and complete each other's thoughts (lines 002-003, 010-012, 016-018). The result is one coherent statement that resembles an individual's talk aloud from a problem solving *protocol analysis*[4] (Ericsson & Simon, 1993).

```
001     Peter: OK, so if we do the reasoning completely, like
002     Jacques: if at constant speed means, acceleration
003     Peter: (overlapping) acceleration is zero,
004     Jacques: if acceleration is like zero,
005     Jacques & 2: (together) net force is zero.
006     Jacques: Two forces act on it, friction and the push.
007     Peter: (overlap) Yeah.
008     Jacques: The push is 500 Newtons
009     Peter: whoa, of yes, but…
010     Jacques: According to the picture it would be to the
        left.
```

---

[4] **Protocol analysis** is a psychological research method that elicits verbal reports from research participants. Protocol analysis is used to study thinking in cognitive psychology (Crutcher, 1994), cognitive science (Simon & Kaplan, 1989), and behavior analysis (Austin & Delaney, 1998). It has found further application in the design of surveys and interviews (Sudman, Bradburn & Schwarz, 1996), usability testing (Henderson, Smith, Podd, & Varela-Alvarez, 1995) and educational psychology (Pressley & Afflerbach 1995; Renkl, 1997). Retrieved from Wikipedia, July 18, 2009.

011 Peter: (overlapping) constant speed so for,

012 Jacques: friction is the other,

013 Peter: (overlapping) wait, to the right.

014 Jacques: (overlapping) is the inverted way of the acceleration.

015 Peter: Yes.

016 Jacques: Of the acceleration.

017 Peter: (overlapping) And for it to be a constant speed means that they cancel out

018 Jacques: (overlapping) yes, they have to cancel, exactly.

019 Jacques: Ok.

020 Peter: Yes, so it has to be 500 then.

021 Jacques: yeah, I'd say.

022 Peter: OK.

Looking at this episode from a Bakhtinian perspective, we see it as examples of a complete *utterance* produced by two instead of one speaker. Generally, an utterance is the unit of speech defined by a change of speaker, which leaves room for a response (a *rejoinder*) by another. In other words, "(t)he speaker ends his utterance in order to relinquish the floor to the other or to make room for the other's active responsive understanding" (Bakhtin, 1986, p. 71). In this case, however, the "speech flow" of the two boys is such that their rejoinders, at points, produce what seems like a single utterance. For instance, lines 001-005 and again lines 016-018. Such linguist phenomena are not uncommon in jointly shared activity, and perhaps maybe the hallmark of successful collaboration (Stahl, 2007). In fact, other researchers (Trausan-Matu, Stahl & Zemel, 2005) have identified such speech patterns in their own work and suggest that it could be compared to tempos seen in music or poetry. They consider such an example of polyphony (another of Bakhtin's notions) in the sense that it produces a certain harmony or unity from a multi-voiced process.

In between these harmonious talk are rejoinders that raise objections to the speech flow, for instance, Peter's "whoa, of yes, but" utterance (line 009). He points to (verbally) some discrepancy or anomaly in the reasoning, or in the interpretation of meaning, but his thought is not completed even when he tries again in line 011. So his rejoinder is ignored. Instead, Jacques continues to support his claim by referencing the photograph that accompanies the question. And, Peter follows along with a rejoinder that takes up Jacques's speech flow (010-015). Peter returns to his line of reasoning about the "constant speed" in line 017, but this time it is to support the conclusion that the answer must be 500 Newtons.

These latter instances are very important in understanding why the two boys do not come to the correct answer, even though their reasoning is relatively sound and justified from the point of view of physics concepts. On one side, it demonstrates a missed opportunity to use a rhetorical style, or *rhetorical genre*, of reasoning that is common in science. This type of questioning of logic can be a dialog or self-reflection as Bakhtin (1986) describes "(q)uite frequently within the boundaries of his own utterance the speaker (or writer) raises questions, answers them himself, raises objections to his own ideas, responds to his own objections, and so on" (p. 72).

It also shows that though the boys are capable of producing aspects of the conceptual knowledge required to solve such a problem (i.e., " if acceleration is like zero" and "net force is zero" the object can still move - Newton's First and Second laws), they miss the obvious when looking for clues in the accompanying photograph. They misinterpret what they know about "direction" of the force. In fact, the question is worded and illustrated in such a way that it is easy to believe that the direction of the force is horizontal – i.e., along the path of the man pushing the lawnmower. From the excerpt above it appears that it is that logic which leads the boys to misread the information from the photograph (line 010).

This suggests that they either interpret the question or photograph too quickly or did not have the requisite understanding of how to read such representations for information. The latter possibility is consistent with Mazur's findings that physics students often have difficulty interpreting the physics from photographic representations. Because these students assume a direction for the force they come to the wrong conclusion and choose 500N as their answer – i.e., multiple-choice "A". However, even with this, the physics that they use to get their wrong answer is right.

CW2 Group 1 (Chi) – 2 girls 1 boys (Gina, Daniella & Rico)

Group 1's students, by contrast, create a different activity system. From this excerpt we can see that they though they produce words that are part of the physics vocabulary (lines 029) they do not produce concepts. They attempt to make meaning by focusing on their answer and defending it rather than looking at other possible explanations. For instances they pursue the line of reasoning that friction must be 500 Newtons because the lawnmower can't be moving if constant speed is zero (lines 030-038). We consider this the "straw man" approach to reasoning, which is consistent with the conceptual change literature and actions taken by students when confronted with anomalous data (Chinn & Brewer, 1993, 1998).

Unlike the Epsilon group we saw above, this group's discourse is slow and unfolds with long pauses in between utterances (line 031). There is little harmony between interlocutors. In fact, the rejoinders are more like independent utterances that do not truly respond to the prior statement. For instances, Rico looks for confirmation that constant speed is the same as constant velocity (line 029) but Daniella responds without confirming or rejecting his query (line 030). Instead she reconfirms her answer (500 Newtons) by stating that the forces must be balanced because they have to equal zero.

```
023    Rico: What'd you put?
024    Gina: I Put A.
025    Daniella: Me too.
026    Rico: Yeah.
027    Daniella: We all put A?
028    Gina: Yes. We can't really argue. There you go.
029    Rico: Yeah. Constant speed. Constant velocity. It's
       the same thing right?
```

030 Daniella: (overlapping on last sentence) Equals zero. Both forces equal 500 Newtons.
031 (10 seconds silence)
032 Rico: The Magnitude of the…
033 Gina: Nah, yeah

It is clear from the excerpts that Rico is this one who tries to string together ideas about the physics involved. His “look it, look” comment, is an attempt to convince the girls through repetition of the same logic of the straw man used earlier.

034 Rico: Look it, look, like if there's like 500, like if there’s as much friction as exerted force it won't move, no?
035 Daniella: What?
036 Gina: Hum.
037 Rico: Look, the gardener pushes the lawnmower at the constant force of 500 Newtons. If there's 500 Newtons of friction...how's it going to move? The net is going to be zero.
038 Daniella: Yeah, it has to be 500.

When the straw man begins to break down, however, the students don’t have the conceptual resources to know how to push forward a new argument. For instance, Rico comes to the conclusion that the lawnmower is moving based on a sense of physical logic “But he is moving” (line 039), which is counter to what the equal forces argument tells them. But, even though this gut instincts are correct (line 046), Rico doesn’t know how to justify his feelings with the conceptual knowledge. In the end the group goes back to choosing their straw man answer because they haven’t been able to overturn it (line 049).

039 Rico: But he is moving. The gardener pushes the lawnmower at a constant (inaudible?)

040 Gina: But we don't know that.

041 Daniella: But when constant velocity (inaudible??)

042 Gina: Yeah, but magnitude of the force.

043 Rico: Ah.

044 Gina: well I dunno

045 (3:25-3:35 silence)

046 Rico: Why, wh, why did that happen... I’d have to say there's not enough information.

047 Gina: Because it probably became [a two way balance?].

048 Daniella: [inaudible??]

049 Rico: What do you...do you guys want to go with A?

050 Gina: Yeah. I guess.

051 Rico: I think it's B.

052 Gina: You think?

053 Rico: I'll put A.

Analysis of Group Discussion – Week 14 (Late-semester)

We compare the above to the group’s activity system seven weeks later, close to the end of their term. What we see this time is a changed structure of interactions for our two focus groups. While Epsilon group, our high ability students, is still producing sophisticated physics concepts and acting knowingly about how to solve the conceptual problems, Chi group, our medium ability students, are now acting in markedly sophisticated ways as well.

Before delving into the data to describe these changes, however, it is relevant to note that there were some physical changes to both groups. Chi group, originally composed of two girls and one boy, has lost one girl (Daniella). At some point mid-term she decided to change groups leaving behind a smaller but well functioning pair. In other words, though the structure changed, the group dynamic was not destroyed. While Chi group lost one of its members, Epsilon group gained a one, a girl named Aurélie. Aurélie was originally from the other class, CW1. She joined CW2 and sat in with Epsilon group for the last three weeks of the semester. It seems as if Aurélie was no stranger to the two boys, but probably was in other courses with them. Although her addition did not change the dynamism of the group it substantially changed their activity system. In the following analysis we will focus on two questions (Question 47 & 48) that allow us to show different aspects of the changes to the group's structure.

Question 47 (see Figure 5.17) requires students to understand the principle of kinetic energy and its relationship to momentum. The correct response to this question is B. The fist voting on the question resulted in a split vote, 53% of the class (individual votes) chose B and 36% chose D. On the revote, 64% of the class (group vote) chose B, and 29% still choosing the incorrect answer D.

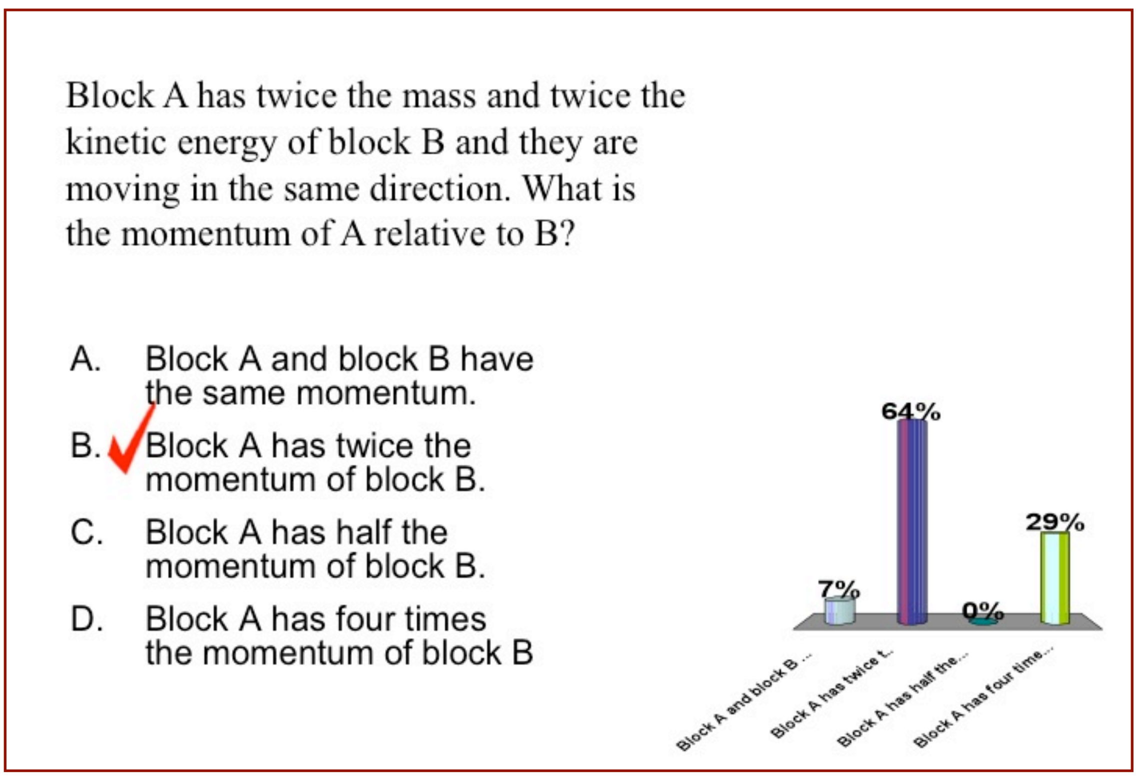


Figure 5.17. Slide of Question 47 presented with the results of the final TPZ vote.

