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Effects of interactive technology, teacher scaffolding and feedback on university students' conceptual development in motion and force concepts

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EFFECTS OF INTERACTIVE TECHNOLOGY, TEACHER SCAFFOLDING AND FEEDBACK ON UNIVERSITY STUDENTS' CONCEPTUAL DEVELOPMENT IN MOTION AND FORCE CONCEPTS

by

Jason Jeffrey Stecklein

A thesis submitted in partial fulfillment
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CERTIFICATE OF APPROVAL

PH.D. THESIS

This is to certify that the Ph.D. thesis of

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has been approved by the Examining Committee
for the thesis requirement for the Doctor of Philosophy
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To Heidi, Mom, Dad and Jordan

We were fond together because of the sweep of open places, the taste of wide winds, the sunlight, and the hopes in which we worked. The morning freshness of the world-to-be intoxicated us. We were wrought up with ideas inexpressible and vaporous, but to be fought for. We lived many lives in those whirling campaigns, never sparing ourselves: yet when we achieved and the new world dawned, the old men came out again and took our victory to remake in the likeness of the former world they knew. Youth could win, but had not learned to keep, and was pitiably weak against age. We stammered that we had worked for a new heaven and a new earth, and they thanked us kindly and made their peace.

T.E. Lawrence,
The Seven Pillars of Wisdom

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ABSTRACT

The utilization of interactive technologies will affect learning in science classrooms of the future. And although these technologies have improved in form and function, their effective employment in university science classrooms has lagged behind the rapid development of new constructivist pedagogies and means of instruction. This dissertation examines the enlistment of instructional technologies, in particular tablet PCs and DyKnow Interactive Software, in a technologically enhanced, university-level, introductory physics course. Results of this qualitative case study of three university students indicate that (1) the use of interactive technology positively affects both student learning within force and motion and self-reported beliefs about physics, (2) ad hoc use of instructional technologies may not sufficient for effective learning in introductory physics, (3) student learners dictate the leveraging of technology in any classroom, and (4) that purposeful teacher structuring of classroom activities with technologies are essential for student construction of knowledge. This includes designing activities to elicit attention and make knowledge visible for low-level content, while augmenting student interactions and modelling procedural steps for higher-level content.

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CHAPTER ONE

GENERAL OVERVIEW AND PURPOSE OF STUDY

Introduction

Clearly the introduction and utilization of new and emerging forms of technologies will affect learning in science classrooms of the future. From common keyboard-enabled classroom computers and tablet PCs to new and emerging platforms like mobile phones and iPads, student exposure to technologies, and to new and innovative teaching approaches employing these technologies, is certain to increase. These forms of and subsequent adaptations to instructional technology have the potential to change and reshape classroom science learning for students in various ways, including: allowing students to work at their own pace (Rogers & Cox, 2008); providing for instantaneous teacher feedback and communication to students and proactive guiding of student activities (Bodenheimer, Williams, Kramer, Viswanath, Balachandran, Balynne, & Biswas, 2009; Hennessy, Ruthven, & Deaney, 2005; Schroeder, 2004); enabling interactive learning opportunities such as peer assessment, teams and simulations (Chickering & Ehrmann, 2008; Evagorou & Avaamidou, 2008; Li, Liu, & Steckleberg 2010; Yuen, 2006) ; teaching life skills needed in the modern world (Sommerich, Ward, Sikdar, Payne, & Herman, 2007); augmenting student motivation and engagement (Amelink, Scales, & Tront, 2012, Dertling & Cox, 2008; Dickerson, Williams, & Browning, 2009; Evagorou & Acraamidou, 2008); solving and analyzing problems requiring sketches, diagrams and mathematical formulas (Enriquez, 2010; Rogers & Cox, 2008); and serving as a means through which to hold student attention and increase student refection on learning (Lin & Dwyer, 2009; Roschelle, Tatar, Chaudbury, Dimitriadis, Patton, & DiGiano, 2007).

Although technology is ubiquitous and has emerged in many distinct forms, its effective employment in school classrooms has come under scrutiny. Critics of instructional technology note the lack of concrete and transparent results, calling into question the allocation and advancement of technology in cash-strapped classrooms. Schools and universities have spent billions on various forms of technologies at the expense of mathematics and science fundamentals, they say, even as standardized test scores have shown little proof of learning improvements for students using technologies in the classroom (National Center for Education Evaluation and Regional Assistance, 2009; Theys, Lawless, & George, 2005). Kothaneth, Amelink, and Scales (2011) suggest that there are three main issues involved with adoption of instructional technology, including issues related to personal teaching styles, cost, and access to appropriate infrastructure. Issues with student and faculty acceptance of these technologies also are a factor, including the lack of student engagement and frustration with new technologies along with deficiency of faculty incentives to introduce and use these new technologies (El-Gayar, Moran, & Hawkes, 2011; Horton, Kim, Kothaneth, & Amelink, 2011; Lim, 2011). Moreover, instructors who have little experience with technology simply do not know how, and in what ways, to employ these emerging technologies within the classroom, i.e. they lack the pedagogical content knowledge to employ technology in the classroom effectively (Franklin, 2007). Selwyn (2013) notes that although most individuals in this technologically enabled era may feel “far more technologically sophisticated” than in previous times, there are “very little few of us are overly concerned with developing critical knowledge of how we interact with digital technologies” (pp.3-4). Instructors then must adapt to the rapidly advancing forms and functions of interactive technology beyond simply clicking, tweeting, and Facebook “liking.” Thus, teachers need to forge advanced teaching techniques with technology while at the same time being confronted by students who are accustomed to these technologies. Limits of money for instructional technologies in the classroom, underfunding of outside teacher development opportunities, and understaffing of support staff in schools also appear to undercut student gains in learning (Richtel, 2011). Consequently, as schools cut budgets and lay off teachers in tough fiscal times, critics have urged more emphasis on reading, math, and writing fundamentals as educators' main priorities.

Proponents of instructional technology, on the other hand, concede the lack of solid empirical evidence from standardized tests even as they stipulate that, for now, there's no better way available to measure the opportunities and benefits afforded by those technologies in the classroom. They caution that various standardized tests do not measure the appropriate skills and proficiencies that students develop while using technologies, such as collaboration, multimedia, and research skills (Gabriel & Richtel, 2011), appreciation of science and increases in science literacy (National Research Council, 2011).

In spite of the contradictory views between critics and proponents, what both do agree on is that effective ways to exploit new and emerging instructional technologies, both pedagogically and instructionally, has lagged behind their ever-increasing development, cost, and scope of introduction into science classrooms (Hennessy, Deaney, & Ruthven, 2005; Sommerich et al, 2007). Traditional uses of technology throughout all levels of education, including simple presentation of facts and concepts and skill-and-drill exercises within large lecture settings also have not been effective in improving student science literacy, motivation for or interest in science nor offered authentic learning instances, especially in the hard sciences like physics (Hancock, Bray, & Nason, 2002; Jolly, 2009). Teachers, though well-meaning, want to put in new and novel elements of learning, but they often don't know how to do so, do so haphazardly, or put too many changes at once. This can result in student learners who cannot adapt, adjust or thrive within these environments. In other words, the simple purchase and adaptation of technology by schools does not necessarily improve learning (Kerwalla, O'Connor, Underwood, duBoulay, Holmberg, Luckin, Smith, & Tunley, 2007; Mayer & Moreno, 1998; Pryor & Bauer, 2008; Simoni, 2011).

Constructivist Learning Practices

National Science Education Standards (NRC, 1996; NRC, 2011) for learning in science classrooms have focused on developing greater science literacy and appreciation of science for all student learners, underscored the importance of increased teacher-student interactions and feedback opportunities for learners, and have urged greater student exposure to authentic science activities in the classroom. According to National Research Council (1996), scientifically literate individuals can "ask, find, or determine answers to questions derived from curiosity about everyday experiences" and can "describe, explain, and predict natural phenomena" (p. 22). Experts also stress the importance of approaching "subject matter disciplines in the context of inquiry, technology, science in personal and social perspectives, and history and nature of science" (p.113). Related to this, the ways in which instructors present and structure these science activities to foster these skills are crucial. According to various authors (Enriquez, 2010; Gunel, 2008; NRC, 1996 & 2011; Tobin & Tippins, 1993; Wells & Arauz, 2006), instructors often have organized their instruction to show science as simple transmission of scientific facts and concepts instead of focusing on developing literacy, appreciation of science, and nurturing interactive engagement within a classroom setting. Gunel notes:

> In a traditional teaching approaches, science teachers usually present science as an accumulation of facts, theories and rules for students to be memorized…. This approach has resulted in poor understanding of scientific concepts, decreasing popularity of science, and declining numbers of students choosing science subject as a specialization. (p.209)

Enriquez (2010) adds that traditional instructor-centered lecture format represents an ineffective learning environment, offering little interaction or examples of collaborative learning, especially in science.

Student-centered instructional approaches, on the other hand, are intended to enhance student understanding by reducing the sense of direct transmission of pre-formulated science concepts. Student learners instead are empowered to both experience and question nature in interactive, group-based environments, where interactive environments can foster overall student learning in science (NRC, 2011). Students can then generate, evaluate and share ideas (Gunel, 2008) in both small- and large-group dialogic interactions (Woodruff & Meyer, 1997), while also engaging in hands-on experiences with nature. From this standpoint, science learning is “less about *content* and more about the *processes* in, and *construction* [emphases added] of, science knowledge within and supported by group activities” (Sherin, 2002).

The National Research Council (2011) says it this way: “Constructing and critiquing arguments are both a core process of science and one that supports science education, as research suggests that interaction with others is the most cognitively effective way of learning” (p.73). These increased student interactions force student expression and revelation of existing ideas and misconceptions (Yip, 2004), allow for collective feedback and critique of individual learners from other stakeholders (NRC, 2011), expose initial student ideas to extension and revision based on exposure to external testing, and also contribute to overall collaborative knowledge-building (Woodruff & Meyer, 1997). In this way student learners can take advantage of multiple classroom opportunities to forge their understandings about science concepts (NRC, 1996). These increases in student interactions should be facilitated by teachers, for example, by structuring activities to increase intra-group and inter-group interactions (Woodruff & Meyer, 1997), providing prompt and immediate teacher feedback (Eshach, 2010), and purposeful scaffolding of student learning (Dickerson et al., 2009).

Teacher feedback can be defined as the intentional responses an individual teacher gives to student learners during classroom activities and in response to students’ utterances. Effective teacher feedback is immediate, intentional, and targeted (Jang & Stecklein, 2010) and is geared towards diagnosing student misconceptions and conceptual hurdles (Tsai & Chou, 2002) as instantiated by vocalized student utterances and observed by teachers within student activities. Teacher feedback thus can increase dialogic interactions amongst learning stakeholders and also can direct student learners to review, rethink, and reinvent their science understandings.

Teacher scaffolding can also affect student conceptual development in student-centered learning (NRC, 2011). “Scaffolding has been characterized traditionally as a process during which an expert supports learner accomplishment of a specific task or attainment of a specific goal” (Sharma & Hannafin, 2007, p.28). This so-called “scaffolding” represents an intention teacher strategy to push and prod student learners to extend and validate extant knowledge through interactions, where teachers “scaffold” learning in a student’s “zone of proximal development” (Vygotsky, 1978). This imaginary teacher scaffold is continually erected and then replaced by the teacher within coordinated activities as students’ knowledge and ideas emerge and evolve through direct contact between a teacher and other learners. Thus, the scaffold is set up as a dynamic and moving frame in which student learners come in contact with new ideas and gradually fades as the learner grows in competence (Sharma & Hannafin, 2007). The overall purpose of this scaffolded environment is then to allow for rich classroom discussions and jointly constructed meanings while at the same time enhancing student retention of science concepts and improving learning for all common stakeholders in the classroom.

Enlistment of Interactive Technologies in the Classroom

The enlistment of interactive instructional technologies at the tertiary level of education offers distinct opportunities. Allocated resources and leveraged costs at the universities and colleges along with on-site educational researchers enable opportunities for the acquisition and enlistment of new and novel technologies (Horton et al, 2011). Inexpensive and widely-available portable tablet PCs and companion software, among them, a PowerPoint-like, interactive software suite known as DyKnow Interactive

Software, are readily available from commercial suppliers and have the potential to augment and improve instruction in university science courses that use interactive technologies (Berque, 2006b; Steinweg, Williams, & Stapleton, 2010). Also, available on-site technology infrastructure enables stakeholders the ability to have interactions with equipment and software whenever and wherever needed (Kothaneth et al., 2011) without which the adoption of technology is often inhibited. These technologies not only can operate as a regular means of teacher presentation, including lecturing but also can provide a platform for teacher feedback to students and permit teacher scaffolding of classroom learning. Tablets PCs in classrooms allow for efficient lecture presentations (Horton et al, 2011), including instantaneous communications, inking capabilities, collaborative activities, and avenues of exploration using web browsers, software programs, and computing utilities, like calculators and office extensions for student text production (Van Mantgem, 2008). Further, these capabilities then can be enhanced by appropriate teaching strategies for use in specific science classrooms. Steinweg et al. (2010) state:

> Presenters can use the digital inking feature during interactive activities such as expanding PowerPoint notes based on class discussions, revising and editing documents, calculating math problems and equations, brainstorming as a group while completing a graphic organizer, or using the highlighting feature to pinpoint key entries on spreadsheets (p.56).

Technologies also can serve as a central locus about which student learners can interact, collaborate, and construct meaning in science in a student-centered learning environment (Enriquez, 2010; Pryor & Bauer, 2008; Theys et al., 2005). For example, software supporting interactive communications can be assisted by tablet technologies, making it possible to have fruitful teacher-students interactions in the classroom, like structuring inter- and intra-group activities. In particular, interactive software, especially those specifically designed for tablet PC use, like DyKnow (van Mantgem, 2008), can enable better, and more frequent, student interactions, synchronous teacher feedback during peer instruction, and recurrent teacher improvisation within course activities (Roschelle et al., 2007). Price and De Leone (2008) point out also that tablet PCs connected to an in-class wireless network and external viewer can become a virtual whiteboard onto which an instructor can present material such as PowerPoint slides, make inked annotations, and display student work, thereby instantly transmitting course information to student computer screens and enabling computer-mediated "communication with substance."

The question that arises then is how and in what ways do new technologies affect individual students' conceptual development and learning practices beyond those quantified by limited standardized tests? While increases in scientific understanding have been linked separately to intentional teacher feedback (Yip, 2004), teacher scaffolding (Tobin & Tippins, 1993), and interactive technologies (Amirian, 2004; Dertling & Cox, 2008; Dickerson at el., 2009; Enriquez, 2010; Hennessy, Ruthven, & Deaney, 2005; Price & De Leone, 2008), little research has been published involving the educational success, and failures, of the novel uses of interactive instructional technologies and student-centered learning practices in a particular relevant setting: a university-level, introductory physics classroom, which utilizes interactive technologies to facilitate learning.

Purpose of Study

The purpose of this dissertation is to examine how student interact with various aspects of an innovative, technology-enhanced, university-level physics course while learning force and motion concepts. These aspects include (1) technology components such as DyKnow and tablet PCs, and (2) teacher scaffolding and feedback used in conjunction with the interactive technology. This research is thus meant to be a systematic attempt to study individual student learning and construction of science knowledge in an environment that combines elements of instructional technology with appropriate instructional strategies. Also, this research is intended to provide a means through which both successes and failures of the utilization of these technologies might be assessed. These results can subsequently be evaluated in a continuing instructor self-improvement process.

In particular, this dissertation aims to describe how students use interactive technology, specifically DyKnow software, in combination with teaching strategies such as intentional teacher feedback and scaffolding of classroom activities, to learn of motion and force concepts within an introductory, university physics course.

Research Questions of the Study

The research questions that guided this dissertation were:

1. How did students interact with technology components, including DyKnow and tablet PCs, within an innovative, technology-enhanced, university-level physics course while learning motion and force concepts?

2. How did students use interactive technology in combination with purposeful teacher feedback and scaffolding in learning motion and force concepts?

Rationale of the Study

Clearly, there has been a surge in educational research concerning the utilization of technology within science classrooms. In *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2011) the authors assert that new technologies can “expand the reach of science, allowing the study of realms previously inaccessible to investigation” (p.203) and that students should “actively engage in scientific and engineering practices in order to deepen their understanding of crosscutting concepts and disciplinary core ideas” (p.217). Documents like the *National Science Education Standards* (NRC, 1996) and *How People Learn: Brain, Mind, Experience and School* (NRC, 2000) also have highlighted the importance of technology and its effectiveness in enhancing learning. Teamed with appropriate teaching techniques, technologies can facilitate active-learning processes and inquiry in science, increase student interactions, and provide ongoing assessment of student learning. Studies have focused on specific use of individual technologies, like tablet PCs, in education, (Amelink at al., 2012; El-Gayar et al., 2011; Enriquez, 2010; Van Mantgem, 2008) and in upper-level physics, biology, and chemistry courses (Price & de Leone, 2008; Pryor & Bauer, 2008; Rogers & Cox, 2008), and with specific software systems to foster interactions, e.g. DyKnow Interactive Software (Berque, 2006a & 2006b). Many studies also have discussed technology use with teacher feedback (Biswas 2007; Bodenheimer, et al., 2009; Hennessy, Ruthven, & Deaney, 2005; Li et al., 2010; Schroeder, 2004) and scaffolding strategies (Dickerson et al., 2009; Englert, Wu, & Zhao, 2005; Ge & Land, 2003; Grincewicz, Zydney, Jones, & Hasselberg, 2011; Hlem-Silver, Duncan, & Chinn, 2007; Sharma & Hannafin, 2007).

However, there are few, if any, studies combining these various elements within a university-level physics classroom. Therefore, a description of how three physics students encountered a specific setting, which combines facets of teacher feedback, scaffolding, and forms of interactive technology within a university physics course, and how did they encountered force and motion concepts within this setting, could prove beneficial for outside administrators, faculty, and even future students. This dissertation thus can serve as a specific case of the enlistment of interactive technology, including DyKnow and tablet PCs, within a unique setting: in an introductory-level university physics course.

Overview of the Study

In this chapter, the rationale for studying how students interact with various aspects of interactive technology and how they might use interactive technology in combination with purposeful teacher feedback and scaffolding in learning motion and force concepts have been addressed. The research questions and the significance of the dissertation have also been stated.

Chapter Two discusses the basic theoretical foundations of constructivist learning environments, including the importance of student interactions, teacher feedback, and scaffolding, and student's beliefs/attitudes about science. Instructional technology is defined and the major findings of research on the effectiveness of these technologies on student learning within constructivist-type classrooms identified. Additionally, an overview of DyKnow Interactive Learning Software and tablet PC technologies is given along with how these technologies utilized within constructivist-type science classrooms. Finally, the dissertation's theoretical framework is presented.

Chapter Three provides a rationale for the employment of qualitative methods and case-study methodology in studying student use of interactive technology and appropriate teacher strategies utilized within the setting. This chapter thus explains and justifies the use of a case-study methodology, including research design, research context, data collection, and data analysis. Finally, the trustworthiness for this dissertation, including issues of credibility, transferability, and dependability, is discussed.

Chapter Four describes the findings of the two research questions for this study. First, this includes an overview of each research participant's experience within the technology-enhanced course. This is then followed by a discussion of each participant's development in force and motion concepts and self-proclaimed changes in beliefs/attitudes about physics at various points-of-interest throughout the course. Next, a cross-case analysis of the participants, which brings together the various aspects of technology force and motion concepts, and student believes/attitudes, is provided. The chapter concludes with a discussion of overall findings.

Chapter Five discusses the overall findings for this dissertation. This includes (1) the necessity for specific teaching strategies when invoking technology in the classroom involving appropriate teacher feedback and scaffolding, (2) the important elements of technology and how they affect student understanding of force and motion concepts, and (3) successes and failures of the use of DyKnow Interactive Software and tablet PCs. Finally, the implications for teaching, future research, and limitations for this dissertation are also presented.

CHAPTER TWO

LITERATURE REVIEW

Introduction

Technologies adopted for the science instruction, like classroom computers, mobile devices, tablet PCs, and iPads, are certain remain an important part of 21st century classrooms. In particular, the incorporation of new and emerging hardware and software in the form of *instructional technologies* promise to affect classroom learning for students in much the same way as constructivist learning theories have changed the curricula, instruction, and assessment of current and future science teachers. In turn, this transformation in learning will then reshape educational theory and instructional practices, most especially in interactive learning environments, revolving around constructivist-learning practices. In constructivist-type learning environments, student construction of his or her mental models depends on student-student or teacher feedback opportunities and teacher scaffolding of instructional activities. The questions then are: How can instructional technologies be purposed in such a way that they affect student conceptual development within a university-level, introductory physics courses, and how can instructors offer appropriate feedback and scaffolding within these instructional technologies?

This chapter will first describe the basic theoretical foundations of constructivist learning environments, including the importance of student interactions, teacher feedback, and scaffolding of classroom activities. Next, instructional technology will be defined and major findings of research on the effectiveness of these technologies on student learning within constructivist-type classrooms identified. Finally, this will be followed by a discussion of a special example of technology within the learning setting: DyKnow Interactive Learning Software and tablet PC technologies utilized within constructivist-type classrooms.

Constructivist Learning Environments

Need for Negotiation and Interaction in Constructivist Classrooms

Constructivist learning theory is rooted in continual learner negotiation and evaluation of cognitive frameworks, based on experience and subject to constant learner revision (NRC, 1996, 2011; Tobin & Tippins, 1993). According to Bettencourt (1993), learners construct knowledge in order to deal with their experience:

> To deal with experience means…to organize it in such a way that our actions bring about desired results and avoid undesired ones. In order to be able to do this, we have to have some idea (no matter how rough and incomplete) of some of the possible results and how to choose between them (i.e. some valuing scheme). These expectations and preferences come from our previous experience (which includes social and cultural dimensions). Trying to bring about our expectations, we construct working hypotheses (no matter how simple) of how entities will behave when acted upon in certain ways. As long as these hypotheses are fulfilled by the results of our actions, we will continue to use them…. They constitute our understanding of the world and serve as tools to be used in future situations. (p. 40)

Thus, student learners should engage in tasks that challenge personal experience and require constant and focused attention on matching emergent conceptual frameworks with existing physical realities. Moreover, according to social constructivists, learning should reside not merely in “recollection” but instead in “active, constructive processes that build on prior knowledge” (Roschelle et al., 2007), where knowledge is actively constructed by the learner in the presence of other stakeholders (Prawat & Floden, 1994).

To Vygotsky (1978), individuals develop their understanding by employing language in social interactions where language requires elaboration of knowledge. In order for these fruitful interactions to occur, students must be actively motivated to learn in science and must focus intentionally on negotiating and constructing personal knowledge frameworks. This can be accomplished by engaging in social interactions

within which argument plays an essential role (NRC, 2000). Knowledge is then constructed and meaning is made through the "social process of language over time" and is "discursive, relational, and conversational" (Ferdig & Trammell, 2004).
Argumentation within this community is therefore paramount. Ravenscroft and McAlister (2008, p.317) assert that "we need to argue effectively if we want to participate and be effective in communities of inquiry, reason and share ideas and redefine her understanding of the world." A community of peers therefore must be present to fulfill this social interactive capacity by offering feedback where "knowledge evolves through a process of negotiation within discourse communities and that the products for this activity–like those of any other human activity–are influenced by cultural and historical factors" (Prawat & Floden, 1994, p.37). Learning in a classroom then should include a focus on the learner's construction of knowledge integrated within environments with adaptive instruction and participation in a community of learners (NRC, 2000). "This notion has led to calls for dramatic shift in classroom focus away from the traditional transmission model of teaching toward one which is much more complex and interactive," note Prawat and Floden (1994, p.37). Moreover, this challenging of personal experience might be facilitated by appropriate and directed instruction, including the integrated use of directed teacher feedback and scaffolding of activities, attempting to enlarge each individual's "zone of proximal development" (Vygotsky, 1978).

According to Hewson and Hewson (1984, p.7), the constructivist view of learning "involves changing a person's conceptions rather than simply adding new knowledge to what is already there" where "learning involves an interaction between new and existing conceptions with the outcome being dependent on the nature of the interaction."
In the conceptual change model of learning (Hewson & Hewson, 1984; Posner, Strike, Hewson, & Gertzog, 1984), the authors assert that conceptual change occurs within a learner when three conditions are met: (1) a new concept has to be intelligible, meaning

that the “person considering has to know what it means, has to be able to construct coherent representation of it and has to see that it is internally consistent”; (2) a new concept has to be initially plausible, meaning that the “person who finds that the new conception is plausible must first know what it means.… But must also believe it to be potentially true”; and (3) a new concept has to be fruitful, meaning that the ideas offer “greater explanatory and predictive power than was previously possible” with older ideas (All quotes from Hewson &Hewson, 1984, p. 7). Therefore, in accommodating a new idea, learning takes effort by the individual learner and does not happen spontaneously. Thus, the learning is *student-centered*.

Student motivation and expectations in science, especially in physics, must play a large role in learning. Motivation and the context in which students learn (Ames, 1992; Hidi & Harackiewicz, 2000) strongly affect student learning and achievement. Motivated students approach tasks more eagerly, develop persistence in diverse situations, and enjoy learning achievements. According to Redish, Saul, and Steinberg (2002), who introduced the Maryland Physics Expectations Survey (MPEX), student expectations about and attitudes toward science, especially physics, affect their learning. Their results indicate that “a large gap between expectations of experts and novices and observe a tendency for student expectations to deteriorate rather than improve as a result of the semester of introductory physics” (p.1). Sahin (2009, p.169) states that, “sophisticated student epistemological beliefs are correlated with success and conceptual understanding in science. Hence, it has been emphasized that students should be facilitated to improve their epistemological beliefs from a novice to a more expert-like level.” Thus, it is important to keep in mind individual student expectations and beliefs about physics, and how they might impact learning.

Teacher Feedback and Scaffolding in Constructivist Classrooms

National Science Education Standards and the *Framework for K-12 Science Instruction* (NRC, 1996; NRC 2011) underscore the need for teacher feedback and scaffolding of activities to increased student interactions in constructivist-type classrooms.

Feedback in a classroom involves conversations between teacher and students (or amongst students) where individual teachers "use the ideas of students" to augment conversations and foster dialogic interactions between teachers and students and amongst learning stakeholders. The National Science Education Standards (1996) declare that "talking with peers about science experiences helps students develop meaning and understanding. These conversations serve to clarify the concepts and processes of science, and help students make sense of the content of science" (p.174). Suthers (2006, p.327) adds that through feedback opportunities "jointly constructed representations become imbued with meanings for the participants by virtue of having been produced through a process of negotiation" amongst learners and teachers.

Teacher inclusion of activities that promote interaction and lead to knowledge about student learning is thus important. This can include configuring activities within the classroom to facilitate teacher-student interactions. Moreover, in constructivist learning environments, a teacher then can take existing student knowledge into account when planning and administering classroom experiences. According the National Research Council:

> Teachers collect information about students' understanding almost continuously and make adjustments to their teaching on the basis of their interpretation of that information. They observe critical incidents in the classroom, formulate hypotheses about the causes of those incidents, question students to test their hypotheses, interpret student's responses, and adjust their teaching plans. (NRC, 1996, p. 87)

According to Hewson and Hewson (1984), this teacher diagnosis is a necessary prerequisite for any teaching strategy because different students incorporate and conceptualize new experiences in different ways. Thus, a teacher must be able to diagnose and modify instruction based on what is emergent in the classroom. This virtuous learning cycle of feedback amongst stakeholders, diagnosis of responses, and subsequent teacher response then necessitates that dialogic interactions between students and teacher and amongst students *must occur* regularly in the classroom. Instructors in inquiry-based environments should then take the role of a *facilitator* who challenges students to focus on their conceptual understandings by organizing appropriate activities, i.e. designing activities that foster dialogic interactions, i.e. feedback opportunities, within the classroom (Jolly, 2009). In constructivist-type classrooms, this feedback should also be immediate, intentional and targeted (Jang & Stecklein, 2010) and should help to augur trust, warmth, openness and friendliness in a non-threatening learning environment (Watts & Bentley, 1987).