CW2 Group 2 (Epsilon) – Jacques & Peter plus Aurélie

The addition of a third student to Epsilon group changed the structure and resources available to the group. What Aurélie brought was a sense of uncertainty, which created conditions for explicitly producing concepts that seem to be already available to Jacques and Peter. As before, the two boys approach the problem from a conceptual perspective and work in an interlocking fashion completing each other's thought. In line 055 Jacques reframes how Aurélie should look at the question. He continues this approach when he model's a rhetorical style of thinking for Aurélie's with his "But then you think, ok…" statement (line 060). It can also be viewed as coaching or mentoring Aurélie when he addresses her in the second person "you." And, checking back for confirmation of understanding with words like "right?" This is a different type of discourse structure compared to what we saw in the week 7 example.

054 Aurélie: It can't be 4 times mass V?

055 Jacques: Look at it this way.

056 Aurélie: I want to see if I have (?)

057 Peter: Its mass times velocity.

058 Jacques: (overlapping) It's mass times velocity.

059 Peter: It's mass times two.

060 Jacques: (overlapping). Though, they say that block A has twice the kinetic energy. But then you think, ok, kinetic energy is a half mass V squared, right? Ok, but it has twice the mass. So your two factor, is ey, is, comes from the mass. It doesn't come from velocity. So they have the same velocity. (pause) Right.

As the conversation proceeds we see a rhetorical style of talk emerging between the three interlocutors. When Peter puts forward a claim, Jacques questions it and Aurélie returns with a confirmation (lines 061-063). Though we do not hear Peter's rejoindre in line 064, it is clear that Jacques is building on Peter's statement and elaborating on what's to be considered regarding the velocity (line 065). As with the earlier example these students are weaving their utterances together to create a certain harmony in this discourse. It is also clear that the two boys continue to each have the individual resources to produce physics and contribute them to the activity system.

061 Peter: So it has the same velocity.

062 Jacques: (overlapping) No, wait, do they?

063 Aurélie: Velocity is going to be the same, yeah.

064 Peter: (??)

065 Jacques: Yeah. Yeah, yeah, yeah. Yeah. Velocity is the same because you have to account for the, the 2 factor, right?

066 Peter: So it's just twice as fast.

067 Jacques: So it's just, Block A has twice the momentum of Block B,

068 Peter: Twice the (?)

069 Jacques: Because they have the same velocity if you look at it, like in terms of kinetic energy.

What is even more interesting is Jacques' follow-up actions. Although the group has already decided and voted for "B" he decides to verify his reasoning by creating another resource, an equation. He borrows Aurélie's notebook and works out the problem (line 072). In the process, he verifies that the answer produced earlier is indeed correct (lines 078, 082).

070 Jacques: can I use your note book? Just a second, to check something.

071 Aurélie: yeah, sure.

072 Jacques: (writing into the notebook) So yeah. So if you look at it this way, like Block A, K of A equals

073 Aurélie: can I keep what you're writing.

074 Jacques: yeah, yeah, sure.

075 Aurélie: (laughs) yep.

076 Jacques: (working out the problem on paper and taking it out while doing so). So times 2M, because it's twice the mass. V squared, so you have, now 2KA. Now, so wait now, forget it, not A, just K, right? So this is 2K. So now KB, you have K equals, um…

077 Aurélie: MV squared.

078 Jacques: (overlapping) MV squared, but in the end it's the same thing, you just cancel the two. So you have to have the same velocity.

079 Peter: (??)

080 Jacques: What differs is the mass?

081 Peter: (not sure about this one?)

082 Jacques: It's B.

From this excerpt we see that indeed these students can work together to produce new knowledge. The contributions to the collective knowledge, however, are not equal. Clearly, Jacques is more knowledge and produces more of the knowledge components, but Peter's contributions are vital to the reproduction of what is present. These two boys have worked out the metarules of the game but are now practicing how and when to apply them. Interestingly, Aurélie, allows them to slow down and reflect further on what they know and do not know. Her request for clarification allows them to be explicit about these metarules.

Question 48 involves the concept of momentum and impluse (see Figure 5.18). This question required students to know that the impluse is equal to the change in momentum. The correct response to this question is A. The fist voting on the question resulted in a near split vote with 38% of the class (individual votes) choosing A and 42% choosing D. After discussion, a remarkable turn about was recorded with 81% of the class (group vote) choosing A.

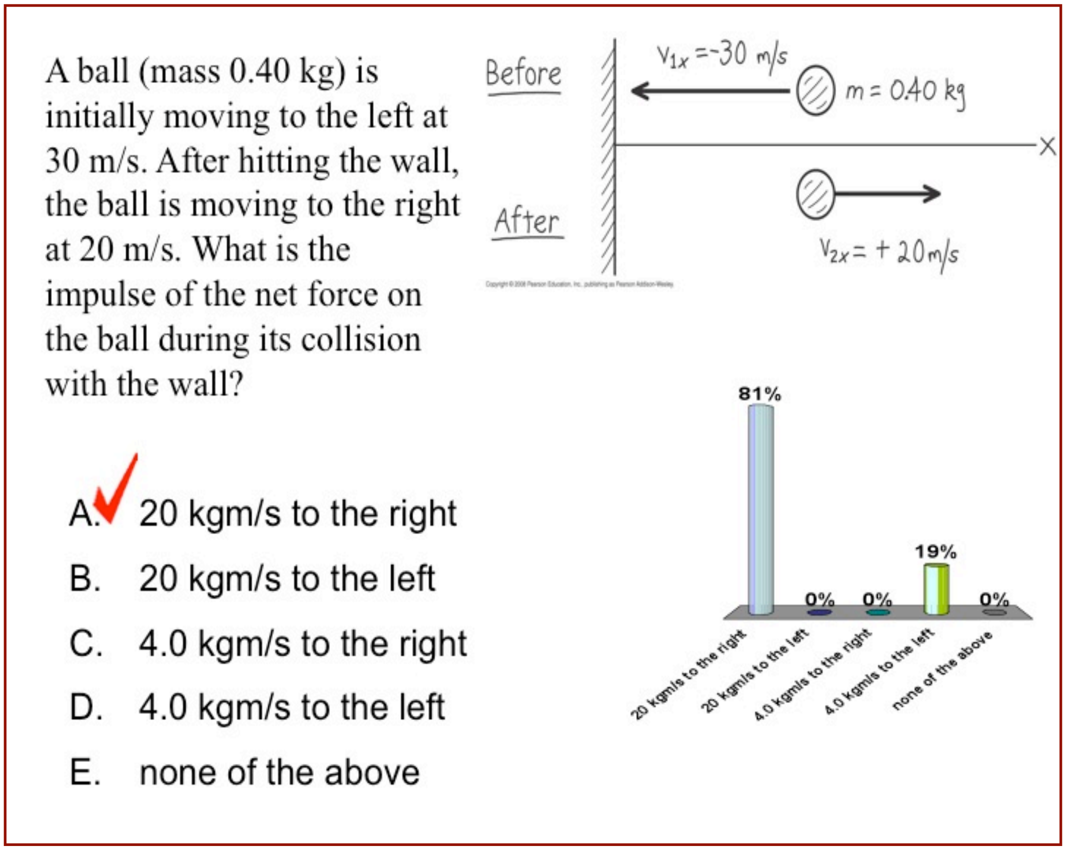


Figure 5.18. Slide of Question 48, presented with the results of the final TPZ vote.

Epsilon's Answer to Question 48

The excerpt below is particularly sophisticated because it demonstrates conceptual reasoning between the two boys that demonstrates agreement on a commonly shared resource that is made present by its absence. This is no cryptic riddle rather it is an attempt to describe what might be call the taken for granted, or as Paul Cobb puts it, the "taken as shared" (Cobb, 1999). Such knowledge, values and standards are culturally and historically indexed so that we can take short cuts in communicating with others with whom we share special relationships (e.g., experts in your discipline, old friends). Here we look at the knowledge that is revealed by the agreements to what is actually missing in the discourse.

Jacques and Peter start with the notion that the answer to the question requires the concept of momentum change. Neither boy explicitly produces the word "momentum" in their utterances yet their discourse progresses smoothly (lines 083 – 086). From this we can infer that the "it" (line 084 & 085) refers to impulse, which is defined as the change in momentum (i.e., final momentum minus initial momentum). Thus when Jacques states, "it's final minus initial" (line 084), Peter confirms this shared understanding of this incomplete statement by moving the reasoning forward (line 086). In doing so, Peter produces the next step in the problem solution, which in turn leads Jacques to complete the thought. In the way that they go about answering the question, it is apparent that these boys have also pulled out the information that the requested question is about impulse is on the ball and not the wall.

083 Boy 2: Guess it's going to the right.

084 Boy 1: You don't have to guess it. It's final minus initial.

085 Boy 2: your initial's negative so you have to subtract it.

086 Boy 1: So you add them up.

When Aurélie asks CW for help she opens the door for the boys to interact differently and produce new resources. In this instance, Jacques produces the notion that a frame of reference, which is really an answer to Aurélie's question to CW (line 087). It is also a good strategy for solving such problems. Which he is forced to repeat several times in the course of this problem solving because of Aurélie's insistance that she hates have to think about such constraints (line 091).

087 Aurélie: (question to CW). Sir, when you move to the left is it necessarily negative?

088 CW: momentum's a vector, so in this case, yes.

089 Aurélie: ok, so…

090 Jacques: so you have to choose your reference frame so positive is this way.

091 Aurélie: Yeah, yeah. I hate it. Uhhhh. I hate it when we have to look at direction and it's as positive or negative. Ça me melange tellment (whining tone).

Later, Jacques does the math (recall that Gina, from Chi group, does this on her own). But even when he does the math Aurélie doesn't seem to be able to reconcile the math with the common sense interpretation of what is going on (line 0100).

092 Peter: it’s A.

093 Jacques: You don’t have to guess it, it’s final minus initial-you’re initial’s negative and you have to substract it.