Teachers can facilitate various feedback opportunities within the classroom. For example, instructors can configure question-and-answer opportunities, allow for group or team learning, and also collect relevant student artifacts for evaluation. Within question-and-answer opportunities, teachers can instantaneously communicate with learners, thereby critiquing, correcting, and extending student knowledge within the classroom. Indeed, even students themselves can also offer feedback in the form of peer assessment in which students evaluate the progression and achievement of peers (Li, Lui, & Steckelberg, 2010). Chen and Tsai (2009) note that creative peer assessment learning activities can not only enhance thinking skills of student learners, but also can assist instructors in establishing a firm hold on a learner’s conceptual development and thus make better judgment of student work. And through the submission of student work, teachers also can examine student ideas and knowledge frameworks. In turn, teacher annotations and evaluation of student work can provide relevant feedback to learning stakeholders.

In providing constructive feedback, teachers can also intentionally *scaffold* learning: teachers can enable dynamic interactions amongst stakeholders where a teacher asks for and listens to student feedback and thereby adapts the teacher-student environment, setting constrained tasks with clear objectives and in meaningful contexts (Hennessy, Deaney, & Ruthven, 2005). Learning then involves the interaction between advanced individuals *scaffolding* a less advanced individual in one's "zone of proximal development." This zone is defined as the "distance between the actual development level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with peers" (Vygotsky, 1978, p.86). And thus through various apprenticeship opportunities, teacher modeling of tasks, and demonstrating effective learning strategies, students can transition into enter new learning areas (Hennessy, Deaney, & Ruthven, 2005). Scaffolding or support is often needed to help students succeed with open-ended, complex, problem-solving environments" (Zydney, 2010). Grincewisz, Zydney, Jones, and Hasselbring (2011) and Zydney (2102) suggests several common attributes of scaffolding instruction, including "recruiting and maintaining learners' attention, simplifying the task, modeling and demonstrating the activities, ongoing analysis and diagnosis, and fading support, leading to eventual knowledge transfer" (p.232). Sharma and Hannafin (2007) describe scaffolding as a:

> Two-step process of supporting the learner in assuming control of learning and task completion. First, the expert provides the novice with appropriate support to identify strategies for accomplishing individually unattainable learning goals or tasks. In the second step, the expert gradually fades this assistance as the learner becomes increasingly competent (p.29)

Technology can assist in supporting scaffolding of learning. Though traditionally accomplished through one-on-one, teacher and student interactions, scaffolding also can be provided in with technology in different formats, including technology-based scaffolds, prompt scaffolds, and peer interactions created with teacher support, according to Bulu and Pederson (2010). Sharma and Hannafin (2007) state:

> Technological scaffolds can also provide procedural and metacognitive support for routine tasks, and thereby support learning in classrooms. Contemporary learning contexts incorporate several support mechanisms and are often characterized by multiple students with a single teacher, who due to temporal and contextual exigencies often scaffolds the learning of groups of students (p.29).

According to Saye and Brush (2002), technology can also facilitate scaffolded interactions by offering unique representational opportunities, and alternative means of exploring ideas and concepts. For example, teachers can pre-plan activities with technology and then administer those activities to “guide students in the learning process, pushing them to think deeply, and model the kinds of questions that students need to be asking themselves, thus forming a cognitive apprenticeship” (Hlem-Silver et al., 2007,p. 101).

Instructional Technology in the Constructivist-Type Classrooms

Coinciding with this educational evolution in science learning has been the birth of the digital age with its accompanying technologies. Currently in the modern classroom there exist numerous and easily manageable types of technologies beyond the ordinary personal computer. These include laptops, tablet PCs, handheld devices like cell phones, wireless systems, and emerging web-oriented software like audio/video applications, e.g. iTunes and YouTube, applets, Twitter, podcasting, wikis, blogs, and many others (Berque, 2006b; Ferdig & Trammell, 2004).

According to the Association for Educational Communications and Technology (AECT), Definitions and Terminology Committee (as cited in Seels & Richey, 1994, p.1), instructional technology is defined broadly as the “theory and practice of design, development, utilization, management, and evaluation of processes and resources for learning." It is “purposeful and controlled” (AECT, 2004, p.16) and includes personnel such as teachers, administration, and support staff along with the applicable forms of technology employed inside and outside classrooms, like hardware, software, and their delivery infrastructure. Hardware in instructional technology is defined as the “physical” form and components of technology, including computers, portable devices, wireless connections, printers, webcams, scanners, microphones, and speakers; software are the programs or codes that enable the user to interact with the hardware to “do” something, like word processing and computer gaming, interacting with in and across programs with other stakeholders. Some examples of software would be Microsoft Word, Explorer, iTunes, or Quicken Money Management. Moreover, the delivery infrastructure of instructional technology can be thought of as the ways in which hardware and software are connected, articulated, crafted, and thus delivered to learning stakeholders (Johnson, 2008). Hardware, software and infrastructure thus can be combined to perform a task. For example, a software program can enable a user to compose a writing sample though typing on the computer’s keyboard, i.e. hardware, thereby displaying a series of symbols on the screen. These keystrokes can then be communicated across the infrastructure to other users, and thus knowledge can be transmitted across the different components usefully.

Effects of Technology on Learning

Technologies that integrate interactive engagement within classroom have the potential to affect learning (Simoni, 2011). Overall, technology can present many benefits in the constructivist-type classrooms, including enabling person-to-person contact and teacher observation of student activities. Moreover, utilizing technology in the classroom can allow students to work at their own pace (Rogers & Cox, 2008), provide for instantaneous teacher feedback and communication to students and proactive guiding of student activities (Bodenheimer et al., 2009; Hennessy, Ruthven, & Deaney, 2005; Schroeder, 2004), enable interactive learning opportunities such as peer assessment, student groups and synchronous simulations (Chickering & Ehrmann, 2008; Evagorou & Avaamidou, 2008; Li et al., 2010; Yuen, 2006), teach life skills needed in the modern world (Sommerich, Ward, Sikdar, Payne, & Herman, 2007), solve and analyze problems requiring sketches, diagrams, and mathematical formulas (Enriquez, 2010; Rogers & Cox, 2008), augment student motivation and engagement (Amelink et al., 2012; Dertling & Cox, 2008; Dickerson et al,, 2009; Evagorou & Acraamidou, 2008), and function as a means through which to hold student attention and increase student refection on learning (Lin & Dwyer, 2009; Roschelle et al., 2007). Chickering and Ehrmann (2008) state that interactive technologies allow for sharing of resources, enable joint problem solving, and enhance and improve faculty-student interactions, especially with shy students. Technologies then can assist in creating learning teams that can improve student learning and also enable apprentice-like activities to occur in classrooms. Lui, Horton, Olmanson, and Toprac (2011) also state that "new media technology can be used to create such 'playful' environments which combine elements of fantasy, narrative, and scaffolded content while bestowing upon students authentic roles with meaningful activities" (p. 262).

Instructional technology also has the potential to augur motivation (Amelink, et al., 2012; Lui, et al., 2011). Hancock et al. (2002) suggest that student motivation is influenced by both personal characteristics and environmental factors, and they further add that instructional technologies have shown promise in affecting this student motivation to learn. Also, they contend that students might be more motivated in student-centered classrooms than in teacher-centered classrooms because students who are conditioned by years of teacher-centered instruction are more motivated to learn technical information in a setting in which they are allowed to exercise significant levels of control and personal responsibility. Amelink et al. (2012) also reported increased student engagement and motivation to learn in learning environments with tablets PCs.

Issues with the Introduction of Technologies in Classrooms

Unfortunately, even after factoring in all the potential benefits of interactive technology, it is not clear how student interactions can be engaged effectively in modern technologically-enabled classrooms. This is especially true with the rapid development of the forms and functions of technology, time limitations and underfunding of teacher development opportunities, and general understaffing of support staff for technologies. Traditional uses of technology in education, including simple presentation of facts and concepts in lecture format, have not improved student motivation and interest in science and thus are not sufficient to foster learning (Hancock, Bray & Nason, 2002). What is clear is that simply adapting technology does not improve learning (Kerwalla et al., 2007; Mayer & Moreno, 1998; Pryor & Bauer, 2008; Simoni, 2011).

Moreover, as emerging new technologies and teaching techniques appear, individual educators and students must adapt. Currently, the application of technology by many instructors has, in many instances, been confided to presenting fact, concepts and figures. Many instructors make use of Power-Point-like slides and other similar displays that mimic traditional "chalk-board" presentations, especially in the biological sciences where the presentation of facts, definitions, and figures are paramount. This has resulted in little regard for overall organization or definitive elaboration with technologies in course curricula, including possible interventions to foster student cognitive processes that take advantage of technologies, like novel problem-solving approaches in physics and chemistry, employment of imbedded audio/visual representations in classroom activities, or directed peer-peer interactions to help foster feedback within the classroom

(Roschelle et al, 2007; Simoni, 2012). Tutty, Scheard, and Avram (2008) add that the lack of resources and widespread use of teacher and student quality measures negatively affects the content delivery in many subject areas and discourages teacher improvement in teacher practices.

While much has been written about instructors, students must adapt too. Schertz and Oren (2006) note that when using technology "students' images about scientific or technological environments were superficial, unreal, and even incorrect," and their "impressions of the characteristics of scientists and technologists were superficial, misleading, and sometimes reflected ignorance" (p. 965). Much of their "learning" appears to be the simple memorization of facts and definitions by solitary individuals rather than deeper interactive learning, like collaborations to solve problems, develop consensus, or perform a laboratory activity. This type of learning is further fostered by standardized testing, like ACT, SAT, MCAT or LSAT assessments, where recollection and retrieval of basics facts and knowledge supersede evidence of deeper learning processes.

The increasing usage of technology necessities that schools augment their delivery of educational services and modify curricula in response to the needs and concerns of learning stakeholders (Oliver, 2008). Schools and universities currently have available hardware and software, and access to various types of network computing, internet connectivities, and E-learning courseware management systems. E-learning and Learning Management Systems are complex, web-based applications, for example *Moodle, Claroline*, and *BlackBoard*, which support student learning, offering services to improve instruction and learning and allowing for systematic, online course support (Oliver, 2008). These technologies are intended to foster teacher-student interactions outside of the typical bounds of the physical classroom, limit the effects of large class size, and attempt to take advantage of administrative efficiencies in the delivery and management of classes (Oliver, 2008). These systems are being engineered today in increasing numbers by various institutions, outside companies, and by open source initiatives to support teachers and learners in performing computer-supported pedagogical scenarios. Retalis, Georgiakakis, and Dimitriadas (2006) urge the creation of systemic patterns of instructional use—codified and available to many users and made in consultation with experts and other experienced peers—so that to not "re-invent the wheel" when it comes to course organization and interactivity. Moreover, it is not only the features of technology that are important, but also the way they are implemented to support student learning (Lehtinen, Hakkarainen, Lipponen, Rahikainen & Muukkonen, 1999). Bekele (2010) underscores in his meta-analysis of research findings on internet-supported learning environments. The author notes that although changes in overall student motivation and satisfaction with interactive technologies are unclear, underlying student technological skills, overall course design elements, and multiple support factors, including teachers, support staff, and tutors, surely must play major roles in emergent student learning. Chang and Yang (2010) further contend that more attention must be paid to the interaction of students and their learning environment, including the use of technology, and that simply introducing constructivist, computer-based technology does not guarantee all students will benefit from it.

Technologies that Integrate Teacher Feedback and Scaffolding

Various sources touch upon the integrated use of teacher feedback and scaffolding within technology-enhanced instructional settings and how this might affect student learning, motivation and attitudes in science. This is social constructivist nature: auguring interaction and negotiation through the use of technology. Multiple types of technologies have been employed with many varying approaches, including approaches with feedback imbedded into conversations and scaffolding of class activities.

Feedback with Interactive Technologies

From simple one word utterances to complex student-teacher engagements, a teacher's responses to what is occurring in the classroom and her subsequent intentional feedback is essential for student learning. According to Chi (1996), a typical pattern for feedback includes: (1) tutor asks an initiating question; (2) student provides a preliminary answer; (3) tutor gives feedback on answer ; (4) tutor scaffolds to improve or elaborate the answer in a successive series of exchanges; and (5) tutor assesses student's understanding of answer (p.S34). Feedback can be categorized in many ways, and teacher questioning paired with feedback can be effective for higher-order learning objectives (Lin and Dwyer, 2009; Yip, 2004). This teacher feedback can occur in large group settings, in small groups or within tutor-tutoree pairs, where Chi suggests four categories of feedback: corrective feedback, reinforcing feedback, didactic feedback, and suggested feedback.

And this meaningful teacher feedback can be especially effective when paired interactive technologies. The teacher-as-facilitator use of various technologies has the potential to offer immediate, intentional, and targeted feedback (Jang & Stecklein, 2010) to student stakeholders, where both the hardware and software capabilities in a classroom can be merged in the right circumstances. This can then allow for relevant and immediate teacher feedback (Roschelle et al, 2007), more numerous student interactions, and can thus augment student motivation and engagement (Dickerson et al., 2009; Evagorou & Acraamidou, 2008). Offering feedback after a certain amount of material is displayed, learners can be given opportunities to pause and reflect on previously-viewed material, evaluate their learning, and confirm whether or not they have appropriately and accurately extracted the information displayed. One drawback, however, is the possible overburdening of teachers in setting up and coordinating group activities and that many teachers can precipitously fall back into a standard lecture format if faced with a lack of time and energy.

Particular technologies can be purposed within a traditional university lecture so that instructor feedback can be facilitated. For example, in a classroom with interactive technologies, an instructor might design each class lecture to evolve within a specific piece of technology, say with tablet PC technology using an interactive software. This could be done through PowerPoint-type presentations or constructed with a more interactive type technology, like DyKnow Interactive Software. The instructor's lecture might then be designed so that student learners must actively participate within the lecture through that technology. Active student engagement within the classroom and collection of classroom artifacts can then ensue, thus going beyond the traditional dissemination of knowledge on an ordinary chalkboard. Within this set up, then, students can interact with each other and the teacher while simultaneously testing existing knowledge frameworks within the technology. This can allow for instantaneous and efficient means of communication of ideas and also allowing for effective classroom argumentation. As a specific example, an instructor may ask student learners to submit their responses a class quiz electronically using the technology. Then the instructor could grade and also redistribute those quizzes back to students quickly.

Scaffolding with Interactive Technologies

Recently, "educators have become interested in scaffolding provided through computer-based tools because of the difficulty of trying to provide individual assistance to each student in a large class" (Zyndey, 2010). Scaffold techniques can be utilized with and within technology applications by a teacher in order to direct learners to important characteristics and identify relevant information (Bulu & Pederson, 2010). Grincewisz et al. (2011) and Zydney (2012) suggest by several common attributes of scaffolding instruction, including "recruiting and maintaining learners' attention, simplifying the task, modeling and demonstrating the activities, ongoing analysis and diagnosis and fading support, leading to eventual knowledge transfer" (p.232). The authors note that within a classroom, teachers operate with multiple zones of proximal development and it is difficult to meet the needs of all students. But by distributing scaffolding across different resources and learners within the classroom, teachers can create an optimal learning environment. Factors that help to explain how and why the scaffolds enhance reflective thinking include specific requirements conveyed in the scaffolds, the structure of the scaffolds, and the use of the critical incidents to anchor reflective student learning (Lia & Calandra, 2010).

Technology can allow for this optimization. Thus, learners can "take advantage of the scaffolding at a time, and in a manner, that best supports their individual needs" (p.233) and multiple levels of scaffolding can be assigned, varying from continuous to faded scaffolding, depending on the activity. With technology, students then can take advantage of customized learning settings, develop solutions by making linkages to extant knowledge frameworks (Ge & Land, 2003), and articulate justifications about their ideas (Lin & Lehman, 1999). Bulu and Pederson (2010) suggest distributing scaffolds across software, teacher, and students, thus making each a part of a larger community and then gradually "fading" the scaffold, thereby allowing the community to act as the "expert other." Grincewicz et al. (2011) noted the difference between "hard" and "soft" scaffolds while using technology. "Hard scaffolds are defined as fix supports… designed based on the anticipated needs of students; whereas, soft scaffolds are described as teacher scaffolding techniques that are adaptive and spontaneous to the current situation" (p.233). The authors note that hard scaffolds are not sufficient at supporting learning for students and that teachers need to "align and utilize all types of scaffolding for students to make successful progress" (p.233).

Problem solving activities and writing with technology can also be scaffolded. The use of problem-based learning environments with hypermedia, i.e. texts, audio and video related by common subjects, and subject links can help engage student problem solving. Problem-based learning “is the learning that results from the process of working toward the understanding or resolution of a helps students develop skills and confidence for formulating problems they have never seen before” (Smith, Sheppard, Johnson, & Johnson, 2005, p. 88-89). Scaffolding might be efficacious because it “enables beginners to solve a problem, carry out a task, or achieve a goal that would be beyond his solo efforts” (Englert et al., 2005, p. 186). According to Belland, French, and Ertmer (2009) computer-based argumentation also can be employed to scaffold with young learners. The results indicates that scaffolds within technology could support argumentation by ‘‘embedding scaffolds within a system,’’ ‘‘having students articulate their thoughts,’’ and ‘‘focusing on the development of conceptual, strategic, and procedural hard scaffolds.” “The widespread use of these new technologies means that more of argumentation reasoning can be participative, public and persuasive,” note Ravencroft and McAlister (2008, p.317). A number of studies also have looked at the scaffolding of writing, including scaffolding reflective journaling activities (Lai & Calandra, 2010). Englert et al. (2005) report that the use of scaffolding mediated by technology significantly improved writing performance, most especially with respect to student abilities to produce organized texts. Technologies, they note, might be employed to help less proficient writer advance their writing skills through anchors, tools, strategies and assistance technologies. Lai and Calandra (2010) indicate that “computer-based scaffolds significantly enhanced the participants’ reflective journal writing as well as the length of their written artifacts.”

Special Case: Tablet PCs and DyKnow Interactive Learning Software used within constructivist-type classrooms

New portable technologies like tablet PCs are similar to regular table-top personal computers but also have the portability of laptop PCs along with the functionality to mark on their screens. Tablet PCs is a type of notebook computer with the screen on which a user can write and comes in two styles, (1) “convertible” which has a keyboard and a screen, and (2) “slate”, which has only a pen and screen and no keyboard (Sneller, 2007). Tablet PCs have the ability to function without dedicated keyboards, enabling students and teachers to write directly on a device’s screen and thereby “digitally ink” with a pen-like stylus or finger-strokes. This capability opens a range of classroom opportunities previously unworkable in a typical classroom, like real-time annotating of documents, authentic writing experiences, long-hand classroom journals, and real-time, collaborative collection and analysis of data (Enriquez, 2010; Dertling & Cox, 2008; Pryor & Bauer, 2008). Tablet PCs further provide the “flexibility of traditional handwriting, ability for multimedia presentation as well as real-time collaboration among students, and the submission of students’ responses to the instructor” (Biswas, 2007). According to Lumkes (2010), tablet PCs have many advantages, including the ability to use many different software applications, integration of graphics and multimedia, advantage of saving results in posting online, ease of following along the progression of written material, and employment of digital inking and colors.

Unfortunately, the pace of these technological developments is outstripping the effective pedagogies for their use and therefore care must be taken in utilizing them in science classrooms. According to Sneller (2007) there is a continued rise in scholarship at the “*tool level* (evaluating uses of tablets by students and instructors) and the *learning level* (measuring actual changes in learning, not just attitudes or perceptions)” (p.S3J-6). She notes at the tool level there variety of positive uses for tablet PCs, including student peer review and problem-solving exercises; student collaboration and communication; the ability to take, organize, retrieve, and even replay digital notes; improvement and feedback between students and instructors; and digital grading and return of classroom artifacts. Stickel and Hum (2008) report that although students strongly backed tablet PCs in an undergraduate engineering classroom, they urge caution in integrating tablet PCs, saying, “the tablet PC must be effectively used, rather than exclusively used” (S1A-12), since some leaners prefer tablet and blackboard work.

Tablet PCs: Teacher Feedback and Scaffolding

Tablet PCs in the classroom can enrich the learning environment in many ways. In particular, interactive communication, teacher feedback, and scaffolding of activities can be supported by tablet PC technologies. These include offering instantaneous communication between teacher and students; enabling enhanced lecture presentations and the ability to analyze problems requiring sketches; permitting digital inking, use of hyperlinks and annotations; and facilitating the use of tablet PC-based interactive systems. In particular, the immediate feedback from teachers using tablet PCs–in the forms of direct feedback defined as immediate responses to requests from students and on-going annotation of course material–can be a very effective tool to increase learning efficiency and may be attributable to increased focus and attentiveness of students in class due to the awareness that the instructor is observing student progress, according to Enriquez (2010). The utilization of technology then can make it possible to have better and timelier interactions while at the same time permitting teacher control and structuring of classroom activities. Teacher feedback and scaffolding approaches using interactive technologies and tablet PCs have been undertaken in a number of studies.

Price and De Leone (2008) note that a tablet PCs connected a wireless network and external viewer becomes a virtual whiteboard onto which an instructor can instantaneously present material like PowerPoint slides. The instructor therefore can make inked annotations and also display student work, thereby instantly transmitting responses to individual students and enabling computer-mediated "communication with substance." Also, when matched with interactive software especially designed for tablet PCs use, including DyKnow, Classroom Presenter and the Ubiquitous Presenter (van Mantgem, 2008), tablets PCs enable better, more frequent student interactions and synchronous teacher feedback through peer instruction and recurrent teacher improvisation (Roschelle et al, 2007).

Dickerson, Williams, and Browning (2009) reported on the effects of the use of tablet PCs in a university-level information technology course. The instructional approach was structured to enhance student learning with tablets with student discussion, teacher demonstration, and direct engagement between students and teacher. The authors note that the variability in skill development among learners was directly linked to the level of support provided during the learning events by the instructor and also that scaffolding of tasks allowed students to make their own decisions on technology without "selling them" on the benefits. Further, they report that tablet PCs had positive effects on students, including increased engagement and motivation.

Hennessy, Deaney, and Ruthven (2005) undertook a qualitative case study of secondary science teachers who scaffolded instruction in a technology-integrated environment. In this setting, teachers acted as mediators of student learning and teacher-student interactions and facilitated student learning through intentional teacher scaffolding by "selecting, changing, amplifying, and interpreting the objects and choices" of students in the technology-rich environment. The teacher thus defined an environment and set of interactions, which enabled students to participate in activities near or at the individual student learners "zones of proximal development." Students were thus active participants in a socially mediated set of conversations. And as students progressed in their learning, teachers then could withdraw their "scaffolding" and allowed students the time and space to develop their "inner voices" (Vanderburg, 2006). The authors then categorized general effective teaching strategies for mediating technologies in these scaffolded learning environments. These techniques included integration of electronic resources with other resources, setting clear parameters for electronic searches, pre-structuring student tasks to support interaction, e.g. pre-formatted exercises, facilitating teacher opportunistic interventions, avoiding student distraction and obsession with technology presentation, facilitating collaboration with technology, and developing a culture of shared ideas. These were assisted by the integration of electronic resources with other resources, pre-structuring of tasks supporting pupil-technology interaction, opportunistic teacher interventions to accommodate learners' shifting needs, interactive whole-class teaching, and promoting active student participation, experimentation, and independent thinking (Hennessy et al., 2005).

While employing tablet PC technology into an introductory undergraduate chemistry course, Dertling and Cox (2008) reported that the major benefits of tablet PCs were improved student involvement in course activities, immediate availability of classrooms notes with teacher feedback, and the ability to analyze many different types of physical problems. They found that there was a statistically significant improvement in test scores of student over the traditional lecture-based approach on an American Chemical Society standardized exam. Students themselves also seemed to have a high opinion of tablet PCs and agreed that tablet PCs were an effective tool for enhancing learning, created a better learning environment, increased availability to notes, promoted student learning, improved student interaction with instructor, and increased work on a variety of different problems using the tablets.

Sommerich, Ward, Sikdar, Payne, and Herman (2007) also performed a study on high school science students and their experiences using tablet PCs. After analyzing responses on a student questionnaire, they concluded that the high school students generally had a positive attitude towards tablet PCs. The students noted that while using tablets that they encountered little difficulty, the tablets malfunctioned infrequently, made school enjoyable, and made it easier to access old notes.

Thought there were advantages in incorporating tablet PCs with the science classroom, care must be taken. As Lumkes (2010) notes, individual instructors must choose the appropriate hardware and software for their own particular teaching method and must be careful to utilize the added flexibility attained by tablet PCs, including annotations, multimedia, pen colors, and the ability to switch between different applications, in a way to "enhance, and not distracted from, student learning" (p.351). For example, adding discussion questions within presentations and making a conscious effort to allow time for student interaction and questions can be helpful for student learning with complex topics. Pryor and Bauer (2008) tested the effectiveness of tablet PC technology in team-taught laboratory sections of an introductory undergraduate biology course. Instructors who used the tablets PCs reported that they enjoyed using tablet PCs although their responses were ambivalent with respect to lab and tablet PC integration. They cited some drawbacks of working with tablet PCs including instructors losing student attention during computer-assisted labs, reduction in student-teacher interactions and dialogues, i.e. reliance on transmission of content, connectivity issues, and significant need for outside support networks.

DyKnow Interactive Software

DyKnow Interactive Software, in particular, has the potential to affect student learning while used in combination with tablet PCs. Berque (2006a) codifies the various uses of DyKnow with tablet PCs where DyKnow "supports teaching and learning by facilitating four mutually supportive activities: collaborative note taking; classroom interaction; out of class review, replay, and grading of classroom materials; and computer monitoring" (p.205). Schroeder (2004) lists the benefits of using DyKnow, including the ability to "ink," collaborate and offer feedback, capability to isolate examples of students' work in class, and then projecting or broadcasting these examples to all members of the learning community to inform the learning process. Corrective teacher feedback, in particular, is assisted by the use of DyKnow. As described by Sneller (2007, p.S3J-5) and the DyKnow Homepage, DyKnow software "has two inter-operable programs within it, Monitor and Vision. Monitor enables instructor to monitor and/or block unauthorized student computer activities, while Vision 'fosters interaction through collaborative note taking, student response tools, content replay, and anywhere anytime access' (DyKnow Homepage)". In summary, the various uses of DyKnow include transmission of low-level content, instantaneous communication and annotation of classroom material, scaffolding of activities, corrective teacher feedback, and the setting up of interactive activities.

Theoretical Framework of the Study

Within an educative setting, a teacher begins with a course curriculum (Hlebowitsh, 2005), the planning of course activities both inside and outside of the classroom. This includes the establishment of the classroom environment, planning of course activities, selecting of educational materials, and purposing of educative implements, like available technologies. The boundaries she sets within this curriculum are influenced by the teacher's teaching philosophy, which is further demarcated by her constructivist learning beliefs and her ideas on utilizing instructional technology to foster science learning within that environment.

The crux of social constructivist learning is to foster social interactions amongst learning stakeholders, which in turn forces individual learners to scrutinize their existing conceptual frameworks. This depends on language (Vygotsky 1986), classroom dialogue (Wells & Arauz, 2006), and subsequent negotiation with and amongst individual learners (Wheatley, 1993). This social negotiation process then can create conceptual conflicts within the student learner so that the learner can accommodate and assimilate new ideas and concepts (Posner, et al., 1982).

In order to facilitate these types of interactions, a teacher can take advantage of intentional scaffolding strategies of activities (Grincewicz et al., 2011; Zydney, 2012). She can design activities to increase connections, elicit and keep the attention of student learners, make student knowledge visible, and model procedural steps or knowledge where, "social interactions enable humans to develop advanced thought through repeated interactions with more experienced individuals in a community" (Vanderburg, 2006, p. 375). The purpose of the scaffolding of activities then is to create a confluence of pressures–assignment/grade, social/interactive, time management, mathematical–within the classroom setting. These lead to student disequilibria and motivation to resolve internal conflict through internal dialogue and social interaction. Timely, targeted feedback strategies that foster student interactions can assist in creating these pressures and mollify extant conceptual conflicts (Jang & Stecklein, 2010).

Further, the utilization of interactive technology can affect instructional strategies and consequently student conceptual development. The adaption of instructional technologies allows for various kinds of scaffolding and efficient teacher feedback that is interactive, targeted, and timely (Dickerson et al., 2009; Evagorou & Acraamidou, 2008; Roschelle et al., 2007). However, technology can only be employed in situations within which stakeholders both accept and adapt to technology, like tablet PCs (Bulu & Peterson, 2010; Ge & Land, 2003). Teachers then must structure activities appropriately with sound instructional goals and must adjust to and become accustomed to new technologies with which they lack familiarity. This includes influencing students' attitudes and perceptions towards technology, creating an environment with a positive image of technology, and engaging support mechanisms to facilitate the use of tablet PCs (El-Gayar et al, 2011). In turn, they also must change their accompanying teaching practices. On the other hand, student learners also acclimate themselves to this new social-learning environment. They must have, or develop, useful learning habits and attitudes which align with the teacher's curriculum, and perhaps appropriate epistemological beliefs, so that they can learn effectively within constructivist type classrooms employing interactive technology. Moreover, their initial beliefs and attitudes about science and how learning occurs within this environment will then subsequently be affected drastically.

Therefore, the simple use of technology is not enough: The effective utilization of technology within a social constructivist classroom must involve intentional teacher scaffolding of activities, social construction of knowledge, and effective teacher feedback to learning stakeholders. This feeds into overall student acceptance and employment of interactive technology while also recognizing that student learners are in charge of their learning, and that subsequent teacher actions are thus reliant on student instantiation of their own learning. Along with this, an overall acceptance of technology by student learners along with an appropriate change of expectations within this environment should be expected.

Summary

Though there are clear advantages in utilizing technology in science classrooms, the simple engagement of technology is not enough. Technology, by itself, is simply a neutral carrier of pedagogy (Johnson, 2008). In current practice, simple presentation of content is not been shown affective in constructivist classrooms, and in general, the ordinary use of technology in science instruction does not account for differences in student achievement beyond those explained by instructor pedagogy (Simoni, 2011). New hardware like tablet PCs along with emerging multimedia, multi-modal environments, learning management systems and social networking possibilities has only recently been investigated.

On the other hand, instructional technology with careful and intentional focus on constructivist learning pedagogies, such as feedback, scaffolding, and purposeful inclusion of interactive activities, have shown promise in affecting student learning. Keeping in mind restrictions on funding, professional development opportunities, facilities, and staffing, technologically-mediated, interactive environments must be created and managed with effective pedagogical approaches for effective learning to occur. These results of these inclusions are increased student interactions, increased student motivation and enjoyment of learning while, at the same time, lessening learning demands and student dissatisfaction with learning environments.

Availability of technology combined with effective pedagogical practices then should be concerns of teachers. And it is clear that all science educators should therefore focus on sound instructional practices with instructional technologies in order to facilitate student achievement. The future of planned instructional technology seems to be bright, however. Given the rapidity of technological advances along with the advent of social networking in its many forms, new approaches will be developed by education researchers and employed in classrooms and should augur optimism in current and future leaders in education.

CHAPTER THREE

METHODS

In this chapter the researcher will outline the dissertation's methodological framework. This chapter discusses the research design and context, types of data collected, data analysis procedure, and the trustworthiness of the dissertation.

Research Design

This dissertation included two research questions: (1) How did the technology components, including DyKnow and tablet PCs, of an innovative, technology-enhanced, university-level physics course impact students' conceptual understanding in motion and force concepts? and (2) how did the interactive technology used with purposeful teacher feedback and scaffolding impact students' conceptual understanding in motion and force? For the first research question, the researcher examined what aspects of an innovative, technology-enhanced course that exploited tablet PCs and DyKnow Interactive Software, played a role in student conceptual development in force and motion concepts, and, for the second question, how and in what ways appropriate teacher strategies supported student conceptual development in force and motion concepts change during ongoing experiences in this instructional setting.

For the purpose of this research, a qualitative, multiple-case-study design was implemented. Qualitative research searches for understanding in complex social environments to uncover the meaning of phenomena for those involved (Merriam, 2009). By "accumulating sufficient knowledge to lead to understanding" (Lincoln & Guba, 1985, p. 227), qualitative research designs involve studying complex social processes, rely on the researcher as the primary instrument of collection, utilize an inductive research design, and make use of thick descriptions in analysis and interpretations (Merriam, 2009; Wolcott, 2001).

Case studies share many aspects of other types of qualitative research, but case studies are situated in, and focused on, the processes, events, and connections within a specific, bounded location (Miles & Huberman, 1994; Stake, 1995). According to Merriam (2009), the case of a case study is "what" will be studied and also acts as a unit of analysis, "a single entity, a unit around which there are boundaries" (p.40). "For it [the study] to be a case study, *one* particular program or *one* particular classroom of learners (a bounded system)… [is] selected on the basis of typicality, uniqueness, success, and so forth, would be the unit of analysis" (p.41). Case study designs are thus utilized to gain an in-depth understanding of a situation, its meaning for those involved, and attempts an "in-depth description and analysis of a bounded system" (Merriam, 2009, p. 40). This type of research design is especially suitable for educational research: the design allows for rich, in-depth descriptions and formative analyses in a single bounded setting, i.e. an authentic classroom environment, and enables maximum flexibility in gauging the interactions across various stake holders.

In this research, a multiple-case study methodology aimed to illustrate and detail the effects of novel uses of interactive technology along with various related activities on participants' growth in understanding of science concepts and to examine the various aspects contributing to this growth process. The dissertation focused on three students and their experiences within an introductory university physics course. These three individual students and their learning experiences within this course were the individual "cases" of the research. Choosing three different cases was intentional: each case individual could be studied, and then the cases compared and contrasted against each other. "By looking at a range of similar and contrasting cases, we can understand single-case finding, grounding it by specifying *how* and *where* and, if possible, *why* it carries on as it does," state Miles and Huberman (1994, p.29).

Research Context

School

This research project was set in a small catholic, co-educational, liberal arts and science university in the Midwest. The university has approximately twelve-hundred undergraduate students majoring in many diverse liberal arts areas and also a small assortment of professional graduate programs, including physical therapy, nursing, and business programs. The university, in its mission statement, encourages personal and intellectual growth, promotes global awareness and social responsibility, and attempts to deepen spiritual values. The university is predominately white with mostly middle-class students from the Midwest. All undergraduate students of the university are required to take at least one science course and the course's accompanying laboratory as part of each student's general education curriculum, while professional programs require either one particular science course or several different science courses as part of their individual programs. This research was conducted during an introductory, technology-enhanced physics course taught on campus at the school.

Introductory Physics Course

The introductory physics course served as research context for this research. The university's pre-existing one-semester course was taught by the researcher and lasted a total of four months during the school's fall term. This course represented part of the general curriculum in the small chemistry department at the university. This course functioned as a required "service course" for students majoring in athletic training, physical therapy, bio-chemistry, and several other fields. The course represented a core component of each student's science curriculum and was thus taken exclusively by students who were non-majors in physics while in their sophomore and junior levels in the university. The course focused on the basics of linear motion, forces, energy concepts, linear and angular momentum, and general rotation motions. The course had a total student population of roughly thirty students.

The course followed a traditional structure within a tertiary physics course. This course included two parts: lecture and laboratory. Both parts of the course were relevant for this dissertation. The lecture component of the course was the main venue for exposure to new science material and met three days per week for fifty minutes, while the laboratory component convened once per week for three hours and was designed for hands-on experimentation. The laboratory activities were coupled to the lecture component's course material. Students are required to purchase course materials for the course including one traditional, problems-based, physics text (Hewlett, 2011), a four-volume probe-based laboratory manual called "Workshop Physics Activity Guide" (Laws, 2004), and a video-analysis laboratory manual (Laws, Teese, Willis, & Cooney, 2009).

Course Environment

The course environment was unique. This course's environment was designed to help facilitate student conceptual understanding in a unique and novel way–by simultaneously introducing and blending two innovative, research-supported ideas into a university physics classroom. This course environment combined (1) interactive classroom technologies, and (2) classroom use of student-centered instructional approaches. Specifically, student-centered practices like intentional teacher feedback and scaffolding were supported by interactive technologies, including tablet PCs, DyKnow Interactive Software and classroom information technologies, like Moodle. The overall structure of this environment thus was different from most curricular and instructional methods in similar introductory, university-level physics courses at other schools. Moreover, this introduction and blending of innovations was examined to chart student development of science concepts.

Student-Centered Instructional Approaches Using Interactive Technologies

This course environment employed student-centered instructional approaches. This was accomplished by structuring course activities–both within lecture and laboratory– to take advantage of student-centered learning practices, like allowing for increased inter-student and student-teacher interactions through intentional teaching methods, providing purposeful teacher feedback, and enabling dynamic teacher scaffolding of student activities.

Classroom and Students

An outline of a typical course "lecture" and "laboratory", including student-centered learning activities and use of interactive technologies is described below. This includes the lecture room and layout, an overall class structure, and a general description of activities.

Physical Classroom Environment

The physics lecture room was a converted chemistry laboratory with multi-person tables and accompanying chairs, an instructor's demonstration table, and various cabinets and shelving for physics equipment. At each multi-person table, students had access to individual tablet PCs during course lectures. Tablet PCs were special computers with "inking" capabilities and came with an attached "stylus" on which student learners could mark the tablet's screen, thereby leaving an "inked" annotation on whatever software application that was in use at the time. Along with exploiting a whiteboard for course information, all course lecture material was transmitted to an overhead projector and to individual student learners via an interactive presentation program called DyKnow. Students then could view and manipulate the DyKnow "slides" on their individual tablet PCs.

Incorporation of Interactive Technology into the Course

Course lectures began each day with a brief, so-called "evolution" on DyKnow. The daily evolution was a short, two-minute mini-quiz in which each student group, say two or three learners clustered together based on seating proximity, was asked to articulate a written response to a general teacher prompt. This prompt was based on the previous day's reading assignment. Student groups then were expected to interpret each prompt together in their groups and formulate a common response from their group interactions. Each individual then could "ink" her written responses on the question's accompanying blank inking area displayed her tablet's screen. The prompts themselves were simple, open to interpretation and may, or may not, have involved simple calculations. For example, after a reading section on forces, student could have been expected to define "contact forces" and then explain how contact forces might affect an object's one-dimensional motion. After all responses were submitted electronically through the DyKnow software to the instructor, a large-group discussion took place and a common class sentiment of reaction articulated. The evolutions were intended to act as a common gateway to group conversations about science concepts and thus were not intended to be overly challenging for the individual group pairings. Rather, evolutions could be considered a warm-up or starter for conversations for each day's activities.

After the daily evolution, the instructor used DyKnow Interactive software and pre-formatted DyKnow slides to (1) outline the class's daily learning objectives, (2) act as a framework for content dissemination and setting up of student activities, and (3) means to facilitate large-group class discussions along the stated topics. The teacher acted as *mediator* and attempted to shape discussion about learning concepts through asking questions and facilitating discussion. Pre-formatted DyKnow interactive slides assisted to transmit and share physics content in much the same way as a typical PowerPoint presentation format would, with varying slides, choices of colors, shapes and formats with the ability to transition between slides. In addition, DyKnow slides could be “inked” on, employed interactive linking to external web browsers, and allowed for inter-group sharing with the whole class via a connected overhead projector. Moreover, the individual instructor also had the choice of the sequence and/or omission of different slides and thus had the ability to “think on the fly” and thus adjust the structure and orientation of the individual class activities, i.e. offer feedback on student learning based on student progress. Importantly for physics, the DyKnow slides also permitted student learners to operate the stylus to manipulate mathematical and algebraic forms. DyKnow also allowed each student to compose written strings in order to solve complex problems on the class slides. Further, fully functioning websites, hyper-linking, interactive polls, student status checks, replays of inking, ability for students to take notes on slides, and the creation of collaborative groupings also were integrated into the learning environment (Van Mantgem, 2008). DyKnow slides were therefore designed and implemented to increase the amount of student-student and student-teacher interactions and enable group problem solving. Teacher feedback and scaffolding in the courses were therefore “built-in” to the technology.

Lastly, at the end of the class period, students were asked to save their individual DyKnow notes. These notes were saved to a dedicated DyKnow server or on their individual flash drives. The DyKnow storage service was purchased by the department so that students would have outside access to their DyKnow notes. When registering for the course, each individual was assigned a unique and password protected account. Students also were advised to download the DyKnow program, free of charge, at their place of residence in order to access these notes.

After the class was completed, the instructor posted a print off, i.e. pdf file, of the DyKnow slides from that period. This file was then posted to the Moodle course site.

Moodle Course Site

The Moodle Course Management System was an important feature of this research. Upon registering for classes, all individual student learners at the university were assigned individual access to the university's Moodle site. The Moodle Course Management System is a highly regarded course management system utilized by many schools and universities. Course management systems, in general, offer educators a means of communicating and enabling instruction outside of the physical bounds of the classroom. On its website, Moodle is described as "learning management system" and is a "free web application that educators can use to create effective online learning sites." "Moodle is a software package for producing Internet-based courses and web sites. It is a global development project designed to support a social constructionist framework of education" (Moodle Website, 2013).

Each individual course also had a dedicated area in each student learner's Moodle site. Instructors of each course thus had the ability to use this Moodle area as a means of communication and dissemination of course material. For example, a link to course syllabus added to the Moodle area to be accessed and viewed by individual students outside of the classroom. In this research, the Moodle course area was used extensively. Besides a means of displaying archived course activities, like class slides and notes, the Moodle area for physics was utilized as a place for scheduling, displaying class outlines and objectives, and presenting myriad course-related documents. Also, each day before class a list of classroom objectives was posted to the individual student's Moodle area so that student learners could anticipate relevant science topics and could thus could be prepared to take part in conversation during class time.

Laboratory Learning Experiences

In-depth, hands-on experiences and recitation (i.e. problem-solving sessions) were combined into a once-a-week, three-hour block. This *Collaboratory* served to underscore the conversational part of class and was focused on student inquiry in a technologically enhanced setting. Laboratory aimed to apply the theoretical principles developed in that weeks' classroom conversations to real-life, everyday situations. Laboratories occurred in the same interactive classroom space as lectures and also incorporated tablet PCs, various physics equipment, and data collection devices. Laboratories were wide ranging in format and were intentionally designed to support both small and large group types of communities. The laboratory texts included a four-volume, probe-based laboratory manual set called "Workshop Physics Activity Guide" (Laws, 2004) and a video-analysis laboratory manual (Laws, Teese, Willis, & Cooney, 2009).

All laboratories first began by arranging students into small groups. These student groups then were instructed to work through different, pre-formatted activities in the course laboratory texts, which covered general concepts in physics like one-dimensional motion. These activities were purposefully chosen by the instructor to match that week's lecture discussions. During a particular lab, student groups were directed first to complete a suite of activities from a "Workshop Physics" module about one-dimensional motion (or 1-D Kinematics). As the activities continued, each student group was asked to begin drawing conclusions, i.e. begin making claims backed by evidence, which could be then communicated to other groups.

During the second half of the laboratory, students shared with other groups their collected data and conclusions in large-group presentations. All student groups were directed to summarize their laboratory experience. This involved presenting to the whole class what their beginning questions were and how they would back their "claims" with sources of "evidence." This included step-by-step explanation of steps involved during the experiment and presentation of a limited number of claims backed by evidence. This was then followed by a short question-and-answer time during which other groups could ask for clarification, air any comments, criticize and/or critique arguments made by the presenting group. Finally, after all small group presentations, laboratory concepts were summarized in a large-group discussion facilitated by the instructor, which included class discussion on common themes, important overall results, and resolving group differences in interpretation in claims.

The intended result of these activities was to form a set of common explanations and themes that moved towards a notion of group convergence and coherence of ideas about what occurred during those particular laboratory experiences (Woodruff &Meyer, 1997). These types of dual settings–small and large group interactions–were intended to assist students to produce a better understanding of the reading material, improve observation skills, enhance his or her interpersonal expertise, and learn useful lab habits while also generating, challenging, and coalescing around commonly articulated themes and explanations about events in nature. Woodruff and Meyer state that "small group discourse is conducive to generating explanations, while the inter-group discussions challenged the acceptability of the ideas students generated" and that "small intra-group formats tend to work to solve problems, large inter-group format tended to identify issues that had not been solved" (p. 30) in small groups.

Structured Problem-Solving Exercises

Structured exercises are important in physics as a way for student learners to become acquainted with real-life, real-world applications of physics concepts and also to gain experience with the use and manipulation of mathematical relationships. As a part of this course, students were assigned several word problems from a traditional physics text. Ordinarily these problems are solved in a linear process: (a) reviewing the problem and looking up the correct physics equations/relationship; (b) employing a problem-solving strategy developed in the course text; (c) manipulating the equation/relationship to find a correct physical answer; and lastly, (d) checking the answer for correctness by either comparing to the text's answer or by validating the "approximate" nature of the answer to a real-life situation. For most students, words and explanations ordinarily take a secondary role to algebraic manipulations and are therefore omitted in lieu of teacher direction. In this course, however, students–as individuals but sometimes in groups–were directed to not only find the correct physical answers but also to construct their answers using a "word structure." This teacher-directed word structure first led students to orient their responses using an introduction, body, conclusion within responses and then, as students became more advanced, promoted innovative applications of concepts and in-depth explanations of real-life implications. This then forced learners to formulate explanations in written, narrative form and also to engage advanced conceptual frameworks to explain, in words, the significance and application of their answers. This structure thus represented a teacher scaffold: it forced students to employ a directed structure that assisted in guiding student to use language and problem-solving skills in tandem to orient their answer and also to engage advanced reasoning to find the "correct answer." All written activities were explained in advance with each aspect of the text production explicated in full. Activities were submitted and scored with a specific rubric generated by the instructor.

Table 1 shows the various course elements of the environment along with if the element emphasizes student interactions, intentional teacher feedback, and purposeful teacher scaffolding.

Instructor

This course was taught by the researcher. The researcher is currently a doctoral student in science education at the University of Iowa and has taught at this particular university course for a dozen years. The researcher is in his early 40s, white, and from a small town in the Midwest near to the institution.

Table 1. Course Element and Areas of Emphasis

Course Element	Student Interactions	Teacher Feedback	Teacher Scaffolding
Overall use of DyKnow Software tablet PCs and Moodle	Yes	Yes	Yes
Class Evolution	Yes	Yes	No
Discussions during Lecture	Yes	Yes	Yes
Various DyKnow Tools (use of stylus, group sharing, polling, etc.)	Yes	No	Yes
Moodle Course Site	No	Yes	Yes
Structured Problem-Solving Activities	No	Yes	Yes

The researcher acted both as course instructor and as a *participant as observer* (Merriam, 2009). According to Merriam (2009), a *participant as observer's* identity and activities are known to the research participants in the setting but “are subordinate to the researcher's role as a participant” (p.124). Merriam notes that this stance is similar to Adler and Adler's “active membership role” (as cited in Merriam, 2009, p.124) where a researcher is “involved in the setting's central activities, assuming responsibilities that advance the group, but without fully committing themselves to members' values and goals.” Therefore, the instructor had participatory obligations in the course, led conservations and prodded participants, while at the same time assumed the role of instructor, assigned course grades, and organized course activities.

Before research commenced, each of the three students signed a release form. This form underscored a number of protections for the student during this research, including confidentiality/privacy, preventing physical harm, and importantly, stating that all results will then be interpreted at the school after all course grades have been assigned. The school's institutional review board approved the release form and all analysis of classroom artifacts was done with the understanding that any student input for feedback would not affect grading of those artifacts or each individual student's grade in general. Moreover, the researcher had a frank and open relationship with each of the student participants. The institution is small and is customary that each instructor knows his/her students by name and has frequent interactions with those students. The researcher made it clear before research began that any student advice would be welcomed and any constructive criticism would not affect grades in any way.

Participants

For the purposes of this dissertation, individual students were the cases and were selected from the student population in an algebra-based introductory physics course taught by the researcher. The participants were from allied health fields (athletic training, physical therapy, pre-Med, Bio-Chemistry) and therefore were non-majors in physics. All students in the course were required for their majors to take this physics course, and importantly before enrolling in this physics course, had little prior exposure to tablet PC use and DyKnow software in other courses. The participants were from the Midwest, in their second or third years at university and with similar socio-economic backgrounds.

Three student research participants were culled from a total student population of roughly thirty students. All students in the course first were assessed early in the term using a baseline standardized concept inventory for forces and motion in general physics, called the Force and Motion Conceptual Evaluation (FMCE) (Thornton & Sokoloff, 1998; Ramlo, 2008; Smith & Wittmann, 2008). This inventory was intended to gauge the level of science understanding of forces and motion prior to sample selection (and later to assist in tracing student conceptual development in force and motion concepts). Three students then were chosen intentionally from the results of this inventory to represent the high-, middle-, and bottom-thirds of the population's baseline understanding of force and motion concepts. These participants were selected two weeks before formal instruction on force concepts commenced. And each participant took part in all regular activities of the course and was asked to participate in four extended, outside interviews with the researcher.

Lauren was a 22-year-old, white female student, majoring in biology and pre-physical therapy. She was from a middle-class economic background and intended to enter the graduate program in physical therapy at the university. When she was in her mid-teens, she moved to a small town in central Iowa from the East Coast after her father changed jobs. Lauren represented a middle-level of preliminary conceptual knowledge of motion and force concepts in this dissertation.

Jeffrey was a 21-year-old, white male student from a small town in northwestern Illinois, majoring in athletic training and pre-physical therapy. He was from a middle-class economic background and aimed to enter graduate school in physical therapy at the university. Jeffrey was a member of two intercollegiate sports teams on campus and served as resident assistant in one of the dormitories at the university. Jeffrey represented a low-level of preliminary conceptual knowledge of motion and force concepts in this study.

George was a 20-year-old, African-American male student, majoring in pre-med and biology. He was from a large city in northeast Iowa, came from a middle-class economic background, and intended to enter graduate school in the field of dentistry. George worked as a resident assistant in one of the dormitories at the university. George represented a high-level of preliminary conceptual knowledge of motion and force concepts in this study.

Data Collection

To aid in answering the overall research questions, research data was collected from multiple sources. Data collection represents "asking, watching, and reviewing" (Merriam, 2009, p. 85) and was in the form of interviews, observations, and documents. In this emergent research, each source of data was collected to inform the analysis of each *case*, i.e. each student learner, and focused on the *processes* and *events* relevant to the research focus within the research setting, i.e. within a university-level physics classroom, which utilized interactive technologies. In particular, all data gathered was intended to clarify and inform how the blending of interactive technologies, teacher feedback, and scaffolding influenced student conceptual understanding of motion and forces in physics.

Data collection took place during lecture and laboratories sections of the course for four months. All data gathered was from one of two different lecture sections of the course and from three different laboratories sections that ran concurrently to the lecture portions but on different days. The researcher was the primary instrument of data collection in these sections and acted as a *participant as observer* in the course, partaking in discussions and codifying results.

Relevant data for this research was categorized into (a) interviews with the participating students, (b) researcher's field-notes and videos of classroom activities, and (c) documents and written artifacts collected from the research subjects. All data, except individual student interviews, was integrated as part of the regular course design.

Interviews

Interviews are "conversations with a purpose" (Merriam, 1998, p.136). The main objective of interviews is to "obtain a special kind of information" relevant to the research and are "person-to-person encounters in which one person elicits information from another" (Merriam, 1998, p.71). Interviews enable respondents to reconstruct the past and interpret the present (Lincoln & Guba, 1984). Thus, they are events in which a research subject can expound and delineate her understandings, recollections, and other relevant ideas for the researcher.

During this research, four individual, semi-structured student interviews were conducted with each research participant. A unique, semi-structured interview protocol (Merriam, 2009) created by the researcher was utilized for each individual interview. Structured interviews protocols help to focus the conversation, reduce superfluous information and also serve as a way to standardize the interviews amongst different research participants so that common research themes and patterns might emerge (Miles & Huberman, 1994). Each interview was formatted into sections aimed at exploring specific processes of student learning and events experienced by the student learner within the classroom (c.f. Appendix A for a sample interview protocol). Due to the fact that the researcher did not know ahead of time how each interview would progress (Merriam, 2009), the order and wording of the specific questions on the interview protocols was altered to suit the flow in the lines of questioning. This sequencing was based on-going researcher interpretation of student responses to the interview questions and also on the analysis of post-interview analysis of individual interview transcripts.

Each interview focused on questions designed to elicit the effect of interactive technologies on student conceptual development (Research Question 1) in the core concepts of motion and forces. These concepts were adapted from the Science Literary Maps in the National Science Digital Library (2012), including (a) how net external forces cause changes in motion, (b) possible relationships of changes in motion to applied forces and the masses of the objects, (c) how forces between two different bodies relate, and (d) student knowledge of the gravitational force and how the four fundamental forces of nature interact. Further, during each interview student participants were asked how, and in what ways, particular aspects of the technology-enhanced classroom instruction, e.g., DyKnow interactive technology, intentional teaching strategies, and group collaborations, influenced their conceptual understanding (Research Question 1). Finally, students were asked about the effectiveness of teacher strategies for use of interactive technology (Research Question 2), i.e. teacher scaffolding and feedback opportunities within the classroom setting.

Each forty-five minute interview was recorded using a standard video recorder and then transcribed into written form by the researcher after each interview. All transcripts will be sent to participants for member checking to ensure transcribing accuracy. Extensive interview notes were taken as each student participant responded to interview questions. This assisted in observing elements that are not readily apparent in visual or audible forms.

The interviews themselves were administered at specific points of interest throughout the term. The ordering of individual interviews hewed mostly with the ordering of the month of instruction, i.e. the first interview occurred within the first month of the term, with the interview taking place during instruction on the first unit, linear motion, but before formal instruction on force or energy concepts. The first interview therefore occurred in the first month of the course after selection of research participants and served as an initial research marker for each student. Table 2 shows the interview schedule, including the relative scheduling of the various interviews, the individual month of the interview administration, previously covered concepts before the interview, and concepts not covered before the interview.

The second interview occurred during instruction on force concepts but after formal instruction on motion. This interview occurred in the second month of the course and functioned to gauge the impact of instruction on motion concepts on student conceptual understanding of force concepts. The third interview took place in the third month of the term after formal instruction on motion and force concepts but during instruction on energy concepts. This interview helped measure how student conceptual development in force concepts had evolved through advanced exposure to motion concepts and also to formal instruction on force concepts. The last interview occurred after formal instruction in all three general areas and ensued during the last month of the term. This interview functioned as a final general indicator of student conceptual development and utilization of interactive technologies. It was the most detailed and longest in duration. Specific interview protocols are shown in the Appendix B.

Table 2. Preliminary Interview Schedule

Interview	Month of Interview	Previously covered concepts before interview	Concepts not covered before interview
First	First	None	Linear motion, Forces, and Energy
Second	Second	Linear motion	Forces, Energy
Third	Third	Linear motion, Forces	Energy
Fourth	Fourth	Linear motion, Forces, and Energy	None

Observations

Observations are a major source of data in qualitative research. Observations are different than interviews in that observations transpire in the setting where the phenomena of interest are taking place and stand as a first-hand researcher view of various phenomena (Merriam, 2009). Observations in this study were intended to help the researcher gain insight into what is happening during various activities, including what interactions are taking place amongst students and teacher, employment of interactive technologies, and evidence of progressions in student conceptual development. During this dissertation, the researcher had extended contact with all participants within the research setting. Researcher observations were in the form of researcher field-notes and videotaping of classroom activities.

Classroom Videos

Along with researcher field-notes, various classroom experiences were video-taped using a small "flip camera" mounted on a tripod. These classroom and laboratory videos provided an alternate view of the course activities and visuals and acted as a means for the researcher to get a second look at any evidence of interest occurring in the classroom but not caught by the researcher in real-time observation or field-note scrutiny. This includes student utilization of interactive technology occurring in the classroom or indications of effective, yet hidden to the observer, teaching strategies. Since no other staff member was available to assist in taping, the entire classroom, not just the research participants, was videotaped.

Classroom experiences were videotaped during instruction on the three major course units, including linear motion, forces and energy. Five videos, each lasting 50 minutes, were taken during each particular unit, for a total of roughly 15 classroom videos. The video camera were introduced on the first day of class—to reduce student anxiety at the prospect of being videotaped–and were set up in the back of the classroom for full-classroom observation. Table 3 shows the type of observation, number of observations per time unit, units of time, and the total number of observations acquired.

Table 3. Numbers of Observations

Observation	Number/Unit of Time	Units of Time	Total Number
Video-taping of course discussions	5	3	15

Researcher's Field-notes

Extensive field-notes and observations were taken. Observations of each research participant in the classroom were in the form of teacher field-notes, articulated immediately after each classroom experience. This was necessary given that the researcher's role as participant and observer, for it would have been impossible to take real-time notes within the research setting. These delayed observations centered on the relevant research aspects of that particular classroom period and took the form of running notes of each student participant's unique classroom activity for that period. Selective focus was placed on observational evidence of student conceptual development of motion and force concepts, and individual employment of instructional technologies. Early observations were "unstructured" observations, i.e. "a stage of immersion permit[ting] an observer to expand his or her tacit knowledge and to develop some sense of what is seminal or salient" (Lincoln & Guba, 1985, p.275), thereby gaining insight into the research setting that later be employed as reference points for subsequent interviews or observations (Merriam, 2009). Later observations became more focused as "insight and information grow" (Lincoln & Guba, 1984, pp. 275). A thick field-note journal was used to record and comment on observations of student subjects relating to the research questions.