(Discussion and revote)

094 Aurélie: Ouais, on est d’accord parce que ça va vers le…

095 Jacques: It’s like, c’est final moins initial, right? Donc final c’est mv 0.4 fois 20 moins…

096 Aurélie: Ah, ok ok. 0.4 fois moins 3.

097 Jacques: 0.4 fois 20 moins -30.

098 Aurélie: 0.4 fois 4.

099 Jacques: it’s 20 positive, so it’s 20 to the right.

0100 Aurélie: uh, ahhh. Ok, ok, ok. Ça ne fait pas de sens. S’il retourne comme ça, il ne va pas retourner comme ça de nulle part.

0101 Jacques: Just look at your reference frame, the axis is to the right, so it’s positive to the right.

While the above is clearly invovles more sophisticated reasoning that the earlier example it is consistent with the type of activity structures shown earlier. With the addition of Aurélie, however, we see a new structure develop.

Chi's Answer to Question 48 – Week 14

When we look at the Chi group's interactions in week 14 we see a very different picture. Gina shows that she can produce physic resources. As such, she is now the person in charge of the knowledge. Note, however, she is not in the position to coach or mentor Rico, rather she shares this knowledge in response to his questions. Also note that unlike the rejoinders produced by Epsilon group, Rico's are made in an effort to get specific knowledge and not as a rhetorical device. The students here are not engaged in rhetorical talk. They have not begun to reflect on their reasoning or problem solving.

```
0102    Rico: I have D as the answer, you have A as the
        answer.

0103    Gina: Impulse equals P2 minus P1.  Impulse equals MV2
        minus MV1. 0.4 times the velocity of the second one is
        plus twenty. Minus 0.4 – and the velocity is negative
        thirty.

0104    Rico: Why is it negative thirty?

0105    Gina: 0.4 … It says negative thirty. Ha! Times twenty
        is eight for the second impulse minus negative thirty
        times point four, negative twelve is twenty.

0106    Rico: Hum. And that was the result for … what's J
        represent?

0107    Gina: J is the impulse.  You have to initial minus…

0108    Rico: What is the impulse of the negative force?  The
        impulse, the impulse, the impulse. I was doing
        momentum. K.

0109    Gina: Yeah. You didn't do the change.  Impulse is the
        change in momentum. Now is it right or to the left?
```

Though Gina produces the physic knowledge (shown above), it is clearly fragile. Also, while Rico's questions act as rejoinders that solicit Gina's elaboration of what she already knows their work as a discursive tool ends there. However, later the speech flow begins to take on a rhetorical style as Gina questions the direction of the impulse (line 0112). Her ongoing need to clarify information for herself is beginning to pay off.

0110 Gina: To the left? I say to the right.

0111 Rico: Yeah it's to the left.

0112 Gina: to the left? Why is it to the left?

0113 Boy X (from another group): because it has these and these going to the left and I don't know if the other ones …

What is even more significant about this interaction is Gina's stance in this participation structure. Not only does Rico begin to appreciate her efforts he commends her on solving the problem by herself (line 0120). While we have seen Gina display a persistent nature before this (demonstrated in the data corpus), here she also displays a sense of pride with her earlier "Ha!" expression (line 0105) and the later "Ya! This is exciting" (line 0120). And, lastly, the "I did eh! (line 0122).

0114 Rico: Cuz I thought it was for momentum. Momentum would be to the left. Four per meter second. So. Because you know it was a negative answer… If you get the momentum…

0115 Gina: OK I think it is to the right because, look. Momentum is left right? If the change in Momentum equals impulse, I mean, that means its changing direction. SO now from the left it's going to the right.

0116 Rico: You're right.

0117 Gina: Sounds good.

0118 Rico: alright. Slap that answer.

(CW shows answer)

0119 Gina: (Claps hands) Ya! This is exciting! I never got it right.

0120 Rico: You did it all … all of that yourself.

0121 Gina: I did eh!

Overall, Gina's talk in this episode is more assured and she is more confident of rules of this particular part of the content. In other words, she demonstrates that she is beginning to understand the rules of the game. And, her willingness to continue playing the game is now been given a boost with her finally being able to answer one of the questions correctly.

Summary Case Study 1

Results show that collectively the students in both groups expended more effort with. They also developed different activity systems. The high-ability case study students have the advantage because of their starting condition. They have more conceptual resources to draw on and can reproduce them more quickly. They engage in collective regulatory & monitoring actions and produce mutually constructed resources. Mid-ability case study students are initially disadvantaged but develop individual resources in time. With public reproduction of conceptual knowledge there is the beginning of inter-animated activities systems. The results suggest that in both cases students begin to act with mutual responsibility, but only high-ability begin the production of collective resources.

We coded these activity systems into two categories and identified indicators of the behaviors that were typical of each. Later we named the categories as (1) Polyphonic systems and (2) Agentic systems (see Table 5.8).

Table 5.8. Activity systems that emerged from the High-ability and Mid-ability groups.

<table>
<tr><th>Activity System</th><th>Description of actions</th><th>Examples from Transcripts</th></tr>
<tr><td rowspan="2">(Early semester)

Polyphonic systems
(high ability students)

(Mid-semester)</td><td>**Inter-animated structures**
• students engage in simultaneous talk (5)
• students complete each other’s utterances (1), (3)
• no pauses between utterances
• rapid and mutual production of physics concepts (2, 4, 5)
• sense of certainty in knowledge reproduction</td><td>01 Peter: OK, so if we do the reasoning completely, like…
02 Jacques: (***overlapping***) if at constant speed means, acceleration
03 Peter: (***overlapping***) acceleration is zero.
04 Jacques: If acceleration is like zero…
05 Both: (***together***) net force is zero.
06 Jacques: Two forces act on it, friction and the push.
07 Peter: (***overlappin***g) Yeah.</td></tr>
<tr><td>**Rhetorical inter-animated structure**
• students ask (15) and answer (16) their own questions
• students identify contradictions (11)
• students reflect on their understanding (13, 15)
• sense that students are responding to each other with the appropriate “rejoinder” (9 – 10)
• slower pace in knowledge production
• sense of uncertainty & rhetoric in problem solution (16)
• sense of construction of mutually new meaning (collective resource)
• identification and use of disciplinary rules & norms (15)</td><td>08 Jacques: I’d say 600 or 500 because actually there's an angle.
09 Peter: There’s an angle, a cosine angle.
10 Jacques: There’s part of it, there’s part of it that is countered by the normal force.
11 Peter: Yeah. ***So there’s a question as to why***, because there's still not enough…
12 Jacques: So, you actually have to find like the value of…
13 Peter: ***Wait.*** 500 cosine 37, which is 400.
14 Jacques: so I'd say B.
15 Peter: ***But wait half a second***, there’s still no interaction, only if its an angle.
16 Jacques: Well it kind of gives it, I'm pretty sure.
17 Peter: aha.</td></tr>
</table>

<table>
<tr>
<td rowspan="2">(Early semester)

Agentic systems
(mid-ability students)

(Late semester)</td>
<td>Intra-animated structures
• students demonstrate individual agency (23)
• “rejoinders” (19) independent of previous utterance (18)
• many pauses between utterances and sense of uncertainty (20, 21, 22, 24)
• slow and individual production of knowledge (18, 20)</td>
<td>18 Rico: Yeah. Constant speed. Constant velocity. It's the same thing right?
19 Daniella: (overlapping) Equals zero. Both forces equal 500 Newtons.
20(10 seconds silence)
21 Rico: The Magnitude of the…
22 Gina: Nah, yeah
23 Rico: Look it, look, like if there's like 500, like if there’s as much friction as exerted force it won't move, no?
24 Daniella: What?
25 Gina: Hum.</td>
</tr>
<tr>
<td>Reflective inter-animated structure
• students continue to demonstrate individual agency (26)
• “rejoinders” (27), (30) appropriate to previous utterance (26), (29)
• students ask questions of each other (27, 29, 31)
• start of self-reflection on own understanding (32)
• confidence in knowledge reproduction (use of individual resources) (28, 32)
• beginning of mutually constructed new meaning (collective resource) (31-32)
• begin to identify disciplinary rules & norms (26)</td>
<td>26 Gina: Impulse equals P2 minus P1. Impulse equals MV2 minus MV1. 0.4 times the velocity of the second one is plus twenty. Minus 0.4 – and the velocity is negative thirty.
27 Rico: Why is it negative thirty?
28 Gina: 0.4 … It says negative thirty. Ha! Times twenty is eight for the second impulse minus negative thirty times point four, negative twelve is twenty.
29 Rico: Hum. And that was the result for … what’s J represent?
30 Gina: J is the impulse. You have to initial minus…
31 Rico: What is the impulse of the negative force? The impulse, the impulse, the impulse. I was doing momentum. K.
32 Gina: Yeah. You didn’t do the change. Impulse is the change in momentum. Now is it right or to the left?</td>
</tr>
</table>

Evolution of Collective Activity System in CW2

Interestingly, the students in this same class, CW2, began to construct collective activity systems as well. These collective systems began online with the teacher's making available an online conference using First Class Client. A sense of mutual responsibility seems to develop when students took up a practice of sharing knowledge with their community. This is consistent with Scardamalia's (2002) collective cognitive responsibility and others studying epistemic agency in collaborative learning environments (e.g., Charles & Shumar, 2009).

The activity that emerged shows the development of a shared regulatory system –i.e., co-regulated processes, which promote self-organization. An explanation for the creation of this co-regulation process maybe the feedback loops developed when students (agents/actors) respond to local conditions by taking on certain roles that moves knowledge needs forward. Two important roles seem to be: (1) coach (peer tutor); and (2) questioner (revealing uncertainty). Additionally, student's "up-takes" patterns are similar to Suthers et al. 2007.

What is most interesting in this collective activity system is that it called into action the role of the community (recall Figure 5.15). Students were able to identify the rules of the physics game and explicitly called for a mutual awareness of these epistemic norms.

We constructed a graphical representation of a sample of the conference postings produced by four students (see Figure 5.19). This figure shows the participation structure and contribution to a class wiki. We focused on 17 postings (approximately 20% of the total) because they reveal a participation structure that is typical of other threaded conversations – i.e., short threaded postings involving a pattern of discourse followed by a contribution to the main wiki (see circled areas). This pattern suggests: (1) particular roles played by certain students; (2) the development of a practice of sharing to a community. For instances the role that Jacques takes on as the mentor and coach of his peers (see Figures 5.19 & 5.20). Though his behavior is exceptional, notice how Angela also takes on a very special role of being the questionnaire. This is very much the activity system that we saw develop with the Chi group (Group 1 in CW2).