Documents

According to Lincoln and Guba (1985), documents and records are any written or recorded material that is accumulated by the researcher during his/her exposure to the research setting. Documents are stable, non-reactive, sources of data from the research setting that "may accurately reflect situations that occurred at some time in the past" (p.276). They are rich sources of information set in the natural language of the setting and include items not "prepared specifically" for the researcher. Table 4 lists the various types of documents and the approximate number of artifacts collected.

Table 4. Types and Numbers of Documents Collected/Research Participant

Types of Documents	Number of Documents Collected/Research Participant
Problem-Solving Artifacts	7
Structured Writing Activities	1
Course Examinations	3
Force and Motion Conceptual Evaluation (FMCE)	2
Maryland Physics Expectations Survey (MPEX)	2
Various DyKnow Related Artifacts and other electronic submissions (Evolutions, interactive group activities, in-class quizzes, class polling and laboratory files)	Numerous

Various documents were collected from research participants, before and after instruction in motion and force concepts, to help inform the research questions. In the this project, these multiple written documents included (1) individual student problem-solving and structured writing activities, (2) written course examinations, (3) student surveys, including pre- and post-unit Force and Motion Conceptual Evaluations (FMCE), and Maryland Physics Expectations Surveys (MPEX), and (4) various DyKnow-related electronic artifacts. All documents were intended to inform how, and in what ways, student conceptual development in motion and forces had progressed during classroom activities. Artifacts from these were collected, marked, re-distributed, and re-collected to student participants into to assist in determining students' overall conceptual growth during the course activities.

Problem-solving artifacts

In nearly all university-level, introductory physics courses, students are assigned word problems from a textbook resource. These "word problems" are intended to give student learners experience with science questions which reflect real-life situations. In this research, word problems "center[ed] on each student's understanding of nature of physics including the building of relationships and interconnections and their mathematical underpinnings" (Stecklein, 2011, pp. 3). Text problems were assigned from a list of available word problems from end-of-the-chapter lists in the course textbook and were chosen intentionally to assist in evaluating student learning in chapters relating to motion and forces. Correct numerical answers were readily available from answer keys, enabling quick and objective assessment of student work. In this research, seven "word problem" assignments will be assigned, collected, marked and archived for analysis, c.f. Table 4.

Structured writing activities

One structured writing activity was also given as part of the research. In this writing activity, participants were asked to vary the *topic*, *type*, *purpose*, *audienc*e and *method of text production* of their science writing based on the writing structure outlined by Hand and Prain (1996). The writing activities were intended to help student build their science knowledge through writing, specifically by invoking a formal writing framework. This written activities was intended to assist the researcher in evaluating not only conceptual knowledge but also how conceptual knowledge had involved. A standard researcher-generated rubric was then used to inform analysis and reflected different structured elements of student writing. The researcher utilized this rubric to assess the quality and uncover evidence of conceptual development in individual writing artifacts. In this research, one structured writing activity was assigned, collected, marked and archived for analysis, c.f. Table 4.

Written course examinations

Three open-book, open-note written examinations were administered throughout data collection. The exams were formatted similarly to the writing activity, i.e. using rubrics specifically constructed for each examination, and like the writing assignment, designed to gauge student conceptual development and preferences. The exams were administered roughly once every five weeks, i.e. fifth, tenth and final weeks of the course, and subsequently were marked by the researcher. The three exams were in-class, open-book writing activities, c.f. Table 4.

Student Surveys

Force and Motion Conceptual Evaluation (FMCE) and Maryland Physics Expectations Survey (MPEX*)*

Two different physics surveys were administered to all students in the course before and after subsequent instruction on motion and force concepts. Responses to these surveys served to help the researcher understand how students' conceptual knowledge of motion and forces changed throughout the course and how various interactive technologies and applicable teaching techniques using those technologies affected student learning.

The first administration of the *Force and Motion Conceptual Evaluation (FMCE)* functioned as a pre-test conceptual knowledge score for research participants. The FMCE is described by Ramblo (2008) and Smith and Wittmann (2008) as a valuable instrument for measuring students' conceptual ecologies and learning for motion and forces, and for large numbers of student, the FMCE has been shown to be reliable and a valid measure of student conceptual understanding of motion and force concepts. The FMCE is a 47-question, multiple-choice assessment employed to gauge and analyze student responses within five clusters, including velocity, acceleration, force (Newton's First and Second Laws), Newton's Third Law, and energy. A second administration of the Force and Motion Conceptual Evaluation (FMCE) took place at mid-term after course units on motion and force concepts.

Student science preferences were also assessed through the administration of the Maryland Physics Preference Survey (MPEX) before classroom instruction on motion and force concepts. The *Maryland Physics Expectation Survey* (MPEX) was given concurrently with the FMCE and explored student attitudes and beliefs about university physics and how those attitudes and beliefs changed as a result of physics instruction (Redish et al., 1998). The MPEX is a 34-item, agree or disagree survey, employing a five-point Likert-scale to assess student attitudes, beliefs, and assumptions about physics (Dalagan & Mistade, 2010). The survey involved dimensions including student independence in physics, student coherence of physics concepts, linking of physics to real-life experiences, how mathematics and physics connect, and student effort in physics. Wittman defines expectations as the "attitudes, beliefs about the classroom, and epistemologies that students bring to the classroom," (2002b, p.2) and declares that the MPEX "could be used to predict if students have the appropriate attitudes and expectations for successful conceptual learning" (2002a, p.1). Redish, Steinberg, and Saul note:

> It is not only physics concepts that a student brings into the physics classroom. Each student, based on his or her own experiences, brings to the physics class a set of attitudes, beliefs, and assumptions about what sorts of things they will learn, what skills will be required, and what they will be expected to do. (p.2)

They define each of the categories as:

> *Independence* [includes] beliefs about learning physics–whether it means receiving information or involves an active process of reconstructing one's own understanding;
>
> *Coherence* [includes] beliefs about the structure of physics knowledge–as a collection of isolated pieces or as a single coherent system;
>
> *Concepts* [includes] beliefs about the content of physics knowledge–as formulas or as concepts that underlie the formulas.

> *Reality Link* [includes] beliefs about the connection between physics and reality–whether physics is unrelated to experiences outside the classroom or whether it is useful to think about them together;
>
> *Math Link* [includes] beliefs about the role of mathematics in learning physics–whether the mathematical formalism is used as a way of representing information about physical phenomena or mathematics is just used to calculate numbers;
>
> *Effort* [includes] beliefs about the kind of activities and work necessary to make sense out of physics–whether they expect to think carefully and evaluate what they are doing based. (p.4)

Therefore, the assessment serves to gauge student's beliefs about the various categories and the evaluation of the test is compared to expert responses. Each of the student responses in various categories are then deemed favorable or unfavorable based on whether or not they agree with expert opinion. Finally, normalized movement in favorable or unfavorable responses is gauged by an Excel template constructed by the researchers (The Physics Education Research Laboratory, 2012).

The comparison of the various FMCE and MPEX scores assisted in gauging each student's conceptual development and physics beliefs and assumptions related to the dissertation's research questions. [1] Copies of these inventories are provided in Appendices A and B, respectively. FMCE and MPEX Surveys were administered a total of three and two times, respectively, c.f. Table 4.

Various DyKnow-related tools

Numerous teacher DyKnow presentations and frequently used interactive activities, including evolutions, interactive group activities, inter-group class responses, in-class quizzes, class multiple-choice/yes-no polling, and other "interactives," were archived extensively. See Table 4. Depending on the course material and the topic of each unique classroom period, teacher slides were formulated using DyKnow with

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[1] See p.9 for this dissertation's research questions

different interactive activities. Each was archived after each class period. All research participants were requested to save and submit in-class student DyKnow activities for further analysis. Particular focus also was placed on learner use of technology, including annotated "lecture note" examples and responses connected to teacher feedback and scaffolding techniques. All relevant data was collected to supplement researcher observations and field-notes. Responses to these tools assisted the researcher to understand how students' conceptual knowledge of motion and forces changes throughout the courses.

Data Analysis

Data analysis represents the process of systematically searching, arranging and interpreting interview data, field-notes, and other materials to increase researcher understanding of a research setting (Miles & Huberman, 1994). In data analysis, qualitative data is continually reviewed and re-oriented to discover new and emerging themes and patterns (Merriam, 2009). This typically blends three main ingredients, including data description, data analysis, and subsequent interpretation, which leads researcher conclusions (Walcott, 1994). Analysis enables the researcher to present to others what he or she has discovered and is "recursive and dynamic" (Merriam, 2009, p.169). According to Bogdan and Biklen (1982, p.145), "Analysis involves working with data, organizing it, breaking it into manageable units, synthesizing it, searching for patterns, discovering what is important and what is to be learned, and deciding what you will tell others."

Data analysis for this dissertation took place throughout and after the term of the course. Data was arranged, sorted, analyzed, and re-interpreted across several levels, including documental, interview, and observational levels. All data, including interviews, writing artifacts, assessment rubrics, and student surveys, was examined with particular attention paid to how interactive technologies affected student conceptual development. Quantitative measures, like surveys, were scored immediately after administration; more qualitative ones, like interviews, written artifacts, and assessments, were assessed continually.

Analysis of Quantitative Data

Quantitative both measures–Force and Motion Conceptual Evaluation and Maryland Physics Expectation Survey–were scored immediately after administration and informed the dissertation's research questions.

Force and Motion Conceptual Evaluation (FMCE) artifacts for each student participant were marked, and compared to standardized scoring methodologies (The Physics Education Research Laboratory, 2012; Thronton & Sokoloff, 1998: Smith & Wittman, 2008). The scoring of the FMCE survey was based on an Excel spreadsheet template developed by the researchers, using a standardized scoring template, which according to Smith and Wittmann (2008):

> Automatically scores each response is correct or incorrect, groups questions into the aforementioned clusters, and calculates a class's normalized gain for each cluster as well as over the entire test. This template has become widely used due to its availability insisting analysis of students' responses. (p.1)

After individual student scores from the pre-and post-instructional administrations of the test were inputted into the template, the template then "divides[d] the questions into content-based clusters and evaluates[d] the correctness of each student's responses within each cluster as well as over the entire test" (Smith & Wittman, 2008, p.1). The clusters include questions on velocity, acceleration, force (Newton's First and Second Laws), Newton's Third law, and energy. For this research, these clusters were further subdivided according to analysis of Smith and Wittman. This included questions relating to force on a moving sled, object reversing direction, force graphs, acceleration graphs, Newton's Third Law, velocity graphs, and energy. The FMCE survey then functioned as a secondary means of informing how, and in what ways, individual student had built their conceptual understanding of force and motion concepts throughout their exposure to this technology enhanced classroom environment.

The other survey, The Maryland Physics Expectation Survey or (MPEX) (Redish, et al., 1998), was analyzed in a slightly different way. The MPEX survey served to measure how student attitudes, beliefs and assumptions about physics evolved throughout their experiences within this environment. The survey was designed as a mixture of different types of student expectation questions in varying order. Questions related to different categories of student expectations, including independence, coherence, concepts, link to reality, math link, and effort.[2] Questions on this survey were structured to "agree" or "disagree" with more "expert" opinion and are thus designed to elicit different types of answers in order to help insure reliability of responses (Dalagan & Mistades, 2010). Scores were analyzed using a special Excel template that codified the student results in a numerical and statistically meaningful way (The Physics Education Research Laboratory, 2012). Responses were deemed "favorable" if the view agreed with mature scientists or experts or "unfavorable" if the view agreed with beginning students or novices. The template then displayed overall percentages of favorable responses for pre-and post-administrations of the test and also presents gains (or losses) amongst the different categories of student expectations.

Analysis of Qualitative Data

Qualitative data analysis for this research dissertation began with the study's research questions. A representation of the qualitative data analysis is displayed in Figure 1.

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[2] See the MPEX discussion on pp. 59-61

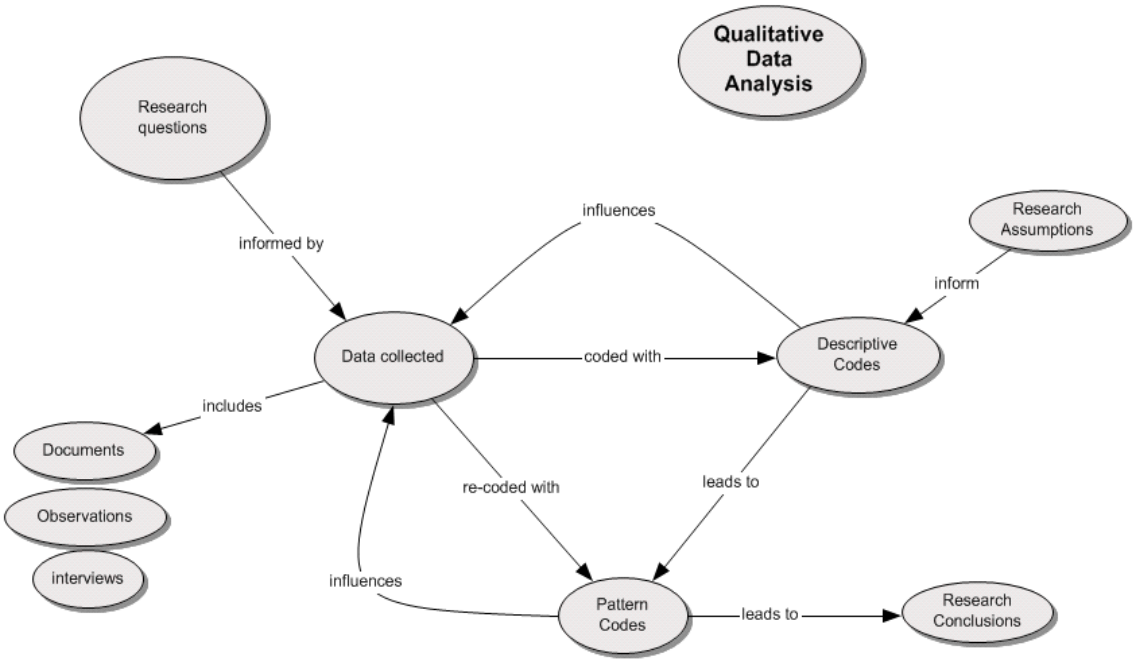

Figure 1. Flow Chart of Qualitative Data Analysis

First, the data was collected, in the form of documents, observations, and interviews within the research setting. The data was then transcribed if necessary and initially coded, using preliminary *descriptive codes* with researcher-generated coding tables based on initial research assumptions. This was facilitated by a commercially available coding software program called ATLAS.ti. Preliminary descriptive codes are shown in Table 5.

This initial coding then influenced subsequent data collection and led to *pattern codes*. This took place as the researcher developed patterns, connections, and interpretations of collected data for each research participant. These pattern codes will then influenced subsequent data collection: new data was coded using a developing set of codes articulated from both the descriptive and pattern codes. This iterative process of coding and re-coding of incoming data continued for each participant until *saturation*

Table 5. Initial Coding Table

Name of Code	Focus of Research	Concept	Description
MOTION CHANGE	Force and Motion	How net external force causes changes in motion	Student demonstrate knowledge of net external force causing changes in motion
MASS EFFECT	Force and Motion	Relationships of changes in motion to applied forces and the mass of the object	Student demonstrate knowledge of relationships of changes in motion to applied forces and the mass of the object
CONTACT	Force and Motion	How forces between two different bodies relate	Student demonstrate knowledge of how forces between two different bodies relate
GRAVITY/FUND	Force and Motion	Student knowledge of the gravitational force and how the four fundamental forces of nature interact	Student demonstrate knowledge of the gravitational force and how the four fundamental forces of nature interact
TAB	Interactive Technology	Use of tablet PC	Student demonstrate use of tablet PC
DYK	Interactive Technology	Use of DyKnow	Student demonstrate use of DyKnow
DYK-ACT	Interactive Technology	DyKnow Activities	Student employ DyKnow activities
INTER-ACT	Interactive Technology	Inter-group (across) interactive activities	Student demonstrate in inter-group (across) interactive activities
INTRA-ACT	Interactive Technology	Intra-group (within) interactive activities	Student demonstrate in intra-group (within) interactive activities
INDEPEND	Perception	Student independence	Student demonstrate independence in activities
COHERENCE	Perception	Coherence of physics concepts	Student demonstrate belief in coherence of physics concepts in activities
CONCEPTS	Perception	Physics Concepts	Student demonstrate belief in physics conceptual knowledge in activities
REALITY	Perception	Link physics with reality	Student demonstrate belief in linkage between physics with reality
MATH	Perception	Mathematics and physics	Student demonstrate belief in linkage between mathematics and physics
EFFORT	Perception	Student effort	Student demonstrate belief in linkage between conceptual advancement and student effort in activities

occurred. Finally, research conclusions were developed for each participant and cross-case interpretations made.

After each of the three cases was analyzed separately, i.e. in-case description, a larger grain written analysis was undertaken in which common themes were then noted across participants, i.e. cross-case description.

Participant interviews were coded throughout the study. First, interviews were transcribed as soon as possible after each interview. Each interview audio and transcript was then reviewed and coded for evidence relating to the research questions immediately after the individual transcript became available. A descriptive coding scheme was employed, and then as patterns and processes emerged, these artifacts were re-examined for new and emerging evidence relating to the research questions. After all four interviews had been viewed and re-examined, a common set of researcher impressions was articulated. Also, participants were also invited to offer feedback on verbatim transcriptions, i.e. they were asked to review transcriptions for accuracy and check preliminary results for errors, therefore providing an initial "member check" on the interviews.

Analysis of classroom videotape samples focused on classroom instances of the utilization of interactive technology and evidence of student conceptual development in motion and forces concepts. Each of the fifteen lectures was reviewed immediately after taping for research evidence. Aided by relevant field-note observations, each video was parsed into shorter clips of interest for more in-depth analysis. These video segmentations were based on identification of critical instances of research interest that occurred in the classroom on that particular day. These instances included classroom occurrences and events not specifically planned by the instructor, important student interactions of significance, relevant classroom surprises, uses of interactive technologies, and profound teaching strategies. These video clip instances were then transcribed and loaded into ATLAS.ti for coding. Then, the researcher read and analyzed each clip for indications of particular aspects of the course that may have affected student conceptual development or preferences and also for hints of student reactions and impact of specific interactive technology use in the classroom. Each clip was coded, first with the preliminary coding scheme and then, as the coding developed, re-coded for emerging categories, patterns and processes.

All hard-bound documents of the individuals were accessible only to the researcher. All relevant data was stored in a safe location. Scanned copies of the each artifact then were loaded into ATLAS and a numbering framework was automatically given to each document by the software. Given the small number of participants no coding catalog was kept for participants, but each individual artifact was given a number by the software program.

Coding

Coding is a process that enables the researcher to identify meaningful data and sets the stage for interpreting and drawing conclusions within qualitative research settings (Miles & Huberman, 1994). Codes are tags, labels, or bins for assigning units of meaning to the descriptive or inferential information complied during the study (Miles & Huberman, 1994; Lincoln & Guba, 1985). Miles and Huberman (1994) describe this flexible process of analysis through coding. They state:

> Initial data are collected, written up, and reviewed line by line…. Beside or below each paragraph, categories, or labels are generated and a list of them grows. The labels are reviewed, and typically, a slightly more abstract category is attributed to several incidents or observations. The incident then can be put onto a qualitative data category (p. 58).

Each artifact in this dissertation was initially coded using preliminary codes relating to the research questions. These preliminary codes were informed by the general conceptual framework and research questions of the dissertation and continually reviewed for new and emerging themes, linkages, and patterns. All codes were first *descriptive codes* and given a descriptive name. These codes were defined generally with a narrative description on preliminary “coding table”, c.f. Table 5. The initial coding table was employed as a tool to summarize segments of data and to trace student

conceptual understanding of force and motion concepts and also to describe various aspects of the classroom that impacted student learning. A preliminary coding scheme based on relevant areas of linear motion and forces, interactive technology usage and student perceptions is shown in the coding table,
Table 5.

Each artifact was coded with different preliminary codes based on each particular research question. The initial coding related to motion and force concepts was based on the major concepts within the Science Literacy Maps from the National Digital Science Library (2012). These concepts included student understanding of (a) how net external force causes changes in motion, (b) possible relationships of changes in motion to applied forces and the mass of the object, (c) how forces between two different bodies relate, (d) how object maintains a constant speed and direction of motion unless an unbalanced outside force acts on it, and (e) student knowledge of the gravitational force and the four fundamental forces of nature.

Descriptive coding took place continually. And as analysis proceeded through continual review, new and emerging codes were developed. These *pattern codes* assisted in grouping the descriptive codes into smaller numbers of themes or constructs and in reducing and channeling data into smaller concepts (Miles & Huberman, 1994). Thus, linkages and patterns were developed as the researcher interpreted incoming data. Miles and Huberman (1994, p.90) describe this as when "looking at a situation, any researcher was to know clearly *what* is going on and *how* things are proceeding–and usually wants as well to understand and explain coherently *why* things occur as they do." They advise that initial coding can be conceptualized in terms of *clustered matrices* where the matrices' rows and columns are arranged to bring together items that "belong together." In this dissertation, multiple conceptual matrices were constructed in ATLAS.ti in order to assist in finding any underlining meanings and explanations within the preliminary coding set. They were intended to trace student conceptual development in relevant research areas, allowing for within- and cross-case analysis. A thorough listing of these matrices/tables is displayed in the table of contents.

As coding progressed inter-student comparisons began to be made. At numerous points-of-interest throughout the course the individual participants were assigned a level of expertise and overall development for each relevant research area. These points-of-interest were generally matched to when course instruction about each concept occurred during the term and also near to when each interview was administered. These three different points-of-interest included (1) during instruction on motion but before force and energy instruction, (2) after motion and force instruction and during energy instruction, and (3) after motion, force and energy instruction. At each point-of interest, student conceptual understanding was assigned a level of expertise and clustered matrices constructed to assist in tracking student conceptual development during the course. For example, early indications of student conceptual understanding of force and motion concepts and use of interactive technology were initially coded. This was during early instruction on motion and contiguous in time to the first student interview *but* before formal instruction on force or energy concepts, c.f. Table 6. This first point-of-interest then helped to mark a starting point in time, offering a standard of reference for further analysis. An example for motion and force concepts is shown in Table 6 with applicable categorization criteria displayed in Table 7.

Artifacts also were coded initially for how various aspects of interactive technology, like DyKnow and tablet PCs, impacted students' conceptual understanding in motion and force concepts (Research Question 1), and how these aspects allowed for teacher feedback and scaffolding and therefore supported student conceptual development in motion and force concepts (Research Question 2).

Table 6. Levels of Student Expertise in Different Force Concepts

Point-of-interest #1	How net external force causes changes in motion	Relationships of changes in motion to applied forces and the mass of the object	How forces between two different bodies relate	Student knowledge of the gravitational force and how the four fundamental forces of nature interact
Student 1	Crude	Crude	Crude	Moderate
Student 2	Crude	Crude	Moderate	Moderate
Student 3	Moderate	Moderate	Sophisticated	Expert

Table 7. Specific level of Student Expertise for Motion and Force Concepts

Levels of understanding of motion and force concepts	Crude	Very low level of knowledge, understanding, and application of motion and force concepts. Little use of mathematics in physics is displayed.
	Basic	Low level of knowledge, understanding, and application of motion and force concepts. Use of mathematics in physics is developing.
	Moderate	Moderate level of knowledge, understanding, and application of motion and force concepts. Use of mathematics in physics is keyed to subject matter and developing.
	Sophisticated	Profound evidence of knowledge, understanding, and application of motion and force concepts. Use of mathematics in physics is matched to the subject matter and problems are solved with little teacher instruction.
	Expert	Profound evidence of knowledge, understanding, and application of motion and force concepts. Use of mathematics in physics is matched to the subject matter and problems are solved with no teacher instruction.

Along with initial coding from Table 5, a dual-coding scheme for the frequencies of usage and level of student preference for each technological aspect (coded for various levels of use or indication in each area) is shown in Table 8.

Table 8. Level of Use of Aspect or Indications of Student Preference

Use of Aspect or Student Preference for Technology	Low	Low level of aspect. Limited evidence of aspect use or indication of student preference.
	Moderate	Moderate use of aspect. Some evidence of aspect use or indication of student preference.
	High	High use of aspect. Large of evidence of aspect use or indication of student preference.

An example of the preliminary coding for course technology aspects for the three students is shown in Table 9. At each point in time, students thus were simultaneously coded for conceptual development and use of course aspects.

Table 9. Student Use of Elements that Support Student Conceptual Development in Physics

	Use of DyKnow and Tablet PC	Use of DyKnow Activities	Inter-group Activities	Intra-group Activities
Student 1	Moderate	Moderate	Moderate	High
Student 2	Low	Moderate	Moderate	High
Student 3	Low	Low	Low	High

An example of the coding for indications of student preferences from MPEX scores for the three students is shown in Table 10, where the overall change toward (+), away (-), no change (0), or ambivalent towards experts' attitudes towards physics is indicated.

Table 10. Student Indications of Student Preferences/Attitudes in Physics

Preferences	Student Independence	Coherence of physics concepts	Physics Concepts	Link physics with reality	Mathematics and physics	Student effort
Student 1	+	+	-	+	+	-
Student 2	+	-	Ambivalent	-	0	+
Student 3	+	+	-	+	+	-

Summary of Data Sources and Data Analysis Methods

Table 11 summarizes each type of data source, whether the source was qualitative or quantitative, amount of data collected, how the data source were analyzed, and which research question(s) the data source will inform.[3]

Trustworthiness

The establishing of *trustworthiness* of a qualitative study demands attention. In qualitative research, the researcher is the primary instrument of description, analysis, and interpretation (Wolcott, 2001). Thus, the means and techniques of forging trustworthiness in quantitative studies, including concepts of both internal and external validity and reliability, need to be reconditioned instead as researcher-centered concepts of credibility, transferability, and dependability, respectively.

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[3] See p. 9 for research questions

Table 11. Data Collected and Analysis Method

Type of Data Source	Data Source	Qualitative or Quantitative	Total Number of Data Source Collected	Data Analysis Method	Relevant Research Questions(s)
Interviews	Student Interviews	Qualitative	12	Iterative Coding	All
Observations	Classroom videos	Qualitative	15	Iterative Coding	All
Observations	Classroom Field-notes	Qualitative	Numerous	Iterative Coding	All
Documents	Problem-Solving Artifacts	Qualitative	21	Scoring with Rubric	1
Documents	Structured Writing Activities	Qualitative	3	Iterative Coding, Scoring with Rubric	1
Documents	Course Examinations	Qualitative	9	Iterative Coding, Scoring with Rubric	1
Documents	Force and Motion Conceptual Evaluation (FMCE)	Quantitative	6	Statistical Analysis	All
	Maryland Physics Expectations Survey (MPEX)	Quantitative	6	Statistical Analysis	All
Documents	Various DyKnow artifacts and other submissions	Qualitative	Numerous	Iterative Coding,	All

Credibility

The credibility of a qualitative study is analogous to a quantitative sense of internal validity, i.e. displaying the *truth* of a research setting, or how the research findings match "reality." The assumptions of qualitative research, however, are that reality of a researcher setting is ever-changing, non-single, unfixed, and un-"quantifiable" (Merriam, 1998), and that the researcher herself is the best source of information about the credibility of what she is reporting (Wolcott, 2001). The "reality" presented in qualitative research then depends on the researcher extracting and conveying to the reader a sense of the research subject's understandings of the world taken from multiple data sources. For a researcher in a multiple case study, he or she must show that a truth value "has represented those multiple constructions adequately" (Lincoln & Guba, 1985) and thus must be "credible" to readers who construct for themselves the multiple realities of the research. This sense of credibility is improved with sufficient engagement in the research setting, persistent observation, rich descriptions of from fieldwork (Wolcott, 2001), triangulation of data sources using multiple data resources, consistent research methods, and member checks. Credibility is this research will be supported by prolonged engagement and persistent observation in the setting, triangulation of data sources, and member checks on interview transcripts (Lincoln & Guba, 1985).