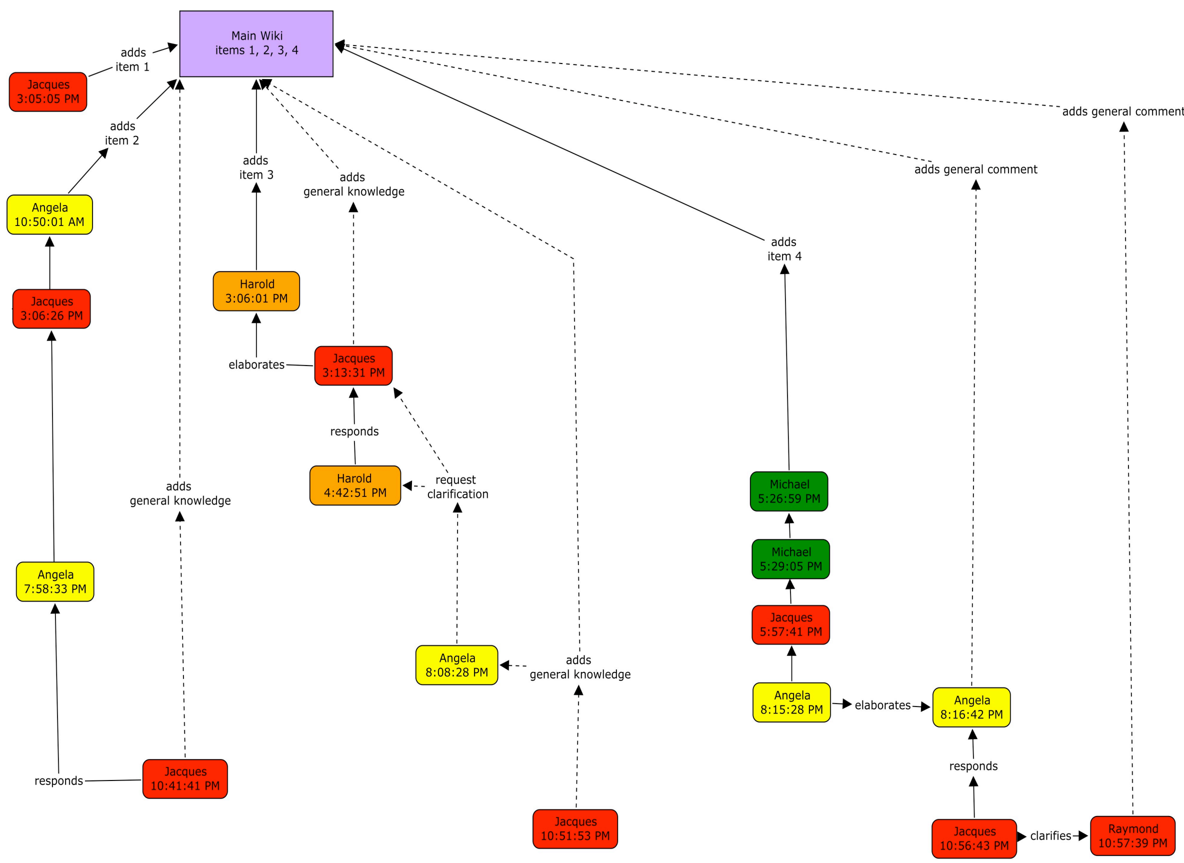


Figure 5.19. Interactions within the collective activity system of CW2's online conference.

Development of Normative Epistemic Beliefs and Content Knowledge

To analyze the development of the collective activity system we constructed another more linear representation (Figure 5.20). This allowed us to study how ideas are introduced and whether they are taken up by subsequent participants. From this figure we see that two kinds of knowledge emerged from the chats: (1) content knowledge (lilac) and (2) epistemic knowledge (blue). Both are taken up by the community and form their collective knowledge and way of talking about this physics problem.

It is interesting to see how the normative use of words develops along with the understanding that there is also a normative way of using words – i.e., the epistemic belief. This example is significant because it is such an explicit demonstration of how this change in belief happens.

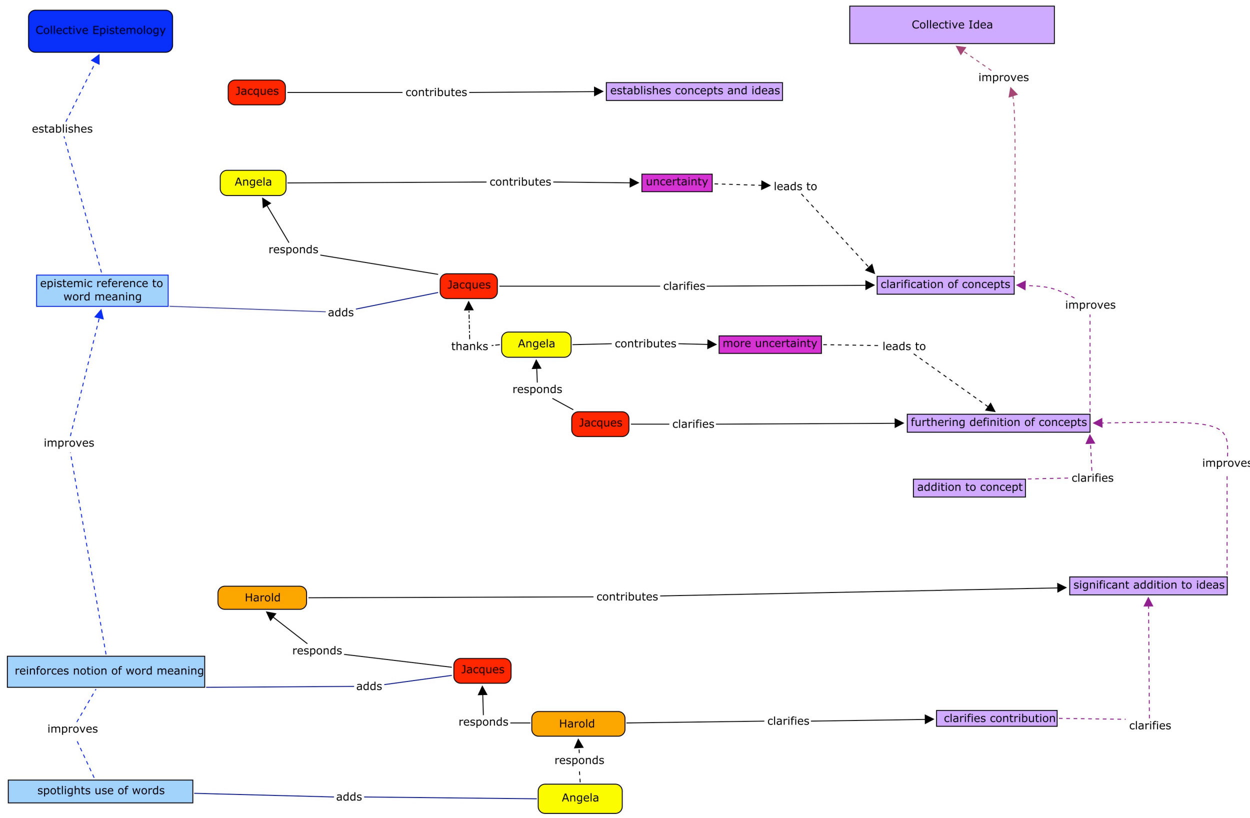


Figure 5.20. Development of epistemic and content knowledge in collective activity system of CW2's online conference.

Case study 2 - Between Class Comparisons

We wanted to know if there were any differences between the ways that the groups structured their interactions based on the different instructions on how to organize their voting – individual vote versus group consensus vote. To make this comparison we selected several instances where both classes were required to discuss the answers to the same conceptual questions. Additionally, we based our selection on instances that best demonstrate typical ways of interacting, one from early in the intervention (middle of term) and one from late intervention (end of term). Additionally, we compared the groups according to their ability levels. In other words, we compared the mid-ability group in CW1 (Traditional PI) to the same in CW2 (Consensus PI) – i.e., comparison of group *Alpha* to group *Chi*. And, the high ability group in CW1 (Traditional PI) to that in CW2 (Consensus PI) – i.e., comparison of group *Beta* to group *Epsilon*.

Question 25 requires students to understand the principles of Newton's second law and that momentum (the tendency of things to keep moving once in motion) the explanation for the continuing motion of the elevator. The correct response to this question is "C" (see Figure 5.21). Therefore, there is no extra force causing the upward motion so the only thing to consider is the relationship between tension and weight when something is slowing down.

ma =$\sum$ F = $T - W$

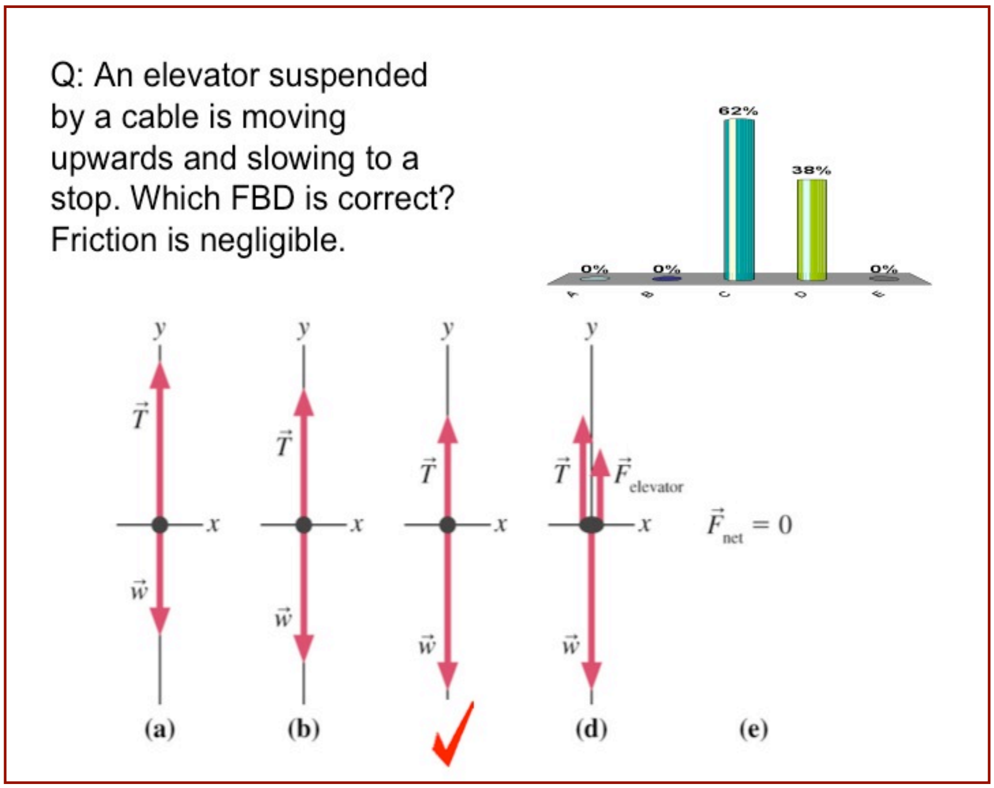


Figure 5.21. Slide of Question 25 presented with the results of the final TPZ vote.

How the Classes Answered Question 25

<u>CW1 (Traditional PI).</u> In CW1, in the first vote the majority of students heavily favored A (50%), followed by C (25%), and a small percentage (17%) chose D. Interestingly, after the discussion there was little change – 58% A and 27% C, and 12% D.

CW2 (Consensus PI). In CW2, by contrast, the fist voting on question 25 resulted in a split vote between C (41%) and D (34%); with A running a distant third with 17%. After the discussion the percentage of students choosing C increased to 62%, with the remainder of votes consolidating on D (38%).

From the above we see that the starting conditions varied substantially for the two classes. In other words, even when both classes did not get the right answer on the first vote, thus precipitating a group discussion and revote, the weighting of their answers to the multiple-choice options was often quite different. We will start by demonstrating an instance of this difference. Though clearly, this starting condition seems to have an impact on the final class outcome, we have no evidence from our data samples (the 2 groups) that it had an impact on the individual group discussions.

Between Class Comparison the Mid-Ability Groups

Alpha (Traditional PI) to Chi (Consensus PI)

The students in Alpha (Traditional PI) presented their arguments in a systematic fashion, their interactions producing an almost "turn-taking" structure. As it worked out, one of the three had selected C as their answer while the others did not so there was reason to have a debate. However, their only debate was over the magnitude of the two forces – i.e., the tension force and weight (line 001-008). None of the three seemed to have been fooled by answer "D".

For the most part the discussion was made up of individual expressions framed by the statement "I" (e.g., lines 001 & 004). But there were also some instances where the girls built on the other's contribution to produce a piece of shared knowledge. For instance, Girl 3's explanation of her decision starts off as an individual action but produces a claim that is rebutted by her peers (line 005, 006). In doing so, the interaction of the three utterances produced the knowledge that applying F=ma to the problem would provide the correct answer as well as the clarification that the elevator was slowing down, which is a case of negative acceleration (line 006).

001 Girl 2: I put C, because the force of the gravity has to be bigger than the force of the tension for it to slow down?

002 Girl 1: Maybe, but it's different because force net is force 0?

003 Girl 2: No it's because-

004 Girl 3: I put like the opposite because for something to go up, the for, the tension has to be bigger than the, er, than the gravity.

005 Girl 2: (overlapping) it's slowing down.

006 Girl 1: (overlapping) Yeah, it's slowing down, so the acceleration is negative. And we use F egal MA

Interestingly, Girl 1 has mistaken answer "E" (F_{net}= 0) to be part of the problem information (lines 007-011), which probably influenced her reasoning. And, definitely influenced the possibilities for the conversation between the others. However, from later comments, not shown here, it is clear that Girls 1 & 3 were convinced by the discussion and changed their answer to C for the revote.

007 Girl 2: cuz F net equals 0, is another answer. (laugh)

008 Girl 1: Oh, ok it's E (recognition).

009 Girl 2: It's not information (amusement in her voice).

010 Girl 1: Oh ok. Oh ok, sorry.(laugh)

011 Girl 3: SO it's...

Chi (Consensus PI). Meanwhile, Chi (Consensus PI) group produced a very different structure from their interactions. None of the three had the right answer, and it is difficult for them to produce the reasoning necessary to solve the problem. Girl 1's reasoning and initial choice seemed very much like CW1 Girl3 (line 015). But she is swayed by the idea of another force being necessary to cause the elevators movement. What is noteworthy in the structure of interactions is Girl 1's sense of agency in putting forward her understanding despite Boy 1's mocking (line 017).

012 Boy 1: What did you put?

013 Girl 1: I thought it was A at first. Cuzzzz,

014 Girl 2: (overlapping) That's what I put.

015 Girl 1: you need more force...against the weight to lift it. Then I switched to D.

016 Girl 2: why?

017 Boy 1: Because it looks like the more complicated one. (tone in his voice).

What is also interesting is Boy 1's pattern of near physics thinking. Time and again his reasoning about the physics produces the right answer, but then chooses the wrong one. Partly because he doesn't trust his ability to do physics "ah, it doesn't make sense."

018 Boy 1: I don't know, I was thinking that like when you're slowing down that there'd be like less tension on the rope. (pause) and that's why Y has, no I mean C has like the least. Like I figured there would be less tension on the rope and more… Ah, it doesn't make sense.

What is truly different about this group's interactions is that when prompted by CW to go beyond their small group discussion, they do so. It seems like in this class the students do not feel constrained by the group structure. Instead they seem to extend their discussion to a larger clustering of students. In this instance, Group 1 turned around to the people behind them and solicited their thoughts. In doing so, the right answer was made available to them and so they began to discuss why "C" could be the correct answer. Even with this, however, the group decided on "D," largely because both Girl 1 and Boy 1 can not move past the notion that movement requires a force (lines 019 & 021).

019 Girl 1: but. It's slowing down and going up. If it's C it would be going down.

020 Girl from other group:(inaudible)

021 Boy 1: Ok so D. Ah, that’s what I originally put. Yeah cuz, yeah yeah yeah yeah yeah, cuz it’s still going up!

Between Class Comparison the High-Ability Groups

Beta (Tradition PI) and Epsilon (Consensus PI).

Epsilon. Surprisingly, one of the two high ability groups, Epsilon, did not get the right answer after their discussion. Their reasoning makes the same interpretation that the elevator requires a force to continue moving – i.e., they discount momentum and Newton’s second law. The two boys, in this case, do not produce an equation or any significant resource to help them solve the problem. Instead they wrestle with concepts approaching the solution from a process of elimination (lines 022 – 032), which generally works as a problem solving strategy. But not this time around.

022 Boy 1: Well actually, what we think, it would be D, but the sum of tension and the force of the elevator,

023 Boy 2: (overlap) is still negative.

024 Boy 1: (continuing on deliberately) is,

025 Boy 2: (overlap) no it’s downwards!

026 Boy 1: (continuing on) Is, lower than W, smaller. (pause)

027 Boy 2: I’m not sure.

028 Boy 1: Well actually I’d hesitate with C.

029 Boy 2: uh?

030 Boy 1: I’d hesitate between C and D.

031 Boy 2: Yeah.

032 Boy 1: It's clearly not A, it’s clearly not A, not B and not E. It's C or D.

As with the group Chi (lower ability Consensus PI) there is intervention from without the group. Boy 3 inserts a comment about “contact” points (line 033 & 036), which provides an anomalous piece of information that the boys need to deal with. It is at this point that doubt is raised (line 039). However, they explain it as a change in tension (lines 041-045).

033 Boy 3: well I don’t know. There's only one contact.

034 Boy 2: Ohhh. Wait it's slowing down.

035 Boy 1: there's only one contact, yeah.

036 Boy 3: there’s only one point of contact.

037 Boy 1: Yeah that's right.

038 Boy 3: so…

039 Boy 1: Maybe actually

040 Boy 2: Yeah,???

041 Boy 1: oh, maybe actually, the tension changes

042 Boy 2: because the system’s being moved up.

043 Boy 2: Yeah.

044 Boy 1: But wouldn’t the tension changes with the acceleration?

045 Boy 2: (overlapping) Yeah but also like, it decides the tension is constant in the rope, but not in the force,

046 Boy 1: (overlapping) Well not necessarily, not necessarily

047 Boy 3: Yeah, not necessarily.

048 Boy 2: D or C?

049 Boy 1: Ohh....... let's keep it with D

Beta group (high ability Traditional PI), on the other hand, have no difficulty producing the necessary resources to solve the problem. It appears that two of the three boys choose the right answer C for the initial vote. In fact, they clown around and try to influence the voting of the other members of the class toward the wrong answer A, which was already the majority vote.

When they get down to the business of explaining the solution to each other, Boy 2 clearly shows his understanding of how to read the free body diagram.

Boy 1 elaborates and reinterprets Boy 2's interpretation of the answer. They do this based on the physics involved in Newton's second law. Boy 2 completes his statement. Boy 1 clarifies Boy 2's statement and elaborates on why they get a negative acceleration based on the mathematics of the equation that they are both working on. Boy 2 completes the problem solution and claims the answer based on his original observation that the force of tension (what's making it go up) is smaller than the weight.

050 Boy 2: Well it's going up and it's slowing down so the weight has to be longer than the tension. So the tension is smaller than the weight.

051 Boy 1: Yeah. Exactly!

052 Boy 2: That's right. I can see like half the people put A, and (the others are all over the place?). (shouting out) it's A.

053 Boy 1: what they see you, see you. Cuz you said the acceleration was negative right? Because it's decelerating?

054 Boy 3: ??

055 Boy 1: No but…when you do force equals mass times acceleration, mass is positive

056 Boy 2: It's positive?

057 Boy 1: Force is negative. Well force divided by mass is equal to a negative acceleration. Which is what you want.

058 Boy 2: Cause it's de-cel-eraaaa-tingggg (slowing down the word.

059 Boy 3: (same time) raaa-tinggggggg.

060 Boy 2: And it's C cause like, it's still going up but like the force making it go up is smaller than the weight. That's why it's going down.

CHAPTER 6

STUDY 4

Using Chats & Wikis in Collective Knowledge Construction

Study 4 Research Question

1. What types of learning practices develop within the settings of classroom wiki when the activity is designed to promote intentional knowledge building?

Study 4 Background

There is much talk about designing online environments with multiple channels, which provide various ways to represent knowledge and various ways for students to interact with each other. What we see in some of these environments, however, is that some channels of communication may promote different ways of building knowledge. In this current research one limitation was the single channel communication of the chat and conferencing environment we used. This seemingly impoverished environment resulted in some interesting developments that we believe were possible only because of this single channel constraint. We will argue that this limitation may be beneficial to some forms of knowledge building when students are working collaboratively.

The theoretical foundation for Study 4 is the same as the other studies in this report. However, we also draw on the Computer Supported Collaborative Learning (CSCL) literature to frame the design of the online environment and to analyze our findings.

Study 4 Method

In this study we wished to examine what types of learning practices could develop within the settings of classroom wiki environment and whether these practices varied depending on the task involved.

We designed a case study within our larger experimental study (examining effects of different modalities of structuring peer collaboration) to look at how students used online activities as a principle mode of building knowledge about certain aspects of Newton's Laws.

Study 4 Participants

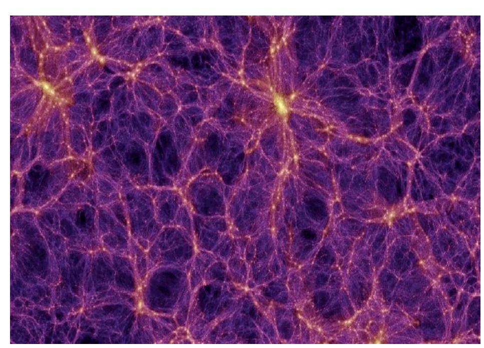
One of the four intact classes of first year introductory physics students taking part in the main research study (Study 1) also participated in this smaller case study (Study 4). This class of 33 students (ratio of girls to boys was approximately 4/3) worked together in self-selected groups of 3-4 individuals. For our case study we selected two of these groups based on their level of participation in the assigned activities. Because the objective of the study was to observe how and what practices develop, we selected the most active cases.

Study 4 Instruments

The Original Question on Dark Matter

Hi everyone.

The purpose of this lab was not only to explore Newton's Laws in circular motion but also to see how such simple dynamics can inspire big thinking. The disciplines you are studying in the sciences are being continually enlarged, which means that when you are done studying much of the latest knowledge will be new to you.



In this sense it is important to master basic principles, learn to model observed behaviours and apply critical thinking to solving unfamiliar problems. This will enable you to keep pace with the increase in knowledge and ground you in the fundamentals. It's easy to get lost in the mounds of data being collected these days!

Questions discussed in Physics Online exercise
(These are to be discussed with your group members and submitted here)

1. Two students are spinning identical stoppers at equal orbital radii. One of the stoppers is moving noticeably faster than the other. What can you say about the number of washers attached to the faster stopper?

2. Earth orbits the Sun because of gravitational attraction. How could you use Earth's orbital data to measure the mass of the Sun? Find the relevant data and calculate the Sun's mass.