Transferability

While internal validity deals with the "truth" in a specific study setting, external validity informs the appropriateness of extending the research findings to a general setting. In other words, an externally valid finding can be appropriated in a broader, more expanded setting and thus can extend to a situation not necessarily identical to the research setting. For qualitative research, however, extending research findings can be more problematic. This is due to the complexities of applying an understanding of a particular unfixed, changing situation to a generalized non-specific, fixed circumstance. As Stake (1995) notes, readers themselves do not come a blank slates; instead, they come to the research setting with their own conceptions, feelings, and assumptions. Transferability is thus improved by providing a through a *thick description* of setting and participants. It is, therefore, the researcher's task to provide thick descriptions of the setting and data so that readers can employ their individual understandings of a research context and form their own explanations. Accordingly, Lincoln and Guba (1985,p.316) add, "It is his or her [researcher] responsibility to provide the data base that makes transferability judgments possible on the part of potential appliers" and that:

> The burden of proof lies less with the original investigator than with the person seeking to make an application elsewhere. The original investigator cannot know the sites to which transferability might be sought, but the appliers can and do. The best advice to give anyone seeking to make a transfer is to accumulate *empirical* evidence about the contextual similarity; the responsibility of the original researcher ends in providing sufficient descriptive data to make such similarity judgments possible. (p.298)

Transferability is this research will be supported by thick descriptions of specific circumstances in the research including setting and characteristics of participants.

Dependability

For the reliability of a study, i.e. the stable, consist, and predictable replication of results, qualitative studies use the term dependability. "Reliability…assumes that there is a single reality and that studying it repeatedly still yields the same results," according to Merriam (2009, p.220). Yet for qualitative research, this clearly does not hold, because "human behavior is never static" (p.221). Dependability is thus broader than the general sense of obtaining similar results from research instruments since the instrument in qualitative research is the "human instrument" and that research occurs in complex and evolving research settings (Lincoln & Guba, 1985). Qualitative research instead is dependable if "the naturalist seeks means for taking into account both factors of instability and factors of phenomenal or design induced change" (Lincoln and Guba, 1985). Therefore, replication of research findings involves the convincing triangulation of data and thorough explanations of a researcher's assumptions and theoretical framework behind the study (Merriam, 1998). Dependability in this research will be supported by explicit explanations of the theoretical background undergirding the research along with triangulation of data sources.

Overview of Trustworthiness

In this research, the trustworthiness of the study was improved in a series of ways. First, the researcher had extended contact with the research setting and participants during the study. Thus, the researcher had a profound and acute sense of the research environment. Second, data triangulation will be achieved through the analysis and synthesis of multiple documents, daily field-notes, participant observations, and extended participant interviews. Third, member checks occurred after participant interviews. Transcripts of the interviews were distributed to participants for feedback and preliminary data analysis was tested against participant reactions. This included the final interview, which provided an extra check on researcher's initial interpretations. Finally, a thick description of research setting, individual participants, and researcher theoretical frameworks took place throughout data analysis and in the final report. Table 12 lists the elements of trustworthiness for both qualitative and quantitative studies and the specific strategies to insure for trustworthiness employed in this research trustworthiness, e.g. (Lincoln & Guba, 1985, p.328).

Table 12. Establishing Trustworthiness

Qualitative Term	Quantitative Term	Shorthand	Strategy Employed to Insure Trustworthiness
Credibility	Internal Validity	Truth of setting how the research findings match "reality"	Prolonged engagement Persistent observation in the setting Triangulation of data sources Member checks on interview transcripts and written analyses
Transferability	External Validity	Appropriateness of extending the research findings to a general setting	Thick descriptions of specific circumstances in the research including setting and characteristics of participants
Dependability	Reliability	Measuring a single reality and that studying it repeatedly still yields the same results or obtaining similar results from research instruments	Explanations of the theoretical background undergirding the research Triangulation of data sources

CHAPTER FOUR

RESULTS

Introduction

The purpose of this dissertation was to describe how student uses interactive technology, specifically DyKnow software and in combination with teaching strategies such as intentional teacher feedback and scaffolding of classroom activities, in learning of motion and force concepts within an introductory, university physics course. These included descriptions of how students interacted with DyKnow Interactive Software, tablet PCs, and other instructional technologies while learning about learning about force and motion concepts, and how these technologies were utilized with teacher feedback and scaffolding strategies to affect learning. In particular, this dissertation addressed two overall research questions: (1) How did students interact with technology components, including DyKnow and tablet PCs, within an innovative, technology-enhanced, university-level physics course while learning motion and force concepts? and (2) how did students use interactive technology in combination with purposeful teacher feedback and scaffolding in learning motion and force concepts?

Overview

In order to answer this dissertation's research questions, a general overview of the classroom environment first will be presented. This will include a comprehensive description of a typical class period articulated from the teacher's perspective. This is imperative so that the specific applications of the features of DyKnow can be elucidated and also to establish how teacher scaffolding and feedback tactics are significant within this setting. Second, a general description of each research participant will be provided along with a description of his/her experience within this technologically enhanced setting. This will include in-depth narratives of how each research participant encountered each element of this technology-enhanced environment, and how these elements were exploited with purposeful teacher feedback and scaffolding in learning motion and force concepts. Third, in-depth explanations of each participant's development within force and motion concepts along with student-reported changes in attitudes and beliefs about physics will be provided. Fourth, a cross-case analysis of student progress in force and motion concepts and student employment of technology will be offered. Lastly, this chapter will conclude with a discussion of findings.

Overall Classroom Environment

The course environment that each research participant experienced represented a new and novel one from most university-level physics courses. The employment of interactive technologies in tandem with imbedded intentional teaching strategies, including teacher feedback and scaffolding tactics, played a very large role in their learning experiences. Teacher scaffolding of activities and the necessity for feedback opportunities within the classroom are well documented (Bulu & Pederson, 2010; Hennessy, Deaney, & Ruthven, 2005; Hlem-Silver et al., 2007; Jolly, 2009; Suthers, 2006). In particular, course activities incorporated collaborative hardware and software to permit and facilitate multiple and continuous student interactions. Many of these activities thus were intentionally planned and *scaffolded* to augment student interactions and allowed for student-teacher and student-student *feedback* opportunities, all the while utilizing interactive technologies. The types of teacher scaffolding that occurred within this environment and the intention of each scaffold are listed in Table 13. These are based loosely on the framework provided by Grincewicz et al. (2011) and Zydney (2012). These included activities designed to increase interaction within the classroom, elicit and maintain attention of the student learners, make student knowledge visible, display procedural steps and modeling knowledge, and facilitate the use of websites and simulations.

Table 13. General Types of Scaffolding and Intention

Intention of Scaffold in Structured Activity	Type of Scaffold Afforded by Technology
Interaction	Activities designed to increase interactions within the classroom
Grabbing attention	Activities to elicit and keep the attention of the student learner
Visible knowledge	Activities to make student knowledge visible to student and/or teacher
Procedural steps and modeling knowledge	Activities to show students procedural steps or modeling knowledge
Websites and learning software	Activities designed to involve websites and learning software

The types of feedback opportunities afforded in the classroom are also shown in Table 14. This was based on the theoretical framework of the study and included instances where the purpose of the feedback was intended for teacher assessment of student learning, creating conceptual conflict within the learner and across student groups, offering correction to student alternative frameworks, and challenging and isolating individual student learners. These feedback opportunities could have occurred between teacher and student, among student learners, or between the student learner and the technology, e.g. student utilization of a writing stylus to ink on the tablet PC screen while simultaneously operating the DyKnow Interactive Software.

Table 14. General Types of Feedback Occurring in the Classroom

Type of Feedback Occurring in Classroom	Type of Feedback	Purpose of Feedback
Assessment	Feedback intended to assess student learning	**Assess** student learning
Interactive	Feedback intended to increase interactions amongst learning stakeholders	Create **conceptual conflict**
Timely/Corrective	Feedback that is immediate between teacher-student or amongst students	Offer immediate correction to **student alternative frameworks**
Targeted	Feedback intended to select or target individual student learners by teacher	Challenge and isolate **individual** learners

Further, various forms of interactive technology were exploited to scaffold activities and allow for feedback opportunities within the classroom. These technologies included DyKnow Software, tablet PCs, websites and web linking, and audio/video equipment. Moreover, all lecture and laboratories were conducted in a technology-enhanced classroom equipped with tablet PCs and an overhead screen for projection of the course material for all student learners.[4] Table 15 first lists the teaching elements of technology utilized within the environment, and if those elements are used by individuals, groups, or both. Also, Table 15 lists the type of technology, whether the element is preformatted by the teacher, type of teacher scaffolding afforded by the technology, and type of feedback opportunity, respectively.

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[4] From the very first day of the course sequence, different language is employed to describe "lecture" and "laboratory." The course syllabus describes the course "lecture" as "conversation" while the "laboratory" is described as a "collaboratory." This is done intentionally to emphasize the interactive nature of the course. The traditional terms will be used in this dissertation to match common usage and reduce reader confusion.

Table 15. Elements of Technology Described from Teacher Perspective

Teaching Element of Technology	Used by Individual, Group or Both	Type of Technology	Preformatted by Teacher?	Type of Scaffolding Afforded by the Technology	Type of Feedback
General use of pre-formatted class slides	Both	Tablet, DyKnow	Yes	All types	All types
General use of preformatted list of objectives	Both	Tablet, DyKnow	Yes	All types	Interactive, Timely
General use of preformatted class evolution	Both	Tablet, DyKnow	Yes	All types	All types
Directed and spontaneous student inking/drawing and filling text boxes on slides	Individual	Tablet, DyKnow	Yes and No	Attention	Interactive, Targeted
Directed and spontaneous electronic submission of student work of slides	Individual	Tablet, DyKnow	No	Interaction, Attention, Visible knowledge	Assessment, Timely/Corrective
Teacher displaying and sharing of individual student or group work	Group	Tablet, DyKnow, A/V Screen	No	Interaction, Attention, Visible knowledge, Procedural steps and modeling knowledge	All types
Individual student ability to control content on individual tablet screen, including color, shapes, and text boxes on slides	Individual	Tablet, DyKnow	No	Attention, Visible knowledge, Procedural steps and modeling knowledge	Interactive
Student group control of individual slides	Group	Tablet, DyKnow	No	Interaction, Attention, Visible knowledge, Procedural steps and modeling knowledge	All types
Student ability to control content on overhead	Both	Tablet, DyKnow, A/V screen	No	Visible knowledge, Procedural steps and modeling	All types

screen				knowledge	
Replay on DyKnow slide	Individual	Tablet, DyKnow	Yes and No	Interaction, Attention, Visible knowledge, Procedural steps and modeling knowledge	Timely
Polling and surveying of students	Group	Tablet, DyKnow	Yes	Interaction, Attention, Visible knowledge, Procedural steps and modeling knowledge	Timely/Corrective
Imbedded websites and software and teacher restriction of browsing	Individual	Tablet, DyKnow, Websites	Yes and No	Visible Knowledge, Procedural steps and modeling knowledge	Interactive, Timely/Corrective
DyKnow server and Moodle course website	Individual	Websites	Yes	Interaction, Attention, Visible knowledge	Assessment, Timely/Corrective

Teacher Perspective of Classroom Environment

In the following description–written from my perspective –an overall narrative understanding of what I accomplish during a typical class period will be provided. Examples of my teacher scaffolding and feedback opportunities afforded within the classroom environment will be described, including my preparation of structured activities and the interactive classroom environment. This description will also detail what features of DyKnow Software my individual students experienced, including the simultaneous use of DyKnow software, tablet PCs and projected screen, and other in-class activities. (Nota Bene: Appropriate footnotes will be provided to aid guide the reader as each element of teacher scaffolding, feedback opportunities, and features of technology is introduced, c.f. Tables 13, 14, and 15.)

Narrative Example of Typical Classroom Day

My class period begins as any classroom period begins in all other science classrooms at any level. I walk into my vast 9-m by 9-m classroom filled with large tables, each measuring 1m by 3 m, each topped with four tablet PCs open and powered up for use, waiting expectedly for student learners. I stride in through the door, and look around. The reminders of science greet me: cabinets and shelves filled with well-used physics equipment; gaudy science posters affixed to the walls; the pungent smell of chemicals wafting in from the adjacent chemistry stockroom; whiteboard markers positioned haphazardly about; and chatter of nearby classrooms evident. At the front of the space near the center of the room are the room's familiar whiteboard and pull-down overhead screen, a long demonstration table, and my chair with a nearby audio/video station. To start the class, I sit down, place my bag down on the front table, and open up my computer, in this case, a tablet PC.

The preparation for this day's events was extensive but worthwhile with my office hours spent diligently preparing activity slides on the DyKnow program for my students. [5] "Today will be the day that we introduce Newton's Second Law of Motion!" I think to myself. This signifies an important day for most of my students who are majors in biology, chemistry, athletic training, or physical therapy. This is the moment for which they have been long waiting: The day my class is formally introduced to the relationship between forces and motion changes.

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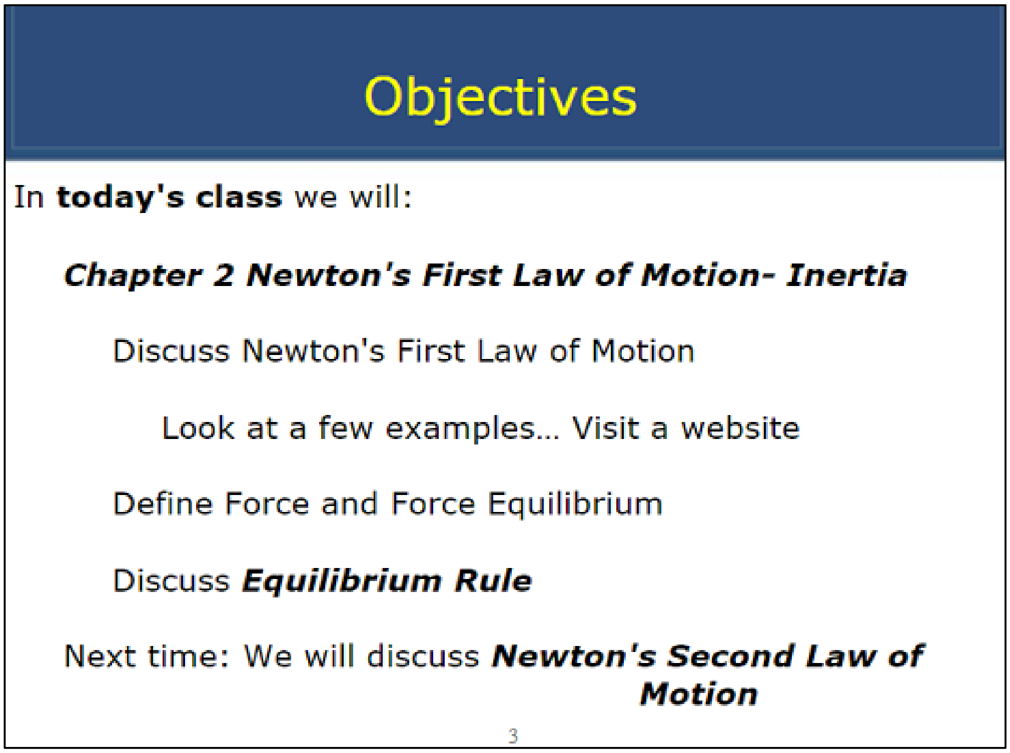
[5] Element of technology: Pre-formatted DyKnow slides



Objectives

In **today's class** we will:

Chapter 2 Newton's First Law of Motion- Inertia

Discuss Newton's First Law of Motion

Look at a few examples… Visit a website

Define Force and Force Equilibrium

Discuss ***Equilibrium Rule***

Next time: We will discuss ***Newton's Second Law of Motion***

Figure 2. Example of a Class Objective List on DyKnow

As my students enter, I greet them, one-by-one, while simultaneously opening my tablet PC, loading up the DyKnow program, and logging into it with my username and password. And after grabbing the remote for the projection system, I push “power on,” and an intense flash of light enters my perspective as the overhead projector brightens and projects behind me onto the large white screen. By the time my students have sat down in their plush, navy-colored rolling chairs near each of the room’s long, black lab tables, the process is complete. DyKnow is active. The DyKnow session has started. The class day’s objectives are on the screen, [6] c.f. Figure 2, and after a brief clearing of

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[6] Element of technology: Pre-formatted list of objectives

my throat, I voice, “Hi, everyone. We have a big day. Please login and let’s do our *evolution* together.” [7]

After saying this, I navigate to the DyKnow slide which holds the beginning activities for the class. While I do so, the overhead screen blinks with compliance as the slide changes from the day’s “objectives” to the opening exercise that I have prepared, namely the “daily evolution.” My students know this procedure well; it has been done every day since we began our experience in physics seven weeks earlier. On the DyKnow slide before them is a question on the screen, a simple question from their assigned reading, c.f. Figure 3. It reads:

> An object has a mass of 0.50 kg and has a net force of 5.0 N applied to it from the bottom of the screen. What is the acceleration of this mass? (Give the direction too!).

I hit the timer and students pick up their small, pencil-like styluses, which are attached by thin, black strings to their individual tablets. Using the small points of the styluses and touching their individual tablet screens, they mark, choosing as they go the appropriate inking style, color, and adding shapes and arrows onto the gray answer area provided that I have provided.[8] After two minutes the timer sounds. I implore, “Let’s submit them.” [9] Each student then presses “Submit” on DyKnow, and their work is instantaneously transmitted to me for evaluation. “Does anyone want to start off our discussion off?” I continue.

Sitting in the front row, Jeffrey quickly raises his hand. I know this student well. Sometimes, I don’t even have to ask the class a question because Jeffrey always responds first; Jeffrey loves to respond first. “Since I know the object has a known mass, and a

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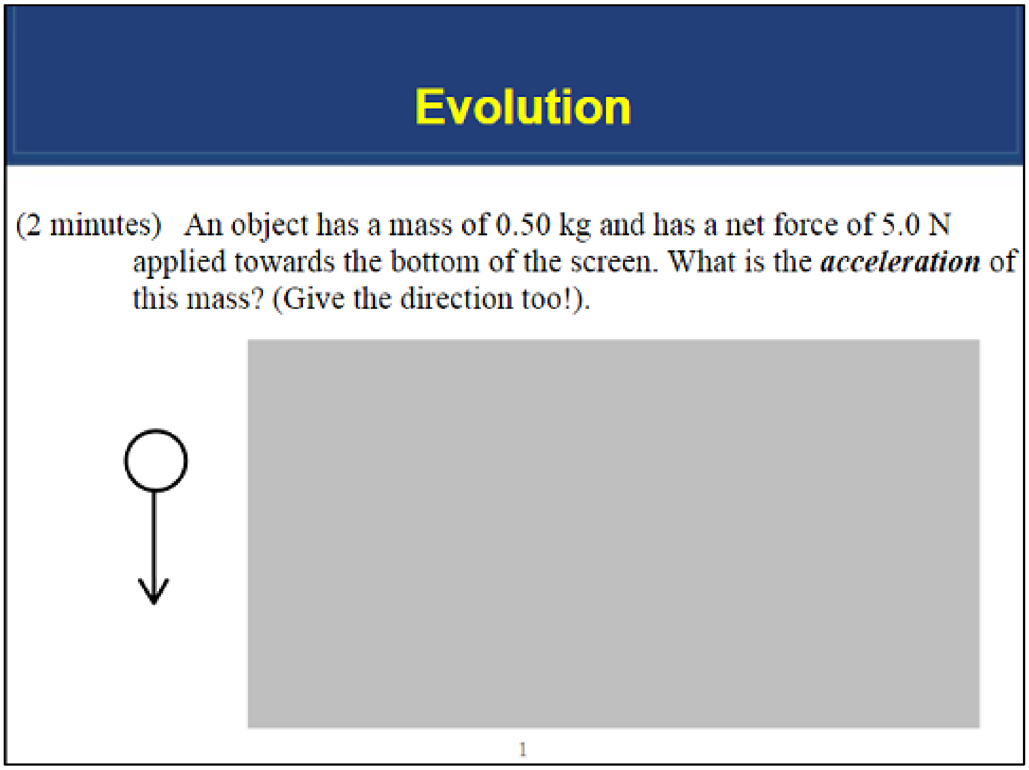
[7] Element of technology: Pre-formatted class evolution

[8] Element of technology: Directed and spontaneous student inking/drawing and use of text boxes on slides

[9] Element of technology: Directed and spontaneous submission of student work

known force placed on it, and from the reading, I can then solve for acceleration by dividing force by mass," Jeffrey intones. "The answer is 10."

Recognizing that the answer is incomplete, I query, "Thank you Jeffrey. Can anyone continue the answer? He might be missing something."



Evolution

(2 minutes) An object has a mass of 0.50 kg and has a net force of 5.0 N applied towards the bottom of the screen. What is the ***acceleration*** of this mass? (Give the direction too!).

Figure 3. Example of Class Evolution

Looking around and affixing my gaze to the right, I observe George with his hands on his chin. Again, I know from my experience this is the signal that George is ready to comment.

George responses, "I would include the direction also along with the units. So the best answer is probably going to be 10 for the numerical part, and for the unit part, I would say meters per second squared. And since the direction of the forces downwards, the acceleration must also be downwards."

"Good. Does anyone want to show their work on the board?" I ask.

After a short silence, Lauren answers, "I will." I nod. With a pat of my finger to the screen of my tablet, I then change the display of DyKnow from my teacher slide to Lauren's inked slide, thereby displaying for all to see a projection of Lauren's work on the screen.[10]

"Lauren looks like she has it right," sounds a student from the back row.

"I agree," I utter. "It looks like her steps are sound. She has all the right steps written down. She uses a text box to write her words.[11] It appears her answer is correct and includes the numbers, the units, and also the directions. Look at how she drew the vector! What does everyone think?"

Nods of agreement were seen throughout the room, and I subsequently click and return to the original class overview for the day's activities. "Okay everyone. Let's take a look at Newton's Second Law today and check if it matches with some of the things you been seeing in your reading. Today I will show you a simple demonstration that I have prepared in which I have videotaped the motion of a small, one-half kilogram mass dropped from a known height. I analyzed the motion in the same way as we did in our recent lab with motion analysis software.[12] Guess what the acceleration was?"

Next, I change the perspective on the projected screen from the DyKnow program to the motion analysis software. I then play the video of the motion with the appropriate motion markings. While the video is proceeding, graphs of position-versus-time,

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[10] Element of technology: Teacher displaying and sharing of student work

[11] Element of technology: Directed and spontaneous student inking/drawing and use of text box on slides

[12] Element of technology: Embedded websites and learning software

velocity-versus-time, and acceleration-versus-time are progressively shown. And finally after the video concludes, I click through and add a linear regression to the velocity versus time graph. “The slope reads 9.7,” I note.

Silence, a recognizable lack of sound, is familiar to me. A verbal push is mandated by way of a hint. Or maybe I could click the software to display a pre-formatted slide, displaying a marked diagram with a sketch of the demonstration alongside the recently completed evolution to hint at their similarity. Which option do I choose? Instead, I decide to change back to DyKnow to project a blank screen on the board and then switch from teacher control to student control. “Now they have the power,” I think to myself. I then query, “Can someone draw the forces on the ball as it drops on the screen for us?”[13]

Jeffrey is quick to pounce and using his stylus, marks on the blank screen for all to observe. He selects the shape of the ball, a circle, from DyKnow’s assortment of shapes, and using the color “red”, attaches a red arrow symbolizing a force vector to the bottom of the black circle. “Here’s my free-body-diagram of the forces on the ball. In this case, drag is probably very small so the only real force is the gravitational force,” he notes.

“So what is that mean for us, Jeffrey?”

“It means that the motion of the object will probably be changed by the outside force because a net external force cause changes in motion.”

“What does everyone think about that?” I inquire. “You all agree? Is there anything you can add?”

“I would add the math steps,” interjects Lauren. “I know from the reading that Newton’s Second Law relates force and the changes in motion, so I can find the

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[13] Element of technology: Student collaborative control of individual slides and student ability to control content on overhead screen

acceleration if I know force and the mass. In this case, I know the force is gravity, or weight, and that equals about 5 N and since the mass is one-half kilogram, then we must have about 10 units of acceleration. See?" she declares as she writes the math steps, one-by-one, on the class screen.

"Cool. Let me replay those steps on the slide," I reply. Again, just with a few clicks, I exploit the "reply"[14] feature of DyKnow in order to display each line of Lauren's math, step-by-step, on the overhead screen. "Look here. She did it correctly. She even put the correct number of significant figures down at the end! Let me replay it a little slower."

I exclaim, "This is a good time for a poll."[15] Again using my finger, I quickly change the slide from the blank screen on which Jeffrey and Lauren marked to another preformatted slide with a class poll. "Here's a poll. It says, 'Is the demonstration the same type of motion as the evolution? Yes or no?' Give an answer."

The students grab their styluses to answer. I glance down at my screen and after a few seconds observes that more than 85% agree that the motion of the demonstration is a very similar to motion of the evolution with the remaining 15% either disagreeing or not sure. I then choose to display the tabulated results with a pie chart–a red color signifying a "yes" and a blue signifying a "no." I then affix this pie chart to the slide with the demonstration and the evolution, each shown side-by-side. Now I have it, all at once, for everyone to see.

"Okay, let's group up.[16] Turn to the students next to you and look at the next slide." I then display a DyKnow slide with one question: "What do forces do to the

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[14] Element of technology: Replay on DyKnow slide

[15] Element of technology: Polling and surveys of students

[16] Element of technology: Student collaborative control of individual screens

motion of an object?" Looking around the room, I quickly create small student groups in DyKnow and remark, "Working together, let's see if we can come up with an explanation. I am enabling you to work together on your group slide. Just mark on your individual tablets, and whatever each of you writes individually will be shown together on your group slide."

I allow the group work to continue for extended period of time, and after a fashion, I reconvene the whole group and invite student responses. "Does any group want to show their work? How about your group, George?"

Immediately George and his group-mates stiffen. And as I project their work onto the board, the rest of the class and I silently verify their work.[17] After a short pause, I intone, "It seems that you're onto it. You said, 'forces change the motion and the mass has an effect.' That makes sense, I think. Anyone else want to volunteer?" A conversation ensues. I project the work of various student groups onto the large class screen. Each one is displayed, evaluated, and discussed in turn.

"I have one more slide. This slide contains a website at which you can look.[18] This website is from Wikipedia. It is the Wikipedia entry for Newton's Second Law of Motion, and if you look closely, you can see some of the facets of force and motion are shown on it." And then I enable student browsing of this website on DyKnow so that students will have the ability to navigate around and explore different websites connected to that particular Wikipedia page.

Looking up the clock and noting to myself that the allotted fifty minutes does not last as long as when I myself was a physics student, I call an end to the class. "Okay,

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[17] Element of technology: Teacher displaying of student work

[18] Element of technology: Embedded websites and learning software

time's up. Make sure you save your DyKnow notes to the server. I will see you next time. Remember the assignment is shown on your Moodle page."[19]

Summary of Overall Classroom Environment

This section represents a brief look at a typical classroom interaction from my teacher perspective. In this dissertation, constructivist learning principles and facets of interactive technology are merged within an introductory physics classroom. Throughout this description of what I experience and do within the classroom, I am continually thinking about my planned activities, various elements of technology at my disposal, and my attempts to create discussion and frequent interactions amongst learners in my classroom. Elements of technology, like DyKnow and tablets PCs, are present and are utilized simultaneously to foster learning. I am finely attuned to what is happening with my students, and I purpose the technologies of the classroom to foster interactions amongst students and me and also between student leaners. I further scaffold my activities to foster interactions to increase attention, make knowledge visible, and model steps for learning (Zydney, 2012), and I also bring in outside resources like websites and simulations to further our explorations. Not only these, but I also attempt to make my activities interactive so that I can give feedback that is targeted and timely to allow for frequent interactions (Jang & Stecklein, 2010). Along with these teaching strategies, many of the elements of technology from Table 15 are present. These include the use of pre-formatted class slides, list of objectives, and class evolutions; directed and spontaneous inking/drawing on slides and submission of student work; use of colors, shapes and text boxes; displaying of student work; student control of content shown on the board; replay on slides and polling; student collaborative control; and ability to embed websites.

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[19] Element of technology: Dyknow sever and Moodle website

Participants' Experiences within the Overall Environment

It clear that the way instructors envision and determine the classroom environment differs from the way students encounter that same environment. In this section, a general portrayal of each research participant will be provided along with an understanding of his/her experience within this technologically enhanced setting. Multiple aspects of the participant will be discussed, including each individual's learning style, his/her notion of ideal classroom environment, individual adoption of interactive technology, and the ways in which they encountered this novel environment. Three participants will be described. Individually, these research subjects will represent low-, middle-, and high-levels of preliminary conceptual knowledge of motion and force concepts: Jeffrey will represent a low-level; Lauren will represent a middle-level; George will represent a high-level.

Participant 1: Lauren's Experiences within the Overall Environment[20]

Lauren is a white female student majoring in biology and pre-physical therapy and intends to enter graduate school in physical therapy. She is from a small town in central Iowa and enrolled in this course to fulfill the physics component of her biology degree. She moved to the region from the East Coast when she was in her teens after her father changed jobs. According to her, she adjusted quickly to the Midwest, making friends easily and earning good marks in her advanced secondary courses in biology and chemistry. She also took a physics course during her junior year of high school. She freely admits that she doesn't remember a lot about her physics experience from high school besides some of the use of technology, like probe-based laboratories. In the past she has job shadowed for physical therapy at a hospital in a nearby major city in east

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[20] All descriptions in this section will be in the present tense.

central Iowa. Lauren represents a middle-level of preliminary conceptual knowledge of motion and force concepts in this dissertation.

Learning for Lauren

Lauren believes that she is an auditory and kinesthetic learner. For her, learning is gaining new perspectives and acquiring knowledge that can be applied, and many times, she accepts that teacher has this knowledge. For her:

> Learning is not just memorizing stuff but actually applying it to things, because anyone can memorize something. Just sit around and repeat and repeat, but I think learning is when you actually have knowledge that you are able to apply to something….You have to apply it or you haven't learned it. (Interview 1)

In order to learn something, she feels that she has to say it back to someone else because she then can be sure she's "thinking in the right manner" (Interview 1). Learning for Lauren needs to be hands-on, like in a laboratory or with something to touch or manipulating in class. It is significant for her that she incorporates her knowledge and connects it to real-world examples and to her field, physical therapy. "When we do stuff in lab and have an actual object that is moving, that's helpful" (Interview 2). She also adds:

> Personally for me when I'm hands-on, I just like to see things applied to real-life. Once a concept is taught [by a teacher] it is important to have a real-life explanation for it for me or even a hands-on activity, like in my physiology class. As soon as something is taught about the human body… Show me a picture, something like, 'Here is exactly how it works, here's why it matters.' (Interview 1)

In science, this acquiring of new knowledge means gaining familiarity with terminology or mathematical relationships that are known to most science people, like information about linear momentum or the definition of linear velocity.

Lauren likes discussion-based lectures and feels they are better than just the teacher talking. Since Lauren is admittedly not good at taking class notes, in her ideal classroom students wouldn't have to keep pace with the teacher but rather would be one where there are a lot of interactions. She notes, “Like in our lecture and where it’s more of a discussion-based lecture, which is helpful because it’s not just you sitting there lecturing at us” (Interview 2). She also mentions that in lecture-based classes “where someone just talks at me and never asks me to do anything with the information, then I don’t learn very well because I just forget it” (Interview 2). Sometimes she’s not sure she understands something when the professor says it, but when other students can describe it in easier terms, then she can understand it. For her, a teacher’s task is to reinterpret information in different ways, and she appreciates it when a teacher uses simple language for his audience. For instance, in her high school’s Advance Placement literature class, Lauren recalls that they didn’t just read their books and memorize passages, but rather they “talked about how the concepts that the author wanted us to know applied to life and what they’re actually trying to say, not just reading it and letting it go out to your head” (Interview 1).

Being an auditory learner, Lauren believes that taking notes is a distraction from the sounds and rhythms of the class period and admits that she has difficulty catching everything as it is being said. However, if she has a class where teachers don’t give her class notes, then she’s forced to take notes. She admittedly has a hard time laying things out ahead of time, loses attention easily, and zones out if it’s just the teacher talking. For Lauren, effective learning means listening and interacting in class with hands-on activities and then, after class, supplementing her learning with notes from others.

Moreover, Lauren studies by taking lots of notes from her readings. (In previous classes she brought her personal computer to class on which she would took notes.) After classes she continually reviews any PowerPoint class notes that her teachers might provide her, repeating key points over and over, and while studying, she emphasizes material related to exams. She feels especially close to her homework sets and believes that those homework sets assist her, especially in science, to obtain better understanding of the material. Finally, having the answers in the back of the book for problem sets is valuable for her too, she notes. When asked about science learning and reflection, Lauren gives an interesting set of answers:

> Q: Where you think students should be in science learning? Do you think students should be, on one hand, receivers of knowledge or constructors of their knowledge?
>
> Lauren: Well, I think we obviously don't know everything about science, you know. You guys went to way more college then we had gone through, you know so…
>
> Q: So far.
>
> Lauren: Yeah, so far. I mean you have to give us the knowledge, but at the same time we need to be to take that knowledge and incorporate it into what we are studying, like physical therapy. I need to take the knowledge that I have from my biology classes and be like 'Hmm, that's how physics plays into it.' You know? Instead of just receiving the knowledge and being like, 'Okay.' When I put my own knowledge into it helps me to understand everything better.
>
> Q: Do you think it's important to reflect on your knowledge?
>
> Lauren: Yeah, I do because if you just take everything that you [teacher] say and accept that that's how it is, you're not really learning anything. You are just [Pause].
>
> Q: Receiving?
>
> Lauren: Yeah, you are receiving it. Yeah, I think it is important to reflect. (Interview 3)

Further, Lauren values group learning if the quality of the group members is good. Group work for Lauren then allows her to reinterpret her knowledge in different ways with different people. She enjoys talking to other people and can study alone or together with others in groups, but feels she is not as good at reading and visualizing. "I can't just read something or look at PowerPoint slides and understand it. I can't do that" (Interview 1). For her, student input is important for learning, and other peoples' explanations are helpful to her. Moreover, Lauren works a lot in groups for her homework exercises. She discloses that the quality of student groupings is a difference for her. She says:

> It depends though because sometimes you have groups that don't focus, or one person doesn't carry their weight. You know? Sometimes it's very hard when you have some people that are not good group workers. But for the most part, I study in groups and it helps me. Me and my friends study. When we study, we focus, which makes it helpful. (Interview 1)

She also declares:

> I like working in a group a lot with homework, especially on stuff that I really don't understand. If I understand it and have a good grasp on it then I usually work alone because that way I don't get distracted. But if it's something that I need input from other people or I don't really know exactly what I'm doing, I might have questions so it's really helpful to work in a group. (Interview 2)

Also, Lauren mentioned she often works with another student Joni in her classroom groups. Lauren believes that working with Joni makes her write out and explain her understanding to someone else, which she believes is better for her learning. For example,

> Q: Is it [working with Joni] helpful to you?
>
> Lauren: Yeah, I like to work with Joni when working on homework. I ask her, 'Hey, I don't get this and explain it to me.' Anybody can be like, 'Here is my problem and look at it,' you know? But to have to write down and explain in words why I used those things that helps me to understand better what I'm doing, not just plugging stuff into an equation. (Interview 3)

Lauren appreciates interactions and discussions because if she can explain it to someone then she "knows" it. Explaining concepts to others is helpful and gives different perspectives, she notes. "Like yesterday in lab I went through it kind of on my own, but at the same time, when I don't know what's going on, I would look at my group members and say, 'Hey, I don't get this do you?' or 'Do you remember that equation that we learned that I don't remember?'" (Interview 2). Lauren is ambivalent about group work with interactive technology, however. She declares that she sometimes has trouble focusing using technology and at times in that setting has found herself losing interest and becoming distracted.

Elements of Interactive Technology for Lauren

There are many facets of interactive technology, like Dyknow, that Lauren appreciates and of which she takes advantage. First, Laura notes that overall she "likes everything" about the DyKnow software, including the fact that learners can write on or annotate their DyKnow slides, and that information can be displayed in real-time on the overhead projector. "I think it helps to keep us attentive. It's interactive. We can put stuff right on the board if we need to. We can interact with the screen and stuff, and it just keeps us from spacing off [laughs]" (Interview 1). Thus, the use of DyKnow helps her to focus on what's on the screen, she says, and taking notes in class is easier for her too:

> I'm just better at listening than trying to take notes. I can just jot things down and still keep up, but if I'm *really* [emphasis added] trying to take notes and if I'm busy writing or not writing down what I should be, I get frustrated when trying to listen and write so, it's better [on DyKnow]. It's almost like I can see your notes directly when I'm trying to review something. I like that. (Interview 1)

She feels that DyKnow is better than taking notes on paper, and she especially likes to see the instructor notes after class from Moodle. She relates that she has employed her personal computer in previous classes for note-taking and feels that tablets are very similar to PCs, as long as you're using a text box. "Tablets are helpful, but PCs are just as good and are more interactive than just pieces of paper" (Interview 3), she remarks. Lauren does not write or ink much on DyKnow; for her, typing is faster and more effective than longhand writing on the tablet screen. Instead, she types on the physical keyboard of the tablet PC and chooses to use "text boxing" within DyKnow. Therefore, she doesn't utilize the inking feature on the tablets and to her that doesn't matter because the things are on the board anyway.

Second, Lauren commented that she valued how the teacher could group student learners, and that they could collaboratively control what is happening on the screen. "I like how we can write in the screens, and when you want us to show you something, you can give us control of what we put on the screen. I think that's neat," she exclaims

(Interview 1). She remarks that shared-control and group interactions benefit her due to the fact that students can reinterpret, in their own words, the concepts. To her this helps her grasp the concepts and this explanation and re-explanation process is essential for her. For instance:

> Q: How about some of the group interactions we do in class? Are useful to you? You know, when we are in groups.
>
> Lauren: Like when we do discussions as a whole? I like that.
>
> Q: What do you like about that?
>
> Lauren: If I can explain it to somebody, then I know that I know it…. I just like it better than you just talking for the whole 15 minutes, and then say, 'Does that make sense to you?' How would somebody else explain it? You know, I think that helps…. Maybe someone who isn't a physics professor puts it in their own words, maybe then I can be like, 'Maybe that makes sense.' (Interview 1)

Moreover, she notes, "We're actually putting our input in, so that's helpful, and also I like how in lab we kind of go at our own pace, in our own groups. We don't have to try to keep up with the pace of everyone" (Interview 2). Additionally, she volunteers that there has been little, if any, of those types of interactions in her other classes.

Lastly, Lauren values the ability to save her work on DyKnow and references past class notes on her DyKnow slides frequently. She also employs DyKnow to review those equations and revisits how the class used certain equations during the classroom. She especially likes the instructor's prepared slides, in pdf form, on which the instructor has done the inking on the DyKnow slides, and that they are "quite helpful" for math equations and problem-solving examples. She comments that she appreciates them and often goes to the course Moodle site to access and print off class notes. Sometimes, however, she doesn't "understand some of the notes that we have put on DyKnow," where:

> I look back at how you do the equations because that's my biggest fault a lot of times. I don't exactly understand how equations are used so that's when I go back to look at how you use certain equations. It is also really helpful because I don't always

> remember everything we talked about lecture. It's nice to have that accessible after lecture. (Interview 2)

Also, she comments that slides do not have the functionality that DyKnow does, so it can be constructive for her to go back to the DyKnow slides, especially for math equations, and recall how the math manipulations were performed.

Other elements of DyKnow are also significant to her. Polls help keep attention and prevent her from spacing off. Lauren says she values the class evolutions too, which are helpful since she can compare her answers to others,' and further:

> Q: How about the evolutions? Are they helpful to you?
>
> Lauren: They are. I like it when it I can work with a partner on coming up with the definition of what you think a concept is because it kind of helps me compare what I think the definition is to what we come together as a group and decide what is. Yeah, I like them. (Interview 2)

Yet, since she can be behind in her reading schedule, she doesn't know how to answer them, which makes them difficult for her. Evolutions serve as "conversation starters" for her, get the class "rolling," and demand that the student learners to be prepared for class. Further, Lauren has trouble thinking of any helpful embedded websites or simulations but comments that the simulations were beneficial in that she could see stuff in "real life" applications. The reason that she doesn't remember any websites or simulations, in particular, is because she won't employ them for exam preparation. Moreover, she notes:

> To see it [simulation] in real life, outside the physics classroom, these are things that I normally would not see because I normally would not go searching for them. Then, sure, they are kind of nice to see. When I take the test, I probably don't think back to the one time we had a web link about it. But they are helpful when I'm trying to see the overall concept of something. (Interview 1)

She also does not utilize the replay of DyKnow feature. She contends that she would have used replay if she had been aware of the possibility of its use outside of the classroom, where:

> Lauren: Sometimes I have trouble following certain things like equations on DyKnow.
>
> Q: You have trouble following equations?

> Lauren: Yeah, equations.
>
> Q: Problem-solving?
>
> Lauren: Yeah, stuff like that.
>
> Q: You don't use replay?
>
> Lauren: Yeah. I know there is a replay, if we were to actually go into our physics classroom and get on those computers and open up DyKnow and everything. (Interview 3)

Connected to this, she was not aware that DyKnow could be downloaded onto a personal computer, free of charge.

Listed in Table 16 are some of the individual learning characteristics and reactions to the use of interactive technologies in the classroom for Lauren.

Lauren's Advice

Lauren thinks that a teacher-constructed section called "How I Did the Problem" would be very helpful on certain DyKnow notes, especially for difficult math equations. She states that PCs would have been just as good as tablet PCs and that students should be told more explicitly that DyKnow can be downloaded free of charge and used outside of class. Overall, Lauren feels that the instructor did a good job of emphasizing different audiences and using simple language to make learning easier.

Table 16. Learning Characteristics and Reactions to Interactive Technology for Lauren

Type of Learner	Auditory and Kinesthetic
Learning Style	"Gaining new perspectives and acquiring knowledge that can be applied" Self-professed poor taker of notes in class Studies by taking lots of notes from her readings Looks over PowerPoints, repeats key points over and over Has to be able to say back to other people to learn Important to have a real-life applications
Ideal Science Classroom	Lots of hands-on activities Opportunities to interact Teacher usage of simple language
Group Learning	Ambivalent towards group learning Other students input is important, but she depends on individual grouping
General impression of DyKnow	"Likes everything" about DyKnow Keeps student interest and attention Interactions on DyKnow help her to learn Values how the teacher assigns students in to groups Likes saving work from which to study
Collaborative control/sharing	Likes the ability to write on and control what is happening on the projected screen Thinks small group sharing was valuable
Tablet PCs, screen	Employs personal PC in other courses Feels that PCs and tablets are basically the same Likes the ability to write on screen but chooses to type in text boxes instead
Stylus, Drawing	Does not ink or write on screen but prefers to type in text boxes
Polling, Surveys, Evolutions	Keeps her attention and foster interaction Sometimes doesn't "know" evolutions Serve as conversation starters and gets "class rolling" Allow her to compare her answers to others'
Class notes, Moodle	Accesses past class notes posted on Moodle regularly Moodle is very important
Websites, simulations	Cannot recall using websites or simulations

Summary for Lauren

Lauren is an auditory and kinesthetic learner. The sounds and the tactile environment of the classroom occupy a much more prominent role than any visuals do for her. For Lauren, learning is about gaining new perspectives, and those perspectives must have applications in real-life situations. DyKnow is an asset for Lauren in her physics course. She likes the ability to write on and control what's happening on the projected screen using DyKnow if asked by the teacher, and values saving her work. She appreciates the opportunities to interact with others on DyKnow and that those interactions support her learning. Yet, she is also ambivalent about group learning. While not using the stylus or inking often, she instead exploits "text boxing" to interact with each DyKnow slide. Polls and the class evolutions aid in keeping her attention and assist in fostering interactions between her and her neighbors. Embedded websites and simulations have a minor role for her; on the other hand, she accesses class notes on the Moodle course site regularly. She has employed her own personal computer other classes and believes that the tablet is very similar to regular PC.

Participant 2: Jeffrey's Experiences within the Overall Environment

Jeffrey is a white male student from a small town in northwestern Illinois majoring in athletic training and pre-physical therapy. He intends to enter graduate school in physical therapy. Jeffrey is a member of two intercollegiate sports teams on campus and is a resident assistant in one of the dormitories at the university. He came to the university because of its "great" athletic training and physical therapy programs and was attracted to the small sizes of its courses. "The small class sizes and helpful professors make a huge impact on learning. The professors are invested into your professional and academic growth. The student-professor relationships are irreplaceable" (Biographical sketch on university website). In high school Jeffrey took advanced courses in chemistry and biology but did not take a physics course. Those courses were very superficial to him, especially his chemistry course, and were facts-driven where teachers went over topics "quickly and moved on" (Interview 1). He volunteers that he doesn't remember much from those experiences because he "notoriously doesn't retain a lot of information," and also that he was a "little lazy" (Interview 1) in high school. But since he has arrived at the university, he declares that he has changed and places much more effort into his learning. Therefore, he can retain a lot of information about "stuff that interests" him, like anatomy. In the past he says he tried to avoid classes with lots of talking and writing; instead, he favors courses that are more conversational and mathematical because he enjoys talking and conversing and excels at mathematics. Jeffrey represents a low-level of preliminary conceptual knowledge of motion and force concepts in this study.

Learning for Jeffrey

Jeffrey classifies himself as a visual and kinesthetic learner. He also describes himself as a very social person, quick to engage. He states that he likes to verbalize and enjoys being able to talk about science. He remarks:

> I'm a real social person, so I like to engage with other people and be able to talk science. I'm kind of interested about science, and I'm interested in people, so it makes it a lot easier and almost enjoyable to discuss it [science]. Whereas, if I'm just reading in the book it's like, 'This is boring, it's too quiet,' you know. (Interview 1)

According to Jeffrey, learning is "actively utilizing information and retaining it by practicing active participation," which then depends on being involved and participating in classroom discussions. "The accumulation of stuff results in learning" (Interview 2), and he asserts that he knows something if he can reproduce it (verbalize it or write it) in a different manner. To actively learn he gets a general grasp of the overall concepts and then goes into detail, starting with a few chunks at a time, and then moving on. And at the end, he reviews everything and sometimes goes over his understanding of the material with other learners. He explains it this way:

> I like to get a general grasp of the concepts, and from there, I like to kind to get into details, starting with a few chunks at a time, you know, fully understanding them and then reviewing them and then moving on, doing the same thing, reviewing that portion and moving on. And then at the end, I just kind like to go over and review everything, usually with another student or someone else. (Interview 1)

In classes, he learns by taking repetitions with online notes so that he can go back and recall what has happened. He feels that he's not a good note-taker and has difficulty listening while the teacher is talking. "I can't write notes and listen at the same time" (Interview 1), he declares. He also prefers something to look at, a visual, to keep his attention. "I don't really listen to teachers that just verbalize and don't have anything to look at" (Interview 1). He also feels he has a difficult time getting a concept and breaking it down, in general, and believes that he retains knowledge that interests more, like material related to anatomy, athletic training, or physical therapy.

Before coming into the physics course, he expected lots of mathematics and detailed equations along with memorization of equations and many problem-solving exercises, the thought of which excited him. "I like math" (Interview 1), he exclaims. (In fact, Jeffrey's ideal classroom would be mathematical one with lots of repetitions of mathematics.) During his experience in physics , Jeffrey notes that his expectations of math equations within science changed because he "understands not just the equations but actually conceptualizing and thinking of them at a deeper level and actually understanding what those equations mean" (Interview 3). But he admits, it is "easier to put numbers into the equations than to critically analyze them" (Interview 1).

He says he enjoys his physics class in which he is empowered to verbalize, explain, and think critically about the meanings behind physical relationships and equations. That verbalization makes a difference, he declares, when "some things are just so obvious to the teacher that maybe it takes a student who may know a little bit less to kind of break it down in a different way" (Interview 4). Moreover, Jeffrey stated was "definitely helpful" to see other students' perspectives aided by classroom discussions. He thinks that working with others is valuable in case he is missing something, and when in groups, he asks a lot of questions to get reassurance from other learners. A big part of learning for Jeffrey is being involved and participating to actively learn. While he's reviewing materials, group learning allows him to go over the material with other students and is something he naturally likes to do anyway. Group work enables students to resolve difficulties without the teacher's assistance, he adds. He states:

> Being able just to talk in groups in class and having a consistent conversation is good because not everyone can talk to you [the instructor] the whole time during class, only one person at a time can. Usually our small groups consist of two, maybe three. And that gives me a lot more opportunity to actively participate, [Pause] reviewing and that kind of stuff, and then in the labs we are able to work its groups so that we can compare ideas and usually other students might know different things, so I get more done, (Interview 3)

And where:

> Having two or three people in a group really kept it open. It wasn't too big a group where people got lost. Everyone can stay involved. The lab groups had a lot of hands-on stuff that I really enjoyed that. I like to do those things. Even in class, every day usually my partner William and I would sit there and talk about things, and even after class, we would kind of hit on some things, what we thought were important. (Interview 4)

Jeffrey did note some social pressure in interacting within groups and that he didn't want to come off as "unintelligible [*sic*]" to other students.

From all indications, Jeff is very quick to comment and to make his voice known in the classroom. Sitting in the front row seems to help Jeff; he explains that in this way he does not become distracted, and also it allows him to comment when he feels he has something to say. However, sometimes that is a disadvantage if he speaks up too much and crowds out others when they are willing to participate. He explains:

> If there was ever a point when no one was answering a question, and I felt I knew something then I would speak up. But most the time, I like to back off and leave it open because I know I am the

> type of person that could dominate the classroom. Sometimes that does happen in other classes, like anatomy. There would be days that I would just take over and just try to do everything. And the teachers would be like, 'All right Jeffrey. Let others speak.' (Interview 4)

Now as he has grown older he says that he at times intentionally does not participate: He does this so that others are able to contribute. He notes:

> As a freshman I was definitely really trying to do everything and now I'm learning that if I'm really unsure of a concept then I'll bring it up again, and if that doesn't work , I will just go to office hours… A lot of times I would wait if I thought I had a unique view of something. Or I would always try to find something that was different, or I felt that other people didn't realize or things like that. It was kind of my way to try to add to class without dominating. (Interview 4)

Elements of Interactive Technology for Jeffrey

Even though this was his first experience with DyKnow, Jeffrey likes the "concept" of DyKnow. And as his experience with DyKnow has become more frequent, he reveals he has grown to "love it." First, he appreciates using DyKnow with the tablet PCs, especially one's ability ink on DyKnow slides with tablet PCs. "It's very useful being able to write and type during class" (Interview 1). He likes that he can see his own notes on the DyKnow lecture slides and also the student's ability to draw diagrams and equations on them. He can ink the screen while taking notes and then can save those notes, saying, "I enjoy the writing on the screen because I can erase it right there. I can save it in my notes so it's easily accessible." However, he quickly adds:

> But I don't take notes a lot, so the only time I would use it would be a shorthand version if I was using equation or something. But it's convenient that I don't have paper lying around everywhere. (Interview 4)

Jeffrey mentioned that he values using the built-in stylus and likes drawing with multiple colors. Moreover, the stylus enables him to ink with colors and be more organized. This inking can be re-sized and thus "shrunken down," giving him more space in which to work. However, he does not use the stylus for certain things, declaring, "I really don't type much, but I use the pen a lot just to kind of draw stuff, like to draw diagrams"

(Interview 4). The only downfall for tablets, he asserts, is that they "die and shut down sometimes if not connected to a power source."

Also, DyKnow is efficient for him with "no movement of [student] groups or distractions and is prettier than a chalkboard" (Interview 1). DyKnow is better than PowerPoint, he affirms, because you're able to submit with the click of a button rather than having to hand in papers, and with DyKnow it takes less time to do class work. "I would say just the varieties of options it has, not just locked into one specific strength, like Word has typing or PowerPoint is slideshows and pictures" (Interview 4). The immediate connection between the overhead projector and sharing on DyKnow are easy too. "Being able to, for you, to say 'Okay, Jeffrey explain this on the board,' and all I have to do is write on this computer screen, and it pops up for the whole class, that's fairly convenient" (Interview 2). He adds:

> I think that [use of the board] was useful. Sometimes I would be intimidated if I was incorrect, but I think that's good to kind of put you on the spot. Because if I am wrong, that's one of the best ways to learn is to just be showed that this is correct and why this is incorrect. Because a lot of times when we put something on the board after it was discussed, you would analyze what is correct. (Interview 4)

Further, Jeffrey appreciates the interactive part of DyKnow. He mentions the ability of the teacher to share information via the wireless connection on the overhead screen and to put notes online on the course Moodle site, outside of class, is important for his learning. This is different from his other classes where there's less interaction and more use of PowerPoint presentations. He remarks:

> I would say with the technology part of it, most classes are just PowerPoint-based or lecture-based. Most of the teachers just lead it, and they are open for questions but not for discussion. I think it is important to be able to hear other peoples' perspectives and the way they can explain it because sometimes the teacher can't explain in the exact way. (Interview 4)

Jeffrey further values having something in front of him to touch and with which to interact along with the ability to access various resources through DyKnow with embedded websites and simulations. He says,

> In most classes with just the lecture portion, I eventually lose interest and just stop listening so I don't learn in that class where right now with physics I'm in the front of the room, you know. You are really promoting conversation, and I have something in front of me to actually touch, use like the laptops or the notebooks. (Interview 2)

Also blocking web access was helpful for his learning. He mused:

> One thing that I noticed at the beginning of the year, students were able to access the internet on your own and that distracted some people. I noticed you eventually blocked it or something happened. That was the key to keep people focused on DyKnow. (Interview 4)

Other aspects of DyKnow are important for Jeffrey too, including polls, class evolutions, and websites. Dyknow polls are useful to see if he's correct for a given example and can show a teacher what students are learning, especially for shy or people, he maintains. Class evolutions remind him to read continuously and push him to actually understand the concepts because he doesn't want to show up "unprepared." Evolutions get the class going at the start of class, getting him on the "right track" while helping him to gauge where he is with respect other students. He notes that he sees them as the instructor's way of expecting the student to have checked and re-checked the material from the book and have "actual repercussions because whatever you are putting on the screen involves me participating." Jeffrey admits that sometimes he forgets to read the reading assignments, however. Connected to this, Jeffrey likes the daily class overview to start class. It helps to direct students on what they will review, what "new stuff to learn" and what he needs to be sure he knows. He asserts:

> Every day in class starting off with a good overview about what we are about to go through, what we're going to review, new stuff we will learn, you know, the basics are good. That's kind of tells me this is what I need to be ready for, and I need to make sure I know this. (Interview 2)

Jeffrey adds that while he doesn't use the web browsers on DyKnow, he appreciates that the instructor can bring in outside websites, like Wikipedia, to help learning. He notes:

> I would say just having access to the Internet [is important]. I don't really use it a lot, but I know you [the instructor] use it a lot which is sometimes nice. I definitely enjoy that because that shows me different ways that we can get information and different ways to relate it so that when I can kind of go back, look at that link or look at other links that are similar to it. It just kind of helps you to learn. (Interview 4)

Jeffrey uses Moodle periodically. He reviews the pdf's of the class notes when needed and appreciates the online material because he cannot write and listen at the same time. He enjoys having access to information online and feels is crucial for his test preparation. Further, looking through class notes triggers "remembrances" for him, and he looks at the class notes (and the book) to get his knowledge:

> You [the teacher] putting the notes online and me being able to go back and see the exact same notes the way you wrote them and kind of have a connection and say, 'Okay, I remember him writing this,' and it kind of makes a connection. (Interview 4)

Listed in Table 17 are some of the individual learning characteristics and reactions to the use of interactive technologies in the classroom for Jeffrey.