3. Physicists estimate the total mass of luminous matter in a galaxy by measuring the galaxy s brightness. They have observed that stars within many galaxies orbit around their galactic centres at speeds higher than expected. Using ideas from this lab on circular motion, give an explanation for these observations.

Figure 6.1. Instructions and questions relating to Dark Matter assignment.

Study 4 Procedure

There were two main activities that called for online collaboration. These activities were scheduled over a 2-week period. Activity #1 consisted of a procedural problem solving session involving Newton's 2^{nd} Law. Activity #2 (Dark Matter Activity) consisted of a conceptual analysis and reflection exercise. In both activities students were required to work in groups using online chats and submit their group work to an online conference (aka wiki). In the latter activity, students were also asked to comment on each other's submissions, in that way extending the conversation began in their small groups.

There were four parts to activity #2. The first was a classroom lecture during which the teacher showed a video of Dark Matter with some discussion about his intended goal of linking this larger topic to the upcoming lab. The second part was a lab class on measuring mass using uniform circular motion, at this point the students were asked to work in groups and provided with some basic instruments and a procedure to follow out (see Appendix A). They were also given a worksheet with specific questions, including instructions on how to report and analyze the data using graphical means as well as comment on the findings (see Appendix A). The students were also asked three follow up questions relating directly to the lab findings. They were instructed to answer all questions as a group, but question #3 was to be answered online using chat.

Analysis of online asynchronous conference

The online chat produced by the four students in this study shows an uneven ability. While the two boys are high-ability students, the two girls clearly are not [line 2:33:36 PM]. This disparity between the participants creates an imbalanced activity system.

> **Bridgette**[2:33:36 PM]: k can someone reexplain what dark matter is exactly

However, the girls produce the self-regulation within the system. There interactions

> **Gabrielle**[2:36:32 PM]: *hey we have to use the ideas from the lab that we did...*

That said, this online group produces and reproduces knowledge that advances their collective understanding of the phenomenon in question – i.e., what is Dark Matter and how it could be related to a simple in-lab activity. In the excerpt below we see Waldo's attempt to question why should Newton's Laws work the same on earth as they do in our own solar system [line 2:31:58 PM]. There is an abstract distinction of local and global effects though there is a slightly imprecise use of expert language: "rate" coupled to the word "work" instead of move.

> **Waldo**[2:31:58 PM]: why should a galaxy work according to the same rate as an object around our sun
>
> **Bruno**[2:32:18 PM]: I agree with Waldo
>
> **Waldo**[2:32:28 PM]: they assumed that cuz the #'s are off, Dark matter must exist

Later, Waldo again looks for proof in the sense of physical, concrete, “ponderable,” evidence. What is really known? There is a tension between his understanding of science and his “buying into its evidences” [line 2.33.36 PM].

> **Waldo**[2:33:24 PM]: can u ever really know u are right until u weigh the sun?

When he and Bruno try to explain Dark Matter to Bridgette (see above question), they produce and re-invent this knowledge. Bruno accepts gravity in the solar system using proper argumentation [2:33:44 PM]. He exhibits sophisticated reasoning in extending argument to galaxy (relative to his level of knowledge). Waldo has a sense of what “they” did, but it’s not a sophisticated epistemological belief. Very colloquial. His overconfidence points to this [2:34:28 PM]. Waldo understands what doesn’t add up in the observational evidence [2:35:14 PM]. The expectation for visible matter to produce these effects, given the understanding of gravity effects are correct, fails so there may be dark matter. What is “it”? What does he really understand here? Is there a contradiction hidden in his imprecise use of language?

> **Waldo**[2:33:41 PM]: ok
>
> **Bruno**[2:33:44 PM]: A planet turn around around the sun because of gravity, which is cause bu the huge mass of the sun... but what about galaxy? why do stars turns around? Is it caused by the same phenomenon? I<m not sure
>
> **Waldo**[2:33:54 PM]: ok heres the explanation
>
> **Bridgette**[2:34:05 PM]: no one can be sure
>
> **Waldo**[2:34:11 PM]: the figured out how much a sun of a certain mass is bright
>
> **Waldo**[2:34:28 PM]: so by adding up all the brightness they know how many shiny objects there are in a galaxie
>
> **Waldo**[2:34:38 PM]: BUT
>
> **Bruno**[2:34:39 PM]: I think I got how they got to this conclusion:

Waldo[2:34:51 PM]: this amount is MUCH less then the amount found using newtons laws

Bridgette[2:35:10 PM]: im really confused right now

Waldo[2:35:14 PM]: so they figure that it is wrong NOT because the laws are wrong, but because there MSUT be invisible dar matter

Bruno clearly summarizes the two methods for determining the mass if a galaxy and contrasts them. He is highly scientific in his approach.

Bruno[2:35:32 PM]: On one hand, they calculated with brightness, comparing the galaxy brightness to our sun brighness...So they got to this number of suns

Bruno[2:36:26 PM]: on the other hand, they calculated like if it would be a circular motion...and they got to a higher score

Later they enter into a rhetorical genre of speech that produces new ideas and knowledge. This reflection of what else could explain the phenomenon they are trying to explain [2:46:53 PM]. This is an example of the reproduction of knowledge and their inter-animated speech creates something completely new idea – Waldo's suggestion that a lens can distort light and affect the data that is collected [2:47:53 PM]. This innovation in their thinking is a significant outcome of the activity system.

Bruno[2:46:02 PM]: I have a question for you guys

Bridgette[2:46:04 PM]: i agree with u

Waldo[2:46:05 PM]: shoot

Bridgette[2:46:08 PM]: k

Gabrielle[2:46:53 PM]: k

Bruno[2:46:53 PM]: Do you think the image in the video we saw, where the light coming from foreign galaxies was distorted by Something, is a proof that black matter exists?

Bruno[2:47:03 PM]: What else could it be?

Waldo[2:47:03 PM]: no

Waldo[2:47:19 PM]: theres tons of stuff in space

Bridgette[2:47:26 PM]: it true

Waldo[2:47:30 PM]: stars and galaxies and whatever

Gabrielle[2:47:34 PM]: no...but i dont know what could it be...

Waldo[2:47:38 PM]: ANYthing with a MASS can distort light

Bridgette[2:47:40 PM]: i believe also that its not necessarily dark matter

Bruno[2:47:41 PM]: But can we call this stuff black matter, of what this stuff is composed?

Waldo[2:47:53 PM]: a lens can twist light

Bruno[2:47:57 PM]: cause i mean, if it was regular matter, we would see it

Waldo[2:48:05 PM]: so ANYTHING out there can be acting as a lens

Bruno[2:48:17 PM]: So you think it a giant glass planet ?!!!! [[

Waldo[2:48:19 PM]: lenses are transparent, or "invisible"

Bridgette[2:48:21 PM]: lol

Waldo[2:48:27 PM]: maybe a gas planet

Bruno[2:48:28 PM]: that could be cool

Waldo[2:48:30 PM]: we cant see gas

Waldo[2:48:33 PM]: like air

Bridgette[2:48:50 PM]: its true arent some of the planets mostly gaseous

Waldo[2:48:59 PM]: maybe there invisible planets

Bridgette[2:49:03 PM]: o i like ur theory

Waldo[2:49:04 PM]: made of air

Gabrielle[2:49:05 PM]: exactly

Waldo[2:49:18 PM]: or some really transparent like gas

Bruno[2:49:24 PM]: cant we? I mean, they surely though about a way to see gaz

Waldo[2:49:34 PM]: which may qualify for "dark matter" cuz it doesnt give off light

Waldo[2:49:42 PM]: it just bends light

Bruno[2:49:44 PM]: Sorry, on this point, Im not well informed

Bridgette[2:49:45 PM]: true

Bridgette[2:49:51 PM]: me either

Waldo[2:49:58 PM]: Im conpletely theorising, I got no idea for real

Waldo[2:50:41 PM]: BTW, do we save this conversation and hand it in er something?

Bridgette[2:51:01 PM]: i think we have to save it somewhere on first class

Gabrielle[2:51:06 PM]: i dont think so...its save automatictly...i think

Waldo[2:51:10 PM]: hmm

Bruno[2:51:12 PM]: I dunno, if gas is really compressed, you can see it, some of our planets are like that...And if it has the energy to bend light, I must be really heavy

Bridgette[2:51:18 PM]: i think gens right

Gabrielle[2:51:31 PM]: but we have to get one answer for the question....no

Bruno[2:51:32 PM]: I think hes gonna check in

Bridgette[2:51:33 PM]: but the galaxy is huge

Waldo[2:51:37 PM]: did it save what Trudeau wrote in class?

Bridgette[2:51:41 PM]: it wouldnt be compressed

Bruno[2:52:01 PM]: So hum...do we all agree on one answer to the question?

Study 4 Results

Dark matter discussion allows us to see how students engaged in explaining a "wicked" problem collectively construct new understanding (similar to the "rise above" that are seen in Knowledge Forum) through refinement of their arguments and their expanding epistemic beliefs. Unlike other areas of science, Physics does not have many controversies that novices can participate in. The Dark Matter exercise is one that allows students to grapple with big ideas by applying basic principles of mechanics (i.e., circular motion).

Using discourse analysis techniques we identified two main themes in the conversations between the four students: (1) the use of science as backing for claims; (2) the emergence of alternative explanations for the phenomenon. The latter suggests the emergence of more sophisticated epistemic beliefs.

What we see in the individual students are different levels of content knowledge, different levels of epistemic beliefs, and different levels of belonging to a scientific community. We will test this hypothesis by comparing these students MPEX results against the norm.

DM exercise allowed all students to engage in physics discourse, specifically, the concept of circular motion. It would be expected, therefore, that these students should have answered related questions better on the final exam.

While all students were provided with the opportunity to engage in the use of physics concepts, some also deepened their understand of both the concept of cm as well as their understanding of the video on dark matter. A few showed that they could expand on this knowledge in their creative amplification and production of explanation of phenomena – possible mechanism to explain the phenomena - lens effect or bending of light, or bending of time. In these cases, it is reasonable to suggest that this is similar to the rise above that KF sees.

CHAPTER 7

Conclusion

Our data show that the peer instruction method has a positive effect on students' conceptual learning gains (assessed using the FCI) compared to other traditional instruction data. Changing the organization of the social interaction in peer instruction to include group vote has a small positive effect on the results of the FCI. However, this difference is not statistically significant.

Study 1 Summary

In Study 1 all four collaborative instruction treatment groups significantly increased their conceptual change compared to the teacher-centered control section. However, there was no statistical difference between these four. Students in these classes were exposed to more conceptual qualitative discussions and less quantitative algorithmic problem solving in class. Our findings therefore suggest that the optimal configuration for in-class collaboration is having students commit to an answer, ask them to discuss between peers and then provide a consensus group vote after the peer discussion. We look forward to more studies replicating the superiority of this instructional design.

The results show that collaborative learning does not eliminate the learning gap between students of high and low entry-level background knowledge. A closer look at these treatment groups produced interesting results. In Treatment Group 4 where no in-class discussion was fostered (i.e., most like traditional instruction), the treatment favored students with higher incoming background knowledge. In Treatment Group1 where students followed the classical Peer Instruction format (individual vote committing, peer-discussion, individual revote), the treatment favored students with lower entry background knowledge. This is particularly intriguing given that Peer Instruction was developed at Harvard University where students have strong background knowledge.