Table 17. Learning Characteristics and Reactions to Interactive Technology for Jeffrey

Type of Learner	Visual and Kinesthetic Likes Mathematics
Learning Style	"The accumulation of stuff results in learning" and "actively utilizing information and retaining it by practicing active participation" Vocal and quick to engage other learners Knows something if he can reproduce it (verbalize it or write it) in a different manner Gets a general grasp of the overall concepts and then goes into detail, starting with a few chunks of time and then moving on
Ideal Science Classroom	Mathematical with repetitions Being able to verbalize, explain meanings behind equations and critically think Visuals are helpful
Group Learning	Enjoys group learning Feels he is naturally social Working with others is valuable in case he is missing something Asks a lot of questions to get reassurance in groups Allows him to go over the material with other students
General impression of DyKnow	"Loved" DyKnow Very efficient and organized Many strengths and tools
Collaborative control/sharing	Values being able to see what other students are doing Forces student learners to be prepared
Tablet PCs, screen	Likes the tablets Sometimes interacts with the screen Small and can be converted to give more space
Stylus, Drawing	Likes writing on slides, drawing diagrams, and writing equations
Polling, Surveys, Evolutions	Keeps him on track Assists in showing the teacher what students know, especially for shy students Pushes him to continue reading outside class
Class notes, Moodle	Accesses and uses class notes periodically Trigger "remembrances" and "connections"
Websites, simulations	Doesn't use websites or simulations Appreciates that the instructor can use websites and simulations Likes being able to see different sources of information

Jeffrey's advice

At the beginning of his experience in the technology- enabled classroom, Jeffrey states that he felt conflicted, and at times, distracted. Taking more time to introduce DyKnow and some of its lesser known aspects would've been helpful, he adds. When asked if he'd take a class with DyKnow again, Jeffrey said,

> I don't know if I'd make a point to take a class because of that [DyKnow]. But I would say if there was a class that was lecture-based or an interactive class with DyKnow, I would definitely take the DyKnow class over the lecture because it gets boring, it's easy to lose track. You get distracted [in those classes]… DyKnow helps me regain focus if I lose it. I would say visually, yes, because if both classes put up visuals but a lot of times you can add something to the picture on DyKnow. You can point out, 'Oh here's an example.' And that makes a difference rather than you [the teacher] just trying to point with your finger [pointing to board] to say, 'This is it,' because some people just don't understand that and is bad for someone like me who has bad eyes. DyKnow is great because the picture's right in front of you so you don't have to look at the front of the room all the time. (Interview 4)

Summary for Jeffrey

Jeffrey is a visual and kinesthetic learner with a highly outgoing personality. Jeffrey believes that learning is best represented by the accumulation and repetition of different types of information. Mathematics is Jeffrey's strong suit, and he prefers to take courses where mathematics plays a prominent role. Jeffrey's ideal classroom would be the blending of his two strong attributes: verbalization/vocalization and his mathematical skills. Jeffrey loves group work in which he can make use of his excellent verbal skills while also interacting and sharing ideas with others.

Jeffrey "loves" DyKnow for myriad reasons. First, DyKnow employed with tablet PCs allows for inking on the screen. Second, it's organized and efficient. Third, it's interactive and possesses many tools that can be employed by student learners, like writing mathematical equations. Jeffrey thus can see and compare his ideas with others through collaborative control, i.e. instantaneous display student work on the projected screen and on DyKnow slides. Lastly, Jeffrey notes that polling/surveys and class evolutions enable his teacher to see what his students know, which is especially important for shy students, while websites within DyKnow can enable advance student exploration and further learning.

Jeffrey accesses course notes on the Moodle site so the class notes would trigger “remembrances” and “connections.” While appreciating the fact that the teacher can utilize embedded websites and simulations, Jeffrey doesn’t make use of them, however. Moreover, he sometimes that he feels that he is unprepared for classroom activities, but that this pushes him to read with more regularity.

Participant 3: George’s Experiences within the Overall Environment

George is a male, African-American student, majoring in pre-med and biology. He intends to enter graduate school in the field of dentistry and is from a large city in northeast Iowa. George serves as a resident assistant in one of the dormitories at the university. This university is close to home, which allows him to retain various jobs in his home city, including being part-time pizza delivery driver.

He has always been interested in science since an early age and tends to be interested in classes in biology, that is, “Ones with less math.” In high school George took advanced courses in chemistry, biology, and physics and feels that those courses along with what he’s currently learning at the university will benefit him greatly in his chosen profession of dentistry. George is in the process of applying to competitive dental schools so good grades are very important to him, and he works diligently to keep his grade-point average at an appropriate level. Course exams and coarse artifacts are abundant sources of points for George, and he tailors his studying so that he will receive high marks on them. Moreover, George is willing to accept and excel in different classroom activities and teaching techniques, including novel approaches to teaching and alternative means of assessment, as long as he is able to generate sufficient points to receive a high grade in that course. Although he achieves good scores on his exams and has high grades, he admittedly must to try harder and study longer than others. He feels it's especially difficult for him to do so, and he has to put in extra effort to get good grades. He notes:

> I know some people who don't even have to study and they get good scores on the tests (Interview 3)… I have to put more effort into it than other people. If I have to do that, I will do that, but there are definitely people who have it easier than me. (Interview 1)

When entering this physics course, George notes that his high school courses and some courses at the university gave him a basic understanding of the laws of motion and some background on Newton and other scientists. And he had done some calculations with motions, including positions, velocities, and accelerations. George represents a high-level of preliminary conceptual knowledge of motion and force concepts in this study.

Learning for George

According to George, he is an "individual learner" and considers himself somewhat of a visual learner too, especially when attending university classes and reading text materials. "I've always been someone who likes to read, get information" (Interview 1). George has multiple definitions of what learning is for him, and those definitions have evolved as his experience within the physics course has progressed. His definitions of learning for him has evolved from:

> Learning for me is just obtaining more knowledge and being able to fully understand it and apply it to real-life. It's a progression of what you know (Interview 1),

to,

> Learning is just understanding new ideas and being able to apply them in real life (Interview 2),

and then to,

> The buildup of ideas that you have about the world and things beyond the world, I guess. [Pause] It's definitely in an upward direction. You start out with less knowledge, and you gain knowledge. (Interview 3)

For George a successful way to learn something is "just to practice doing it" (Interview 1). He describes this process in which he studies teacher course notes and his own classroom notes and then comes up with his own interpretations and questions. He states:

> I study my notes and PowerPoints and then come up with questions I need to ask the teacher. I'll figure out one or two questions that I need to have answered by the teacher that I just can't figure out on my own. And then if I've overlooked something, I need the teacher to tell me about it, maybe with a certain concept that I may have passed over when I was looking at the material. (Interview 3)

George observes that he learns by practicing skills and that he understands more when he enjoys what he's doing. He mentions that he learns best alone with a self-reflection process: Many times he excels in his classes by simply looking at PowerPoint displays generated by individual teachers. "I can learn perfectly fine with the PowerPoints, and I apply that to lab and other [situations] usually" (Interview 3). George also values writing outlines from PowerPoints, which he states helps him learn the material. For example, he declares:

> Anything conceptual I can learn from the book and highlight it and make a study guide or a PowerPoint of it. I just read it over and over again until I'm able to talk about it in an intelligible way. So, memorizing is one thing, but actually understanding what you're talking about is different. You can't really get by with memorizing anything. (Interview 1)

When asked how his learning preferences changed during his immersion in physics, George mentions individual reading and his aversion to group learning.

> George: My learning preferences? Well, I had to change them, kind of. I just usually highlight everything now, and I'm not really used to that and then I go back and read it, but I usually don't do that.
>
> Q: What you do? Just read it?
>
> George: I just usually read it and write a sheet of notes that explains everything and organizes what I see.

> Q: So, when you study you do a lot of reading?
>
> George: Yeah.
>
> Q: What about studying?
>
> George: Well, that's about it, but it's just a matter of making yourself read it over and over again.
>
> Q: So do you ever get together in study groups?
>
> George: No, I try not to. (Interview 1)

Infrequently, George states he brings in outside resources like past labs or internet resources, but mostly he reads what's in the book to buttress his learning.

For George, an ideal classroom would have elements of PowerPoint presentations with missing pieces of information mixed in to keep his attention. Along with those he would include fun hands-on activities with few classroom conversations or class groupings. "You have to put in information in your PowerPoints. You have to complete an answer [in a missing area] and put in there so you're actively looking at it" (Interview 1) where:

> I like to use your PowerPoints, and they are really helpful. Because students can just, if they are dedicated, they could just print the PowerPoint out and just study the PowerPoint. That's pretty much all the information that they really need to know in addition to some other things maybe. But the PowerPoints are really helpful and the labs are kind of fun too. (Interview 1)

George is not a proponent of group learning. "I do not like them [groups]. I cannot learn in groups. When I have a study group of people, I just cannot learn" (Interview 1). Many of his classes are not lecture classes, he states, and therefore have a group-learning component:

> Well, the thing is with me is that [science] classes have changed so much that I really never have a lecture setting anymore. So it's just kind of different for me…. Not a lot of my classes, but in physics it seemed more lecture. I just don't pay attention as well. (Interview 4)

When asked if he considered the physics class a lecture type class as opposed to a group-centered environment, he said, "Kind of. I just find it kind of hard to keep active when

I'm just sitting there. So if there's something for me to do, I know I have to contribute to the conversation" (Interview 4). In his previous biology classes, they would sit down in a circle and discuss facts and concepts, but he didn't like it because it lacked PowerPoint slides with specific information for him to study. George admits that some of this resistance to group activities has to do with grades and point values, saying:

> When I'm around other people and am trying to study, I just can't focus, and I want to talk. I just want help and usually just end up helping people learn, and I don't learn anything myself. I am the one that has to tell everybody what's going on. (Interview 1)

George thus likes to work alone and at his own pace and declares that it's harder for him to understand if someone else is trying to explain it to him. "It's more stressful for me if it's my peers trying to explain to me because, I don't know, maybe they don't explain it as well as a teacher could. Sometimes group work is not helpful because students goof off" (Interview 2), he explains. George does divulge that he competes with other students if he has good group and within that type of group enjoying to doing the hard parts, i.e. the "hard work," and is very independent within that setting. Consequently, classroom conversations are of minor importance for George, beyond just making him talk to the teacher and people around him.

George sits in the front so that he does not become distracted by other learners. Being a solitary learner, he tends to be quiet, though engaged. He will comment if no one else does, just to move the conversation along and keep it from becoming stale. Rather than ask a lot of questions in class, George discloses that he is always one of the first students into the classroom and lingers to ask questions after class if he is confused about something. George also believes it is very hard for people to learn in general and very difficult for teachers to push student learners beyond their accustomed comfort levels, especially with time constraints from other courses and outside commitments. Too much teacher direction might lead to students who are too hurried in their preparation and thus not ready to answer difficult questions in class. For example, he states:

> I guess towards the end of last semester, I will be honest [Pause] I didn't read as much as I should. Instead, what I did was go through really fast and find the key concepts and just write them down on a piece of paper, and go through them quickly before a test. (Interview 4)

Interestingly he notes that, "I really could learn in the course without going to class. I could just study to my own. So in class is just hard for me to pay attention. I really get a lot of my learning on my own" (Interview 4).

Elements of Interactive Technology for George

George has no previous experience with DyKnow and little experience with tablet PCs before this course. He states the DyKnow is "awesome" for a number of reasons. First, the DyKnow program and a tablet PC allow students to interact with PowerPoint-like slides. The portable tablets are "cool," he notes, and interest him because they allow him to draw, doodle, and annotate DyKnow slides. He says that he likes to mark and color on the DyKnow slides with tablet PC stylus, consistently using different shapes and styles to augment his individual slides. George also appreciates the portability of tablets, and feels that they're more affordable than regular PCs, and personal computers cannot be marked on and are tied to the table, he states. Moreover, he says,

> The personal computer is bigger, and you can't write stuff as easily on it. You'd have to type on it and then go through with your mouse and click where you want to go and stuff. With the tablets you can stick it with your finger and just touch where you want to start typing. (Interview 1)

He also appreciates how the text and pictures are put together by the teacher so that the Tablet PCs and DyKnow work together, "go[ing] hand-in-hand and you can't have one without the other," he maintains. However, the styluses are just too easy to doodle with, he exclaims, but overall he thinks the "pens" are important. He mentions that he employs the stylus a lot during class and probably marks a little bit too much, even mindlessly doodling during class time.

Second, he observes that DyKnow is "efficient and saves time" (Interview 4). He doesn't have to print out the notes, which he says wastes paper. (If there is an imminent exam, however, he states that he can print out the notes from which to study.) George believes that the instructor notes, i.e. DyKnow slides, are well put together. "I think they're pretty cool" and volunteers that he doesn't use his own DyKnow class notes outside of class even though he knows there is more information on them. Instead, he relies on these instructor notes posted on the course Moodle site because those PowerPoints are good enough for him. "It's really nice how the PowerPoints are online, and you can access all the information after class. You can study that PowerPoints and get the entire gist just of what you need to know" (Interview 4).

Third, he is especially fond of interacting with what the teacher is saying in real-time. Teacher preparation of DyKnow slides is paramount to him, feeling that employment of blank areas on each individual slide and interactive questions aids in keeping student learners' attentions. Otherwise, he would "get bored" and lose interest. "I like to be able to interact with what you're saying and write notes off to the side," he explains. George further appreciates collaborative control, explaining:

> I think it's good to have us interact with you [teacher] and other students so you can put information on the board and change it. And students can see it on the screen and they can write extra stuff there if they want to. (Interview 2)

Thus, collaborative control feature in DyKnow helps George construct his understanding and also see what other student learners know. Yet, not everything displayed on the screen has value for George. He asserts:

> I just think it's really cool how you can do that [give control to student learners]. I don't know how important it is for students to put what they think on the screen just because they're the ones that are in the process of learning. However, if a student has a really good insight on something, then I think it would be really good. (Interview 4)

Lastly, George doesn't follow along on the overhead screen but instead looks at his own tablet's screen for class information. Since he chooses to sit in the front, he doesn't look at the projected screen as much because his viewpoint in the classroom–in front to the left of the teacher– obscures the screen.

A few other features of DyKnow are valuable for George, including polls and evolutions. He says he appreciates the competition of DyKnow polling because he gets to see what other people know and also that they are anonymous, which allows student learners to feel safe and give honest answers. He also notes how he, at times, has become competitive with other students and wants to have "answer" before everyone else in class, like during the class evolutions. He also believes polls helps students learn what material is essential for the tests and that polling keeps his attention. George clarifies that he has experienced class polling in other classes, namely his anatomy course, where they used a remote-control clicker. He contends that it is easier and more productive to give polls in those courses where there is significant content to be learned, like anatomy. DyKnow evolutions force him to come to class and know the course readings. "I can't get by [on evolutions] without being prepared" (Interview 1). Sometimes, however, George feels rushed on the evolutions, especially when they were math calculations, saying, "What happens is when we are calculating, and I don't know how to do it and just can't keep up, I don't even submit it because I don't have the right answer for it" (interview 4). Moreover, towards the end of the physics course, George notes that he kind of "got lazy" and went to Wikipedia to retrieve the answers and in general did not consistently read from the book.

Lastly, a couple of features of DyKnow were not important to George, including DyKnow replay, embedded web links and simulations, and solving of math equations. George doesn't use DyKnow replay, or even know about it. The employment of web links and simulations are "cool" and "are good for the big picture," but the problem is that a student can't print out the web links or simulations from the pdf's of the DyKnow slides, according to George. When asked if he embraces the representation of math equations and solving problems with DyKnow, including use of replay, the following exchange occurred, which shows George's distaste of mathematics:

> Q: How about DyKnow with math equations? Was that a powerful thing for you?
>
> George: I think math is challenging for me, but I haven't been pressured enough to do it.
>
> Q: So when you say pressured, what do you mean?
>
> George: I really haven't had to do a lot of math much.
>
> Q: So when you get into an environment where there is math, do you feel pressure?
>
> George: Yeah, if I know I have to do math, I will learn it, but if I can get by without doing it, I'm not going to do it because I don't like it.
>
> Q: Math is not your favorite thing?
>
> George: Yeah. (Interview 4)

Interestingly, George ever-willing to rely on using mathematical equations to solve problems when answering questions involving physics, c.f. next section.

George's Advice

George's advice for the class centers on dissemination and content of classroom notes. Since he consistently studies the PowerPoints of the class conversations, a problem for George has been trying to find the right PowerPoint for the particular day of classwork on the course Moodle site. "There's a list of them that I have to go through [on Moodle]. So maybe a more organized list on Moodle would be helpful. You can still find them if you look for them, they're still there" (Interview 4). Also, the amount of information on each slide also makes a difference for George. Therefore, an instructor must be careful on just how much to display on each individual slide, according to him. "In anatomy and physiology, for example, each classroom slide had PowerPoints, except it got to the point we didn't even really need to look at the book at all. There was just so much information the PowerPoints!" (Interview 1).

Summary for George

George is an achievement-oriented learner, studies hard, and does what it takes to achieve high grades. He is a very independent and overall does not believing group learning, for he would rather study by himself, individually. His ideal classroom would be one with lots of PowerPoint slides, i.e. lots of content, testing of that content, and lesser amounts of conversation and mathematics. A big part of George's learning thus is the employment and review of PowerPoint slides and visuals, and he tends to shun courses that have a lot of mathematics because he is not highly mathematical. George thinks that DyKnow is "awesome." He especially likes using the stylus and the tablets on which to draw and doodle. The ability of DyKnow to show instructor slides, share of content, and to see others' work are big drawing points for George.

Listed in Table 18 are some of the individual learning characteristics and reactions to the use of interactive technologies in the classroom for George.

Table 18. Learning Characteristics and Reactions to Interactive Technology for George

Type of Learner	Visual and "individual learner" Reserved and studious Does not like mathematics
Learning Style	Obtaining more knowledge and being able to fully understand it and apply it to real-life Buildup of ideas that you have about the world and things beyond the world, starting out with less knowledge and you gain knowledge Studies his notes and PowerPoints and then comes up with questions I need to ask the teacher Queries teacher before or after class
Ideal Science classroom	Lots of PowerPoint slides with blank areas interspersed within content for student to complete Fun, hands-on classroom activities Little or no group work Constant "testing" of content to collect class points
Group Learning	Has distaste of group work Feels he has a burden to carry in groups Competes with other student learners if placed in a "good group"
General impression of DyKnow	Is "awesome" Very efficient and organized Likes answer boxes and interactive questions Values to annotate the slides with stylus
Collaborative control/sharing	Appreciates how and in what ways the teacher and students could put things on the board and then change it Sometimes has obscured view of the board
Tablet PCs, screen	Likes tablet PCs Feels tablets goes hand-in-hand with DyKnow Likes the portability and affordability of tablets
Stylus, Drawing	Continually drawing and doodling in class
Polling, Surveys, Evolutions	Helps keep student attention to learn what is necessary for testing Forces him to be prepared for class Could become competitive
Class notes, Moodle	Believes class notes on Moodle are very valuable and uses them often
Websites, simulations	Are "cool" and help for the big picture

Participants' Development in Force and Motion Concepts

In this section, a general description of each participant's progress in force and motion concepts will be offered. The basics of motion encompass how an object moves, i.e. the *kinematics* of an object's motion, including concepts of position, speed, velocity, acceleration, and the use of axes and vectors in determining direction of movement. The basics of how the motion of an object varies, i.e. the *dynamics* of an object's motion, include the fundamental application of forces and Newton's Laws of Motion, based loosely on the grade 9-12 progressions within the "Laws of Motion" strand maps found in the science literacy maps (National Digital Science Library, 2012). These applications include Newton's First Law that "any object maintains a constant speed and direction of motion unless an unbalanced outside force acts on it;" Newton's Second Law that a "change in motion (direction or speed) of an object is proportional to the applied force and inversely proportional to the mass;" and Newton's Third Law that "whenever one thing exerts a force on another, an equal amount of force is exerted back on it."

Each student is assigned a level of proficiency for three different points of interest within the course. The first point of interest is after the start of class but before the first exam. The second point of interest is after the first exam but before the second examination. The third point of interest is after the second exam. The levels of proficiency in motion and force concepts range from *basic* to *expert*, c.f. Table 7 in the previous section. In this way, each participant's development within force and motion concepts is traced while using various interactive technologies.

Lauren's Development in Force and Motion Concepts

Introduction to Lauren's Development in Force and Motion Concepts

Lauren's progress within force and motion concepts is described in the following sections. Lauren represents a middle-level of preliminary conceptual knowledge of motion and force concepts in this study. Within motion concepts, Lauren moved from moderate to sophisticated to expert levels of proficiency. With Newton's First Law she moved from basic to moderate to sophisticated. With Newton's Second law she advanced from moderate to sophisticated to sophisticated. And with Newton's Third Law she advanced from basic to basic to moderate. Force and motion learning progressions for Lauren are shown in Table 19. Levels of advancement for all research subjects for each point-of-interest are displayed below in Tables 26, 27, and 28 along with a summary table, Table 29.

Table 19. Force and Motion Learning Progressions for Lauren

Point-of-Interest	Concepts of motion, including position, velocity, and acceleration	How net external force causes changes in motion 1st Law	Relationships of changes in motion to applied forces and the mass of the object 2nd Law	How forces between two different bodies relate 3rd Law
1	Moderate	Basic	Moderate	Basic
2	Sophisticated	Moderate	Sophisticated	Basic
3	Expert	Sophisticated	Sophisticated	Moderate

First Point of Interest

At the first point of interest Lauren had a moderate understanding of motion concepts. These included the basic definitions of position, velocity, and speed; understanding of setting an origin and direction for axes and vectors; the differences amongst velocity, speed, and acceleration; and a basic understanding of kinematical equations of motion for constant acceleration.

Lauren defined motion simply as "basically when something is [pause] moving," and its relationship to forces as, "when an object is in motion sometimes we know forces are acting on it, but it can still be in motion because of inertia" (Interview 1). She underscored the fact that she had little understanding of motion before her university physics course and remembered little from her physics class in high school. Yet, Lauren demonstrated an understanding of the differences between velocity and speed and between velocity and acceleration.

> Q: How about if something is in motion? How would we describe its motion?
>
> Lauren: Direction, velocity, speed. I guess velocity is speed and direction.
>
> Q: What's speed and velocity to you?
>
> Lauren: Velocity is how fast something is moving in a particular direction and speed is pretty much how fast something is moving. There's acceleration.
>
> Q: What is acceleration to you?
>
> Lauren: How fast something is getting faster [laugh]. I guess it's kind of the way to describe it. How fast something is speeding up. (Interview 1)

In Interview 1, she was asked to describe the motion of the car, initially moving at 55 mph and coming to a stop in five seconds. She responded:

> Well, you have it moving at an initial speed so if you wanted to find [Pause]. You probably want to find its deceleration because it's coming to stop. So, to do that you would use one of the equations that I don't know off the top of my head but where you could plug in the initial speed and the time and the final speed…. Then, you can find how [Pause] many meters per second the car had to decelerate in that five seconds.

Lauren thus seemed to lurch towards the obvious–putting numbers into equations retrieved from a book, and her ability to recall those forms in order to perform those calculations appeared premature. Still, she showed that for a simple situation she could quickly calculate the average acceleration and the speeds after a certain amount of time,

> Q: So with those numbers you have 55 mph in five seconds so let me ask you after the first second, how fast do you think you are moving?
>
> Lauren: Probably [Pause] 44.

> Q: Why did you say 44?
>
> Lauren: Because 55 divided by five seconds you are slowing down. You're slowing down 11 after the first second.
>
> Q: After the second, how fast would you be going?
>
> Lauren: Thirty-three. Thirty-three and then probably 22, 11, and zero.

She was also able to talk about positional change in direction and sign, signaling an earlier understanding of vectors concepts.

> Q: All right, so what do you think is happening with position of the car?
>
> Lauren: It is moving. Well, if you have your y-axis here to the left of the car.
>
> Q: So upwards? I will just draw in [draws y-axis upwards].
>
> Lauren: Yeah.
>
> Q: So maybe x and y?
>
> Lauren: Yeah, the x-axis. Yes, it is moving in, yeah, the positive direction x-direction [hesitating], and the y-direction is it relevant because, I mean, if you want to talk about it the forces are equal in the y-direction.

Thus, Lauren had a moderate understanding of motion concepts at Point-of-Interest 1.

Lauren's understanding of force concepts was still in its early stages at Point-of-Interest 1. According to Lauren's earlier understanding, forces equated with energies.

> Q: What is a force to you?
>
> Lauren: A force is [Pause], umm, like energy acting [Pause] in a direction [Pause]. Yeah I can't think of anything else. It's kind of hard to describe what a force is, but I would think energy, or I am trying to think of the synonym for force. Basically, yeah, energy.
>
> Q: Basically expending energy to do something?
>
> Lauren: Yeah, yeah.

In the above example, the forces were balanced in the y-direction so the motion did not change in the y-direction, but she still included it in her description in the horizontal motion of the car.

> Q: So what are they [forces] in the y-direction?
>
> Lauren: Gravity and the supporting force.
>
> Q: And they're not balanced?
>
> Lauren: I mean they are. They are equal so it's in equilibrium in the y-direction but…
>
> Q: How about in the x-direction? What's happening with the forces?
>
> Lauren: You have a force that is…. I mean, since obviously it is moving in the positive direction. You have a force moving it that way, which is, I guess, the wheels turning, pushing it that way.

She was quick to note, erroneously, that the object was moving in the positive direction, because there must be force moving it. This signifies a semi-Aristotelian notion of forces, where an Aristotelian notion of forces is loosely defined as a case in which an outside force is necessary to have motion. Thus, Lauren had a basic understanding of Newton's First Law at Point-of-Interest 1.

So was the car speeding up or slowing down? Were there net forces on the car in the above example?

> Lauren: It [car] is slowing down because you have friction going in the opposite direction, friction of the road. And if you're braking, you have the brakes as friction on the car, which is what is going to slow it down to 0 mph. But [Pause] you could find the force exerted by taking the mass of the car times the acceleration. That's the second law.

Lauren thus was able to cite Newton's 2nd Law and would have been able to calculate the net force applied to the car, if necessary, had the mass of the car been known. Thus, Lauren had a moderate understanding of Newton's Second Law at Point-of-Interest 1.

Further, Lauren indicated that Newton's Third Law dictates that there must be opposing force on the single, isolated object, which is not true. For example,

> Lauren: If there was absolutely no friction or anything, which there has to be something here to slow it [car] down, but if it wasn't, it we keep going at 55 mph away. That's the inertia. That's the First Law. And the Third Law, the opposing force, I mean, that is again what is going to slow you down. That's like friction combined with the brakes, you know.

> Q: Do you mean how the tires pressing on the road? Is that actually what's propelling it forward?
>
> Lauren: Like I said, the tires pressing on the road are what's propelling the car forward, but when you put those brakes down you're slowing down how fast those wheels are pressing, propelling you forward. And [Pause] I'm trying to think.... The road doesn't really, in this case of the car, exert more or less force, it's really just the brakes are new force that are coming in and exerting a force of friction.

Hence, she implied in this case that the Third Law causes the object to slow down and also confuses the directions of the vertical and horizontal forces. Lauren also had difficulty explaining how a support force can be equal to the gravitational force and noted erroneously that gravity must support a mass to keep it from moving. "Every force has a force against it," she states. Thus, Lauren had a basic understanding of Newton's Third Law at Point-of-Interest 1.

Lauren mentioned that some of the details of forces and motion had become clearer for her. She was clearly cautious, however, about describing motion together with forces.

> Q: Are you basically starting to get some details on force, or is it fundamentally changing what you thought before about forces?
>
> Lauren: Details, yeah, but velocity I always thought was, yeah, it's speed. You know how fast something is moving. I never knew what velocity was so that's kind of [Pause]
>
> Q: That's kind of fundamentally changed? I don't know if that's a good way to say it?
>
> Lauren: Yeah, velocity has more fundamentally changed because I really didn't know what that one was. Yeah, the details have become more clear so that's why I am more cautious when I talk about momentum or rotation, things I really don't know a whole lot about.
>
> Q: So you're just getting some understanding to it?
>
> Lauren: Right.

Lauren's levels of advancement for Point-of-Interest 1 are displayed in Tables 19 and 26.

Second Point of Interest

The second point of interest for Lauren came after the first exam and class introduction of force and motion concepts and while in the midst of class discussions on energy and momentum concepts. At the second point of interest Lauren had a sophisticated understanding of motion concepts, growing from moderate level at Point-of-Interest 1. She maintained a grasp of the basic definitions of position, velocity, and speed; choosing of and setting of origin and axes; differences amongst velocity, speed and acceleration; and the employment of the kinematical equations of motion for constant acceleration. Lauren showed the ability to effectively employ one-dimensional kinematical equations of motion for constant acceleration in Exam 1. Further, she was able to solve for the acceleration of a plane while landing on the deck of an aircraft carrier using positions and velocities, and thus was able to decipher the net horizontal force on the plane using kinematical equations of motion and Newton's Second Law of Motion.

When asked how her understanding of force concepts had changed since the beginning of the semester, Lauren offered an equivalence between energy and forces but also referenced how forces can affect motion.