Interestingly, there was no significant difference between these four classes with respect to their expectations about physics, as assessed by the MPEX. In other words, their "Expert-like" attitudes and beliefs did not significantly change after instruction. Though these results are not statistically significant they suggest trends toward Expert-like beliefs.

Study 3 Summary

Study 3 shows that the differences between the treatment groups is only seen in the qualitative data which shows that CW2 students (Consensus PI) spend more time on discussing physics concepts in their Peer Instruction conversations than do the students in CW1 (Traditional PI). Furthermore, their conversations showed more signs of collaborative activities such as building on each other's ideas and knowledge as the engaged in the concept task. With more time spend discussing their answers and trying to convince each other it was reasonable to suggest that these students may also have a deeper understanding of physics. If this is so, it was not captured by the FCI, which leads us to suggest that the FCI may be too blunt an instrument to capture the conceptual change of these students. Or that given more time the small differences seen between the treatment groups might not develop into a steeper trajectory of positive gains for CW2 (Consensus PI).

Lastly, students in CW2 (Consensus PI) were different in the ways that they continued their collaborative activities. Though both groups were given the opportunity to work on-line on both assigned and self-directed group conferences, only CW2's conference grew in an exponential fashion. One explanation is that group vote helps to create less sense of competition and more cooperation. Therefore, students are more willing to help each other both in class and outside of class.

Importance of Results to the Host Colleges & College Network

Dawson College and John Abbott College are both institutions with dedicated teachers who strive to find innovative ways to promote students' understanding and meaningful learning. In doing so, teachers at both institutions already make efforts to use social constructivist approaches and tools in their classroom, but often there is insufficient empirical evidence on which to base decisions or convince the skeptics. This research provides support for the use of collaborative activities in the instructional design of physics courses. Specifically, it shows that Peer Instruction is particularly effective. Furthermore, it shows that forms of PI that increase the amount of student discourse, i.e., Consensus PI, is most effective in creating a sense of community within the classroom. This result seems to be promoted by having agentic students, and promoting this agency with outside of class activities such as the online conferences.

While our results show that online collaboration was more effective than traditional instruction, it also shows that this form of instruction benefited the high-ability students more so than the low-ability students. We believe this is likely to be an artifact of this particular intervention, which had limited scaffolding in the online environment. As such, these results suggest two important concerns: (1) online collaboration requires scaffolding for students; (2) online collaboration requires more structured activities. Both of these are consistent with the research conducted by researchers such as Pierre Dillenbourg and Nikol Rummel, independently, who write about "scripting" of collaborative tasks. In conclusion, these results suggest that more research is required to understand how to design and support online collaborative learning.

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APPENDICES

APPENDIX A

MPEX QUESTIONNAIRE

MPEX QUESTIONNAIRE

Student ID__________________________ Group __________ Date _____________

This questionnaire is designed to assess your feelings about learning physics in general, and not specifically about this course. We are asking you to look at these 40 statements and answer each by circling the number that best expresses your feeling. The choices are based on a scale between 1 and 5 where the numbers mean the following:

1: Strongly Disagree	2: Disagree	3: Neutral	4: Agree	5: Strongly Agree

Work quickly. Don't over-elaborate the meaning of each statement. These statements are meant to be taken as straightforward and simple.

If you don't understand a statement, leave it blank.
If you understand, but have no strong opinion, circle 3.
If an item combines two statements and you disagree with either one, choose 1 or 2.

1	All I need to do to understand most of the basic ideas in this course is just read the text, work most of the problems, and/or pay close attention in class.	A
2	All I learn from a derivation or proof of a formula is that the formula obtained is valid and that it is OK to use it in problems.	A
3	I go over my class notes carefully to prepare for tests in this course.	D
4	"Problem solving" in physics basically means matching problems with facts or equations and then substituting values to get a number.	A
5	Learning physics made me change some of my ideas about how the physical world works.	D
6	I spend a lot of time figuring out and understanding at least some of the derivations or proofs given either in class or in the text.	D
7	I read the text in detail and work through many of the examples given there.	D
8	In this course, I do not expect to understand equations in an intuitive sense; they must just be taken as givens.	A
9	The best way for me to learn physics is by solving many problems rather than by carefully analyzing a few in detail.	A
10	Physical laws have little relation to what I experience in the real world.	A
11	A good understanding of physics is necessary for me to achieve my career goals. A good grade in this course is not enough.	D
12	Knowledge in physics consists of many pieces of information each of which applies primarily to a specific situation.	A
13	My grade in this course is primarily determined by how familiar I am with the material. Insight or creativity has little to do with it.	A
14	Learning physics is a matter of acquiring knowledge that is specifically located in the laws, principles, and equations given in class and/or in the textbook.	A

15	In doing a physics problem, if my calculation gives a result that differs significantly from what I expect, I'd have to trust the calculation.	A
16	The derivations or proofs of equations in class or in the text has little to do with solving problems or with the skills I need to succeed in this course.	A
17	Only very few specially qualified people are capable of really understanding physics.	A
18	To understand physics, I sometimes think about my personal experiences and relate them to the topic being analyzed.	D
19	The most crucial thing in solving a physics problem is finding the right equation to use.	A
20	If I don't remember a particular equation needed for a problem in an exam there's nothing much I can do (legally!) to come up with it.	A
21	If I came up with two different approaches to a problem and they gave different answers, I would not worry about it; I would just choose the answer that seemed most reasonable. (Assume the answer is not in the back of the book.)	A
22	We use this statement to check that people are reading the questions. Please choose number 4 (Agree) as your answer.	D
23	Physics is related to the real world and it sometimes helps to think about the connection, but it is rarely essential for what I have to do in this course.	A
24	The main skill I get out of this course is learning how to solve physics problems.	A
25	The results of an exam don't give me any useful guidance to improve my understanding of the course material. All the learning associated with an exam is in the studying I do before it takes place.	A
26	Learning physics helps me understand situations in my everyday life.	D
27	When I solve most exam or homework problems, I explicitly think about the concepts that underlie the problem.	D
28	"Understanding" physics basically means being able to recall something you've read or been shown.	A
29	Spending a lot of time (half an hour or more) working on a problem is a waste of time. If I don't make progress quickly, I'd be better off asking someone who knows more than I do.	A
30	A significant problem in this course is being able to memorize all the information I need to know.	A
31	The main skill I get out of this course is to learn how to reason logically about the physical world.	D
32	I use the mistakes I make on homework and on exam problems as clues to what I need to do to understand the material better.	D
33	Really understanding science is only for those who want to be scientists.	A
34	Working with others on problems is important because we can share our understanding and knowledge.	D

35	To be able to use an equation in a problem (particularly in a problem that I haven't seen before), I need to know more than what each term in the equation represents.	D
36	It is possible to pass this course (get a "C" or better) without understanding physics very well.	A
37	Learning physics requires that I substantially rethink, restructure, and reorganize the information that I am given in class and/or in the text.	D
38	A scientist is someone who seeks knowledge because s/he does not have all the answers.	D
39	Scientists belong to a community of people attempting to understand the world (*knowledge seekers*), as such, doctors, engineers, geologists, psychologists, sociologists, etc., can all be described as scientists.	D
40	By attempting to understand the world, I become a member of the knowledge seekers community.	D

You may write any comments or questions about this survey in this box:

Thank you

Acknowledgement: This survey is adapted from the MPEX Version 4.0, ©U. of Maryland PERG, 1997

APPENDIX B

Schedule of Turning Point™ Questions for Classes CW1 & CW2

Schedule of Turning Point™ Questions – CW1 & CW2

CW1		**CW2**	
date	**Question #**	**date**	**Question #**
05-Sep	Q2	08-Sep	Q2
05-Sep	Q3	08-Sep	Q3
05-Sep	Q4	08-Sep	Q4
09-Sep	Q5	08-Sep	Q5
09-Sep	Q6	08-Sep	Q6
12-Sep	Q7	10-Sep	Q7
12-Sep	Q8	10-Sep	Q8
12-Sep	Q9	10-Sep	Q9
23-Sep	Q10	22-Sep	Q10
23-Sep	Q11	22-Sep	Q11
23-Sep	Q12	22-Sep	Q12
23-Sep	Q13	22-Sep	Q13
30-Sep	Q14	29-Sep	Q14
30-Sep	Q15	29-Sep	Q15
30-Sep	Q16	29-Sep	Q16
30-Sep	Q17	29-Sep	Q17
07-Oct	Q18	06-Oct	Q18
07-Oct	Q19	06-Oct	Q19
07-Oct	Q20	06-Oct	Q20
07-Oct	Q21	06-Oct	Q21
09-Oct	Q22	09-Oct	Q22
09-Oct	Q23	09-Oct	Q23
09-Oct	Q24	09-Oct	Q24
09-Oct	Q25	09-Oct	Q25
10-Oct	Q26	09-Oct	Q26
10-Oct	Q27	09-Oct	Q27
10-Oct	Q28	09-Oct	Q28
10-Oct	Q29	09-Oct	Q29
16-Oct	Q30	15-Oct	Q30
16-Oct	Q31	15-Oct	Q31
16-Oct	Q32	15-Oct	Q32
16-Oct	Q33	15-Oct	Q33
16-Oct	Q34	15-Oct	Q34
04-Nov	Q35	03-Nov	Q35
04-Nov	Q36	03-Nov	Q36
04-Nov	Q37	03-Nov	Q37
04-Nov	Q38	03-Nov	Q38
18-Nov	Q39	17-Nov	Q39
18-Nov	Q40	17-Nov	Q40
18-Nov	Q41	17-Nov	Q41

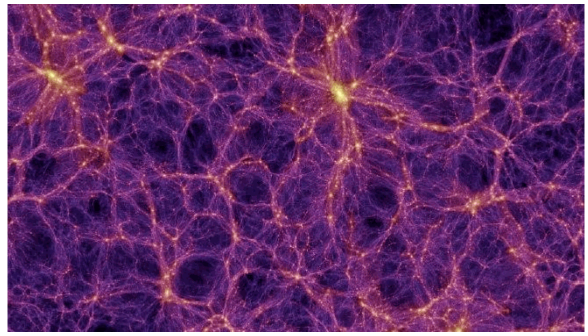
18-Nov	Q42	17-Nov	Q42
18-Nov	Q43	17-Nov	Q43
20-Nov	Q44	20-Nov	Q44
20-Nov	Q45	20-Nov	Q45
20-Nov	Q46	20-Nov	Q46
25-Nov	Q47	24-Nov	Q47
25-Nov	Q48	24-Nov	Q48
25-Nov	Q49	24-Nov	Q49
28-Nov	Q50	26-Nov	Q50
05-Dec	Q51	04-Dec	Q51
05-Dec	Q52	04-Dec	Q52
		04-Dec	Q53

APPENDIX C

Dark Matter Assignment

<u>The Original Question on Dark Matter.</u>

Hi everyone.



The purpose of this lab was not only to explore Newton's Laws in circular motion but also to see how such simple dynamics can inspire big thinking. The disciplines you are studying in the sciences are being continually enlarged, which means that when you are done studying much of the latest knowledge will be new to you.

In this sense it is important to master basic principles, learn to model observed behaviours and apply critical thinking to solving unfamiliar problems. This will enable you to keep pace with the increase in knowledge and ground you in the fundamentals. It's easy to get lost in the mounds of data being collected these days!

Instructions
In this discussion area,

1) You will pose your group's answer to ***question 3*** on the Lab Activity handout (original copy attached).
The other questions and part of the analysis will be submitted into the group conference area with the document provided there.

2) You will submit your response to ***question 3*** next Thursday, November 6th, but *not before*. Before posting your group's response you will instant message on FirstClass (I have placed a chat room in your group areas) with your group at least once at a time convenient to everyone.

This will enable me to assess participation. A mark will be given for the quality of your participation as individuals.

3) Each group will then have the opportunity to critique the other groups' responses. Based on this discussion, the best response will be chosen and a bonus mark awarded to the winning group.

I will update this document if further details are needed.
Cheers--JT

Lab Activity #4
Dark Matter and Circular Motion

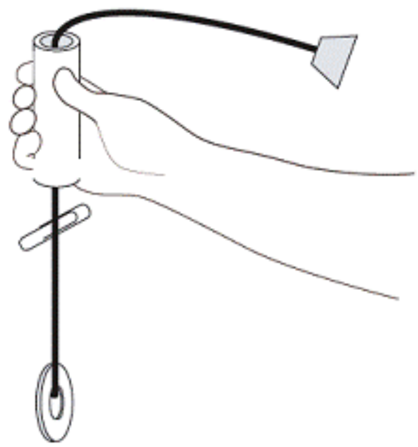


Figure 1 Centripetal motion apparatus.

Measuring Mass using Uniform Circular Motion

An object moving at a constant speed in a circular path is accelerating (i.e., the direction of the velocity vector is constantly changing). This acceleration is caused by an unbalanced force acting towards the centre of the circle (centripetal force). Any change in the unbalanced force will produce a change in the orbital motion of the object.

Make a Prediction

How will the speed of an orbiting body change as the applied force increases, if we keep the orbital radius constant?

The more the applied force increases, the faster the object has to move (if its mass and its radius are constant).

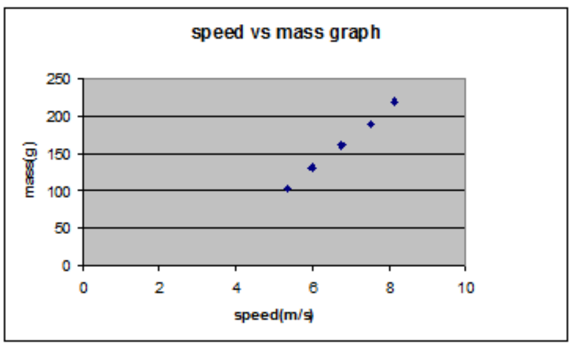
Table 1: Circular motion data

Number of washers	7	9	11	13	15
Mass of washers (g)	102.48	131.76	161.04	190.32	219.6
Time for 10 cycles (s)	3.8	3.4	3	2.7	2.5
Speed of stopper (m/s)	5.34	5.97	6.76	7.51	8.12

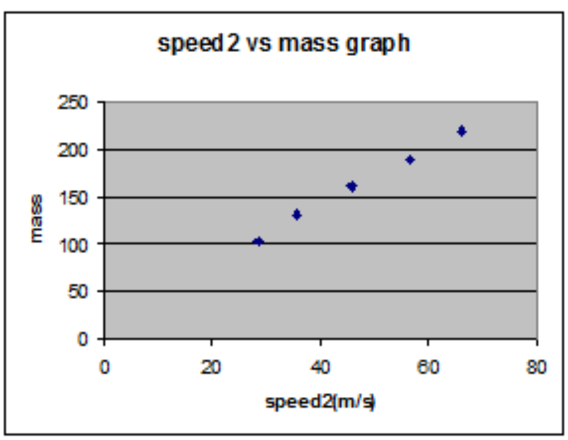
Mass of rubber stopper = 15.3g
Mass of 15 washers = 219.6 g
Length of string from top of tube to middle of stopper = 0.323 m

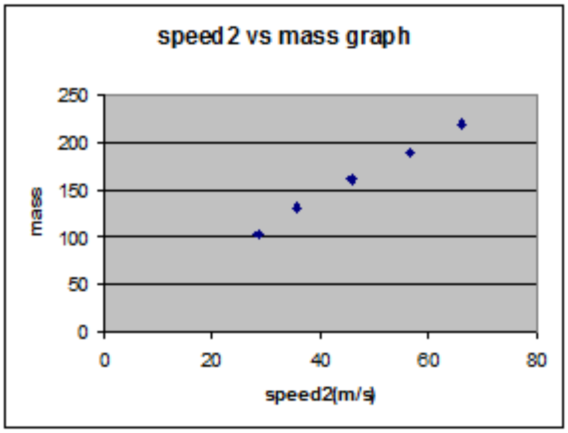
Submitted part of the Analysis

2. Plot the speed v of the stopper against the mass m_W of the washers. Do this using excel.



3. Make a second plot of the data in excel using v^2 against m_W.





The slope of the line (in SI units): (0.19032kg - 0.13176kg) / (56.4m/s - 35.64m/s) = 2.82x10^-3 kg x s x m^-1

Comment:

Was your data in 3. very linear? Comment on how your results could be improved.

Even though our data in 3. are very linear, we think that these results can be biased in many ways. The results were may have been inaccurate due to sources of error such as, the friction of the tube on the string, which was not accounted for in the calculations. Also the friction and imperfection of the string due to the fact that the experiment assumed it was an ideal frictionless, weightless piece of string. Another source of error may have been the method of counting rotation, the person that was counting may have counted wrong, which results in the results becoming increasingly inaccurate. The last source of error was the timer due to the fact there is an amount of time added to the actually time of the 10 rotations, this would also result in inaccuracy in the results.

Questions

(These are to be discussed with your group members and submitted here)

1. Two students are spinning identical stoppers at equal orbital radii. One of the stoppers is moving noticeably faster than the other. What can you say about the number of washers attached to the faster stopper?

If one is moving faster than the other, and that the radii are constant, then acceleration toward the center is bigger. This acceleration is produce by the tension acting over the stopper mass. Since the stopper's masses are equal, then its higher acceleration can only be produced by higher tension acting on it. Since tension is equal to the washers weigh, we can affirm overall that a higher speed means a higher number of washers.

2. Earth orbits the Sun because of gravitational attraction. How could you use Earth's orbital data to measure the mass of the Sun? Find the relevant data and calculate the Sun's mass.

Given that:
Average speed = 29 783 m/s
Earth orbital average radius = 1.496×10^{11} m
$G = 6.7428 \times 10^{-11}$

$F = (G\, m_1 \times m_2) / r^2$ $\quad a = v^2 / r$

$F = m\, a$

$((G\, m_1 \times m_2) / r^2) = (m_2) \times (v^2 / r)$

$m_1 = (v^2 \times r) / G = (29783^2 \times 1.496 \times 10^{11}) / 6.7428 \times 10^{-11}$

$m_1 = 1.97 \times 10^{30}$ kg

3. Physicists estimate the total mass of luminous matter in a galaxy by measuring the galaxy's brightness. They have observed that stars within many galaxies orbit around their galactic centres at speeds higher than expected. Using ideas from this lab on circular motion, give an explanation for these observations.

Answer submitted online to the group conference and JT (wasn't asked to submit to JT).

From: Bruno November 6, 2008 10:44:27 PM
Subject: GAJK
To: Discussion on Dark Matter and Circular
Cc: **Joel Trudeau**

The explanation for these observations could either be black matter or a failure in Newton's law applied to galaxies.

In the first case, the presence of black matter could explain the difference between the values obtained by the two methods. Knowing the mass of our sun and comparing its brightness to a whole galaxy, we can estimate the mass of the luminous matter. On another side, applying newton's law, we can estimate its mass using the speed and the orbital radius of the particle motion and the force that is pulling (gravity), as in these simplified formulas:

a = v2 / r where a = F / m

Using that, we can find a total mass which is way over than the brightness technique value. We can than say that there is mass that the brightness hasn't noticed, which means black matter. This invisible matter could influence the speed of the particles.

In the second case, a lack in the Newton's law could explain this difference. We made the assumption that the law we use are absolute and applicable to galaxies. Maybe those formulas can't work with big phenomena like galaxies.

We thought that for both cases, there is not enough evidence to accept or discard one theory or another. More proves, like the creation of black matter in laboratories, are needed to jump to a conclusion. The fact that scientists don't agree on this question is a good clue that this question cannot be solved easily.

Researchers

Biographical Information

Elizabeth S. Charles
is on faculty at Dawson College. She is associated with the Center for Study on Learning and Performance (CSLP). She is on the Editorial Board of the International Journal of Computer Supported Collaborative Learning (ijCSCL). Elizabeth Charles holds a Ph. D. in Educational Technology from Concordia University. Her research experience includes a Post Doctorate in Cognitive Science at Georgia Institute of Technology, a visiting researcher with the Math Forum at Drexel University in Philadelphia and Principal Investigator on four PAREA research projects. Her most recent publications include a chapter in Studying Virtual Math Teams, a Springer Publication, 2009. Her research interests range from learning implications of social constructivist pedagogy to collaborative learning in online environments to the development of collective agency. Dr. Charles can be contacted at: echarles@dawsoncollege.qc.ca

Nathaniel Lasry
is professor of physics at John Abbott College, a faculty member of the Center for Study on Learning and Performance and a Research Associate of the School of Engineering & Applied Sciences at Harvard University. Trained in particle physics, Nathaniel Lasry holds a PhD from McGill in Cognition and Instruction. He currently splits his time between teaching physics and doing research in physics education. He is also the author of Understanding Authentic Learning: from social practice to neuro-cognitive processes and of several papers on science education, ranging from neurocognitive models of learning to the effectiveness of technology in classrooms. Dr Lasry is also passionate about teaching science through magic, something he can occasionally be seen doing on Discovery channel. Dr. Lasry can be contacted at: lasry@johnabbott.qc.ca

Chris Whittaker
is professor of Physics at Dawson College. He studied Engineering Physics at Queen's University (B.Sc. 1989, M.Sc. 1992). As an undergraduate he specialized in aeronautical and nuclear engineering and for his Masters degree he studied how the apparent viscosity of nematic liquid crystals changes in electric and magnetic fields. Chris also holds a Master's degree in Social Work from the University of Toronto (1996) and he has prepared two radio documentaries for the CBC program Ideas – including one about physics called "Size Matters" which originally aired in October 2002. Professor Whittaker can be contacted at: cwhittaker@dawsoncollege.qc.ca

Joel Trudeau
is a professor in the physics department at Dawson College. He is the founding father and co-coordinator of the Science Participating with Arts and Culture (SPACE) project. He obtained his M.Sc. from McGill, and is pursuing his Ph.D. in early universe cosmology. Professor Trudeau currently is involved in physics education research studying knowledge building through technology supported collaboration. He is also a member of another PAREA project investigating factors that influence the attraction and retention of science students with the goal of improving their persistence in the domain. Professor Trudeau can be contacted at: jtrudeau@dawsoncollege.qc.ca