> Q: How has your understanding of force concepts changed since we have started to talk?
>
> Lauren: Now I know force. Force makes a change of an object's movement and that you don't necessarily have to have a force to have movement. *You just have to have force to have a change in movement.* [Pause] I mean, force, hmm, I guess a never really thought about forces before physics. I just knew force was on amount of energy or something like that. I just have always thought of force as something exerted on an object, but I never thought of what it was. Now I know what it does to objects and when it's needed. (Interview 2)

Lauren thus had a moderate understanding of Newton's First Law at Point-of-Interest 2. She had moved from a semi-Aristotelian notion of motion towards a more Galilean notion of motion, i.e. one in which net forces *change* the motion of the object, not *cause* it. Her definition of force still involved energy concepts, however. “Forces are something exerted on something else, and energy is really what’s behind that force, kind of driving the force,” she explained. Lauren was also aware of the First Law when she talked about a related topic, circular motion. “You’re constantly changing your direction so you would have to have some kind of force to keep that object changing direction,” and, that:

> Q: How is force different than energy?
>
> Lauren: I mean forces, like an actual applied force? Oh, what’s another word for force? It’s actually applied to something. It’s not doing anything yet, so I guess forces are something exerted on something else, and energy is really what’s behind that force kind of, driving the force.

Lauren’s Exam 1 also seemed to show a more robust understanding of the First Law. In the exam she was asked to analyze the motion of an aircraft as it landed on the deck of an aircraft carrier. She noted that the arresting wire of the aircraft carrier applied a decelerating force on the aircraft, causing it to change its horizontal motion, or in the x-direction. Therefore, a net, outside force had caused a change in the horizontal motion of the aircraft.

Lauren had a sophisticated understanding of Newton’s Second Law at Point-of-Interest 2. On the first exam, she had little or no trouble finding the force given the object’s mass and the acceleration of the object, in that case, an aircraft being decelerated by arresting wire. She was also capable of using the kinematical equations of motion to calculate an average acceleration, which she, in turn, utilized to calculate the total outside force on the aircraft. She further had little trouble demonstrating that the vertical forces are in equilibrium while the aircraft is moving horizontally, i.e. the vertical motion is not changing since the vertical forces are balanced in that direction.

During interview two, Lauren was asked to analyze what happens when a small object in motion collides with a large object at rest.

> Q: Okay, when it [small object] comes in contact with the large object. You're saying there is a force between them?
>
> Lauren: Yeah. The large object, it's Newton's Third Law, every force has an opposing force.
>
> Q: Okay.
>
> Lauren: But this one [small object] would probably bounce off the larger.
>
> Q: Why would you say that?
>
> Lauren: Well, I guess, because [Pause] going by what we talked about in lab and the experiments with the cars running them into the wall. This is an object that's a lot bigger. One object can bounce off of the other because of the outside impulse, and then you talk about collisions with the time. And you can kind of gauge what the forces are based on the time of the impact. We don't have any cushion here that I know of, so the time is not going be increased so that forces can be pretty big if this one runs into this one and it's kind of bounce right back off so. So I guess that's what I get out of it.

In the above example, the small and large objects exert equal and opposite forces on each other. Hence, the easy response would have been to say that the force on the large object due to the small object is equal to force on the small object due to the large object, all attributable to Newton's Third Law of Motion. She made an error in saying that the force on the smaller one due to the larger one will be different than the force on the larger one due to the smaller one. Instead, Lauren attempted a complicated response, related to collisions and the use of forces and times, i.e. the concept of impulse, to the above example.

> Lauren: Well, the large object is exerting a much larger force on smaller object.
>
> Q: So you you're thinking they're going to come into contact?
>
> Lauren: Yeah, they're going to come into contact. And this one [large mass] is not going to have as much force on it as it is going to have on the small one. So, well, if it bounces off of it, the impulse would send it accelerating off in the other direction, if you wanted to look at it that way. [Pause] As far as forces go, gravity and normal force come into play as always.

Rather, these two applied forces should be the same due to Newton's Third Law of Motion. Thus, Lauren had a basic understanding of Newton's Third Law at Point-of-Interest 2. She also had a bit of confusion on the sign and direction of the acceleration of the small object, where one moves to the right yet is accelerating to the left.

> Lauren: It's kind of confusing because it's moving to the right and it's accelerating to the left. That confuses me.
>
> Q: What does that mean to you? If something is accelerating to the left, what is that?
>
> Lauren: To me that means it is speeding up to the left, but we have talked about acceleration in terms of negative and positive. It means it's decelerating, and it could mean that too.
>
> Q: So what would that mean for forces?
>
> Lauren: [Long pause] Forces? Well you would have to have friction to slow it down.

Further, at first she doesn't know which way that friction force would be applied on the mass, but she quickly corrects herself.

> Q: So where would it [friction] be directed?
>
> Lauren: Friction? It would be directed on this object upward because the gravity of this object is down. Just kidding [laughs]. It would be in left direction if it's moving right and decelerating to the left, friction would be to the left [questioning herself].

Lauren's levels of advancement for Point-of-Interest 2 are displayed in Tables 19 and 27.

Third Point of Interest

The third point of interest for Lauren came after the second exam and after classroom introductions of force, motion, energy, momentum, and rotational concepts. At the third point of interest Lauren had an expert understanding of motion concepts. She continued to exhibit an excellent overall understanding of the basic definitions of position, velocity, and speed; understanding of setting an origin and direction for axes and vectors; differences amongst velocity, speed, and acceleration; and lastly a thorough understanding of kinematical equations of motion for constant acceleration.

In Exam 2, Lauren was asked to interpret and analyze the vertical motion of an object falling through a known distance, using energy and momentum concepts. In the second exam, she was asked to describe how Dan the Bank Robber would flee the police by jumping off of a building and then hitting a ground-level airbag. In her response, she successfully integrated notions of object position, velocity, and acceleration within this "free-fall" motion, including relating positional change with energy transfer and velocity change with change in an object's momentum during a collision. Lauren correctly described the accelerated motion of this object as it fell vertically near the earth, including qualifying the gravitational acceleration near earth with negligible air resistance and noting that the object's "negative" velocity increases as the time of the fall increases.

Lauren defined motion as "movement and has to do with forces or inertia" (Interview 3). This was very similar to her earlier understanding of motion as "something is moving" (Interview 1). In Interview 3, Lauren described how linear motion is related to rotational motion, e.g. that linear motion depends on an origin and a set of axes, while rotation depends on an axis of rotation.

Lauren had a sophisticated understanding of Newton's First Law at Point-of-Interest 3. In interview 3, Lauren found it difficult to define force without using the word force:

> Force is something exerted on an object, like if you're pushing an object or pulling an object. You're putting a force on it. Like if you are pushing a box across the floor and you are putting a force on that box… So, basically, the amount of strength or [Pause], but it is hard to define force without using the word force.

She defined force as a push or pull while earlier defining a force as "energy acting in a direction" (Interview 1) and force as necessary to "change movement" (Interview 2). Lauren correctly defined for the First Law as "an object is in motion it tends to stay in motion, or if it's at rest, it tends to stay at rest." And when asked can if one can have an object moving linearly without a force, she responded:

> Yeah that's just inertia. You can be in equilibrium like when you [Pause] you have a hockey puck that is sliding across the ice that has inertia. There's no friction, there's no force either way on the puck [Pause] the only force is really the normal force, I guess. But [Pause] equilibrium is when all the forces balance out, like when a car is going down the road at 55 mph, and it is just staying like that, you know. All the forces are balanced on the car so that would be in equilibrium.

Thus, Lauren had an intuitive notion of force and understood that motion can occur even without a net outside interaction. And she continued to hold that motion can occur without a net outside linear interaction.

Lauren also related her understanding of torque, i.e. the rotational analog to force during linear motion.

> Q: So what is your understanding of torque, and how might it be different than forces?
>
> Lauren: Torque is like a force can be in a linear plane. Torque is the force that causes a rotation, so torque is always been a cause of rotation, forces in general does not have to cause a rotation but when it does, it's called a torque.

Thus, she defines torque in a similar way to force. She was further asked about the necessity of a "rotational" force for "rotational" motion, reminiscent of the Aristotelian notion of linear motion in which "linear" force would be necessary for "linear" motion. The Lauren was quick to note that rotational motion can occur without a torque.

> Q: Can you have a rotation without torque?
>
> Lauren: Yeah [Pause] you can have rotational inertia. If something is rotating, it's going to stay rotating but that torque is going to cause it to change direction or rotated a different way.
>
> Q: So on object in rotation, tends to stay in rotation?
>
> Lauren: [Pause] Let's see, something that would be in rotational equilibrium would be like two people on a teeter totter and both people weigh the same exact weight, and they both are both exactly the same distance away from the axis. That would be rotational equilibrium because the forces are the same and torque is the same since torque is like the lever arm times the force.
>
> Q: What would happen if your forces in that case you weren't the same, like a weight force might not be the same?

> Lauren: Then it would go, it would tip towards a side because your forces are all different although your torque would be different too because your weights are different.
>
> Q: Your forces are different?
>
> Lauren: Your forces are different so your torque would be different.

Lauren had a sophisticated understanding of Newton's Second Law at Point-of-Interest 3. In Exam 2, Lauren correctly detailed change in motion of Dan the Bank Robber and stated that Dan's motion would be accelerated by an outside force, i.e. an airbag, and that Dan's motion would be affected more readily because his mass was smaller than the object with which he was colliding, the earth.

Lauren had a moderate understanding of Newton's Third Law at Point-of-Interest 3. In exam two, Lauren interpreted the example of Dan the Bank Robber fleeing the police by jumping off of a building and then hitting an airbag. She explained the change in motion using momentum and impulse concepts, saying:

> When Dan collides with a bag, an impulse is applied on the bag. The bag in turn has an equal and opposite force on Dan, which causes him to rebound. The bag is a larger mass than Dan and is sitting in the ground, so although there are equal and opposite forces in this collision, Dan will be rebounded upwards. (Exam 2)

In other words, when Dan interacts with the bag, Dan and the bag exchange equal and opposite forces, thus causing Dan's momentum to change. Therefore, she was able to both identify Newton's Third Law and utilize it in a very complicated example.

Lauren further described how her understanding of motion and forces in Interview 3, and how these experience with motion and forces had impacted her understanding of her chosen field, physical therapy. These included the overall use of Newton's laws of motion and the application of forces onto a body. For example, Lauren talked about the importance of force and Newton's Third Law, while the same time minimizing the impact of Newton's First Law.

> Q: Do you think the PT [physical therapy] people would have some familiarity with Newton's laws of motion?

> Lauren: Yeah, probably.
>
> Q: What do you think that they would know?
>
> Lauren: They would have to know that every force has an equal and opposite force, you know. [Pause] I am guessing that physical therapy doesn't have a whole lot to do with inertia, like Newton's First Law because we are not normally in inertia, I guess.
>
> Q: Why do you have to know forces?
>
> Lauren: You have to know how much force you can put on, you know, somebody, and which direction and stuff like that. I don't know like a lot yet because I haven't taken biomechanics.

When asked how the physics of motion might apply to her chosen field, Lauren said:

> Sometimes it's [physics] hard to apply, but I think everything that I learned in my science classes obviously applies to real life. Like in physics, motions apply to everything we do every day, and all my other science classes, they apply to my field.

Lauren illustrated this with the example of what a physical therapist might encounter with the patient who had knee surgery, and how forces would be involved:

> Knee patients when they come out of surgery or like a couple days out of surgery, they [physical therapists] like to measure the angle of their knee joint. The therapist will go up and press down as much as they possibly can on the knee to flatten it out as much as they can. Now that's a force! They're putting a force on the knee. And then measuring the angles, the angle of the knee, you know, and stuff like that. Or you put them through an initial strength test to see how far from their baseline they are. Or if they are sitting in a chair, you'll tell them, "Press against my hands," which is a test of force strength.

Lauren's levels of advancement for Point-of-Interest 3 are displayed in Tables 19 and 28.

Lauren's Force and Motion Concept Evaluations

The pre- and post-instruction administrations of the Force and Motion Concept Evaluation (FMCE) for Lauren occurred before and after course instruction on motion and force concepts. The results for Lauren are shown in Figure 4 below.

Lauren's performance on the pre-instruction evaluation was quite weak with an overall pre-score of 13.5% (The Physics Education Research Laboratory, 2012). All individual clusters results, including evaluations of the forces and motion on a sled example, reversing directions and movements, graphs of forces, accelerations, and velocities, and Newton's third law, were low. Initially, Lauren had some idea of general force concepts, c.f. bar graph of "Force Sled" and "Velocity Graphs," but little else.

The after-instruction results were more promising. Lauren made progress on many clusters. She responded correctly on all questions related to "Reversing Directions" and "Force Graphs." Her overall gain[21] for all questions was 40.6% with advancement in "Newton's Third Law," "Acceleration Graphs," and "Velocity Graphs". However, she made little or no progress on "Force Sled," "Reversing Direction," and "Force Graphs" questions.

Lauren's Maryland Physics Expectation Survey

The pre- and post-instruction administrations of the Maryland Physics Expectation Survey (MPEX) for Lauren occurred before and after course instruction on motion and force concepts. For the analysis below, the strength of this change in the favorable/unfavorable score is defined as Table 20 below. It should be noted that the design of the assessment indicates that a large increase (decrease) in a favorable response matched with a large decrease (increase) in the unfavorable response is define as a positive (negative) result. A positive result then means the student's beliefs/attitudes about physics moves toward expert opinion on the MPEX assessment.

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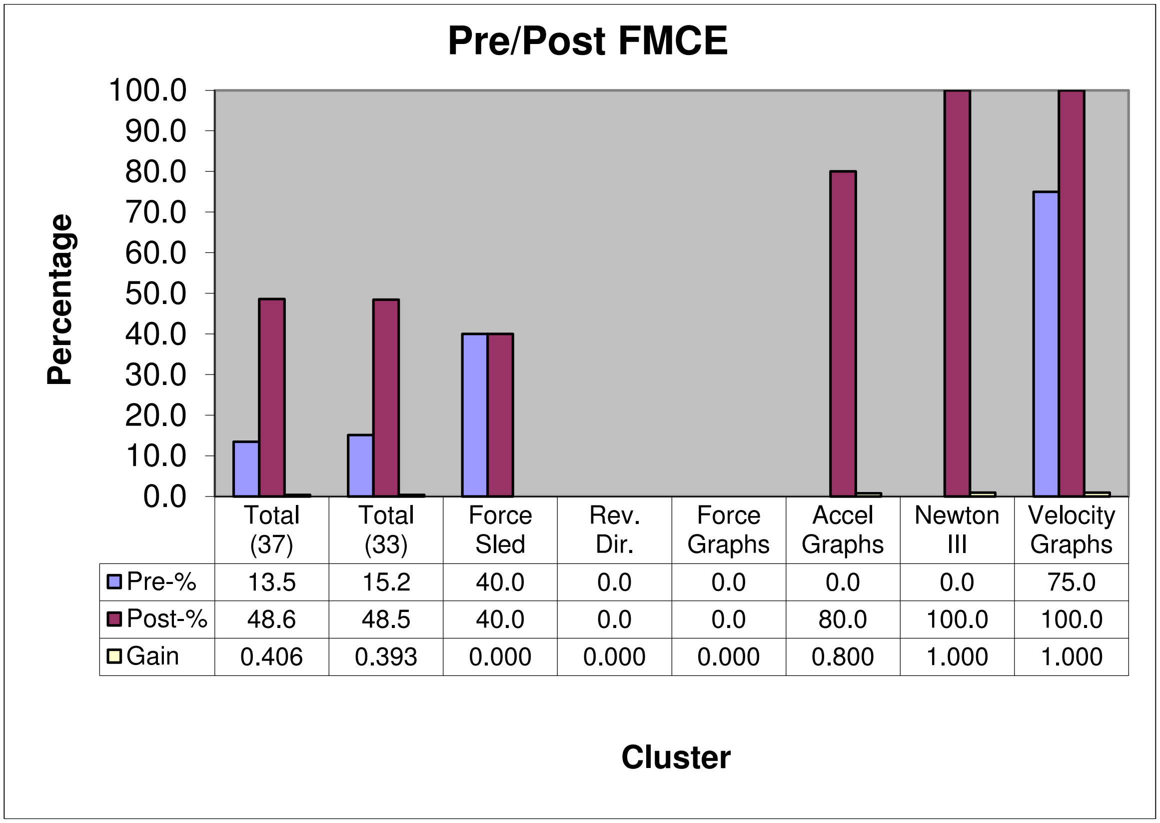
[21] Gain is a measure of the normalized gain: What percentage of the possible improvement did they attain? $Gain = \frac{Post-\%-Pre-\%}{(100-Pre-\%)}$



	Total (37)	Total (33)	Force Sled	Rev. Dir.	Force Graphs	Accel Graphs	Newton III	Velocity Graphs
Pre-%	13.5	15.2	40.0	0.0	0.0	0.0	0.0	75.0
Post-%	48.6	48.5	40.0	0.0	0.0	80.0	100.0	100.0
Gain	0.406	0.393	0.000	0.000	0.000	0.800	1.000	1.000

Figure 4. Lauren's Performance on Force and Motion Concept Evaluation (FMCE) Results for Pre- and Post-Instruction

The results for Lauren are shown in Table 21. Table 21 displays Lauren's pre- and post-assessment scores changed in each of the categories. Lauren's "Overall" favorable score moved upwards considerably from 47 to 79, while her unfavorable score moved downwards from 5.9 to 2.9. This indicates a strong improvement in favorable attitudes towards learning physics. In the post-assessment, she also showed perfectly favorable scores, i.e. no unfavorable responses, in the following categories, including "Independence," "Coherence," "Concepts," and "Reality." In the "Math-Link" and "Effort" categories she became more unfavorable and also more unfavorable.

Table 20. Strength of Changes Amongst Pre- and Post-Instruction on Force and Motion concepts

Strength of Change	Change Amount	Symbol
Large	Change ≥ 30	+++,---
Moderate	30 ≥ Change ≥ 10	++,--
Small	10 > Change	+,-

Table 21. Lauren's MPEX Pre- and Post-Assessment Results for Each Category

Cluster	**Status**	**Pre Score**	**Post Score**	**Change**	**Strength**	**Expert Opinion**
Overall	Favorable	47	79	+++	Large	Toward
	Unfavorable	5.9	2.9	-	Small	
Independence	Favorable	50	83	+++	Large	Toward
	Unfavorable	0	0	0	Zero	
Coherence	Favorable	80	40	---	Large	Ambivalent
	Unfavorable	20	0	--	Moderate	
Concepts	Favorable	20	100	+++	Large	Toward
	Unfavorable	20	0	--	Moderate	
Reality	Favorable	75	100	++	Moderate	Toward
	Unfavorable	0	0	0	Zero	
Math-Link	Favorable	20	40	+++	Moderate	Ambivalent
	Unfavorable	0	20	++	Moderate	
Effort	Favorable	40	60	++	Moderate	Ambivalent
	Unfavorable	0	20	++	Moderate	

Another way to analyze the results for the MPEX is to look at pre-and post-normalized movement. Lauren exhibited a positive normalized change, in the second quadrant, in her "Overall" score and for the "Concepts" category. [It should be note that, as Wittman (2002a) states, "Movement in the second quadrant (favorable scores increase, unfavorable scores decrease) indicates improvement" (p.10)]. She also became more favorable in "Reality," and "Independence," but at the same time showing no normalized movement unfavorable for those categories. Lauren did not show a normalized unfavorable increase in any category. However, for "Coherence," she became both less favorable and also less unfavorable, and for "Math-Link" and "Effort" she had moderate increases in both favorable and unfavorable responses, which could mean more neutral responses for these categories, c.f. Figure 5.

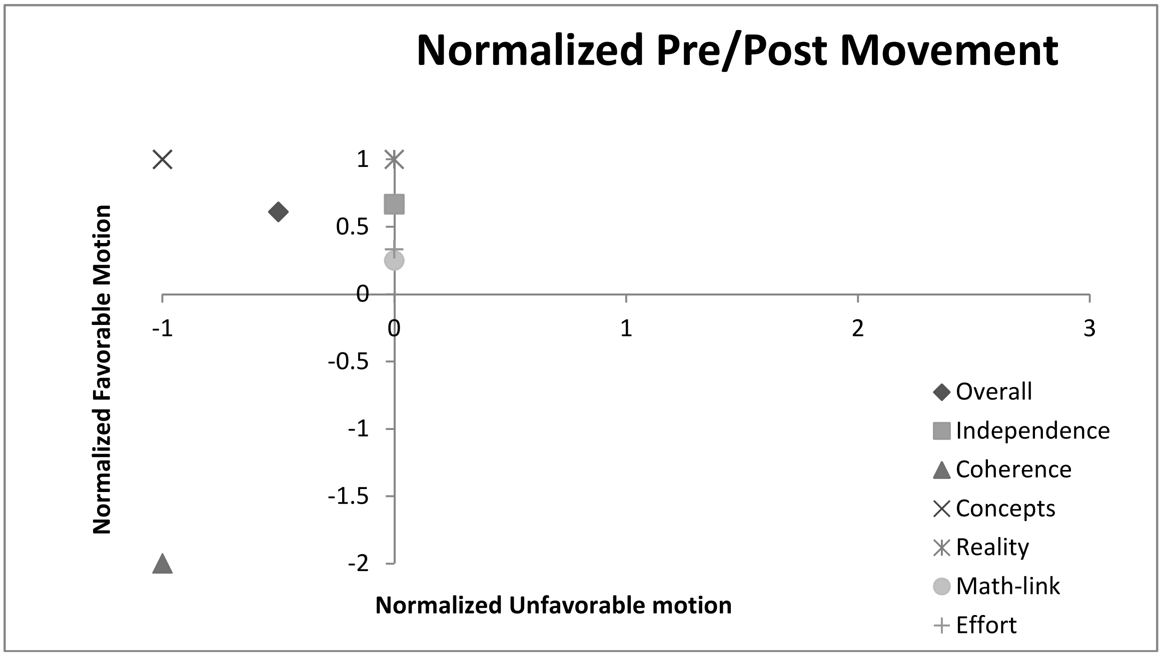


Figure 5. Lauren's Normalized Pre- and Post-Assessment Movement for Each of the Categories

Jeffrey's Development in Force and Motion Concepts

Introduction to Jeffrey's Development in Force and Motion Concepts

Jeffrey's progress within force and motion concepts is described in the following sections. Jeffrey represented a low-level of preliminary conceptual knowledge of motion and force concepts in this study. Within motion concepts, Jeffrey moved from moderate to sophisticated to sophisticated levels of proficiency. With Newton's First Law he moved from basic to moderate to moderate. With Newton's Second Law he advanced from moderate to moderate to sophisticated. And with Newton's Third Law he progressed from crude to basics to moderate. Force and motion learning progressions for Jeffrey are shown in Table 22. Levels of advancement for all research subjects for each point-of-interest are displayed below in Tables 26, 27, and 28 along with a summary table, Table 29.

Table 22. Force and Motion Learning Progressions for Jeffrey

Point-of-Interest	Concepts of motion, including position, velocity, and acceleration	How net external force causes changes in motion 1st Law	Relationships of changes in motion to applied forces and the mass of the object 2nd Law	How forces between two different bodies relate 3rd Law
1	Moderate	Basic	Moderate	Crude
2	Sophisticated	Moderate	Sophisticated	Basic
3	Sophisticated	Moderate	Sophisticated	Moderate

First Point of Interest

At the first point of interest Jeffrey had a moderate understanding of motion concepts. These included the basic definitions of position, velocity, and speed; understanding of setting an origin and direction for axes and vectors; the differences amongst velocity, speed, and acceleration; and a basic understanding of kinematical equations of motion for constant acceleration. Jeffrey also had a basic understanding of kinematical equations of motion for constant acceleration.

Jeffrey defined motion in Interview 1, saying:

> Motions… There are different kinds of motion, like understanding that there is linear motion, which is lot more basic and easy to kind of learn about. And speeds and velocities also because, you know, velocity includes direction so being in a linear state of movement, your calculations are easier. If there is no change in direction, so velocity is pretty much the same as the magnitude of the speed

> with the exception of the directional portion. Motion can be, [Pause], it's hard to really break this down in a simplified way.

Jeffrey was thus able to see the difference between speed and velocity. But, he encountered difficulty explaining exactly what motion was to him and did not cite a need to have any origin or directions for axes without prompting.

> Q: Hard to do [define motion]?
>
> Jeffrey: Yeah, motion is really difficult to explain. You almost need information to jump off of.
>
> Q: And so motion for you is what?
>
> Jeffrey: Movement of an object would be very broad way of saying change in position of an object [Pause].
>
> Q: Now, before this class, how would you have said motion? Would you have used simpler terms or?
>
> Jeffrey: I would've said motion is the same as movement.

During interview one, he was asked to describe the motion of a car initially moving at 55 mph and coming to a stop and five seconds. He relates:

> Right now, in this example, the car is obviously in a linear motion because it's moving in one direction. It is not going up or down. It's going straight to the right. So, in this case, you know, I would put the start of the x-axis on the left and the positive being to the right, knowing that position is changing towards the right, in a positive manner. I understand that there are forces that the brakes are applying on the car, which are slowing it down or decelerating it. So its initial speed is going 55, so in five seconds it decelerates to zero.

He was therefore able to define a set of axes and described directions of motion. And with prompting from the questioner, Jeffrey was able to define motion, the need for directionality, and was able to quickly calculate the average acceleration. He further cited the need to use calculations and that he had the ability to perform simple calculations.

When asked about individual forces, Jeffrey defined a force is as a push or pull where:

> Q: Now, tell me what your understanding of forces is? What are forces?
>
> Jeffrey: Forces? They are pushes and pulls on an object. Usually the object has to have matter in order for forces to be applied on it. And usually when there is a force on something, there is an equal and opposite force on it somewhere, unless up in space where it's just Newton's First Law. It just takes off in that direction of the force, and it [velocity] is just constant until another force acts on it.

Jeffrey was quick to define Newton's laws and stated that they make a good "reference" for him.

> Q: So, tell me what your understandings of Newton's Laws are? How do they relate to the actual forces?
>
> Jeffrey: It's kind of just a nice reference because just knowing Newton's First Law that object in motion stays in motion and Newton's Second Law that forces are equal to mass times the acceleration, and then Newton's Third Law being every force has an equal and opposite force, that's kind of general. It's just kind of a nice reference in that you can kind of go back to and think about when you're describing motion and thinking about it. And going, oh well, you know Newton was very sophisticated on the subject and will just go back to Newton and his laws, like for force, you need mass and some accelerations, and usually occurring unless there is a force of zero. [Pause] The net force is important kind of a force because that decides whether there is acceleration, deceleration, you know, or a change in speed or velocity.

He was able to define Newton's First Law and had a definition of force. However, he still held a semi-Aristotelian notion that a force needs to be present in order to give motion, "for something moving, there need to be forces, pushes or pulls." Jeffrey therefore had a basic understanding of Newton's First Law at Point-of-Interest 1. He could also define Newton's Second Law and could do basic calculations for simple cases, like a car decelerating o an object slowing. Jeffrey thus had a moderate understanding of Newton's Second Law at Point-of-Interest 1.

Jeffrey had a basic understanding of Newton's Third Law at Point-of-Interest 1. Jeffrey understood the general interaction between the ground and a car, i.e. the ground and the car exchange forces. For example:

> Q: So which way would the pushes or pulls be here [pointing to the example]?

> Jeffrey: The pushes and the pulls? The forces would be the ground pushing on the car upwards and the car, while it's braking, is pushing forward and slowing down because of the ground pushing back on it.

But, he was confused on part of the Third Law: he felt that if every force had and equal and opposite force, there should always be equilibrium, i.e. if forces were always balanced, then there would be no change in motion, ever.

> Q: What are some basics of force and motion that we need?
>
> Jeffrey: Forces, like, pretty much basically like Newton's Third Law, every force has an equal and opposite force. I think that's pretty basic and general, and everyone needs to know it. Support forces are very important, knowing that gravity is pulling me down and there's something holding me up, a force, not just a block of wood or whatever [Pause, questioning himself] forces? Push and pull, I mean [Pause].

Jeffrey further explained that forces and motion concepts had become clearer for him up and until that point in the course,

> Q: So when you came into the course what was your understanding of Newton's Laws and forces? Has it changed?
>
> Jeffrey: I heard about an object in motion stays in motion, but I didn't know it was through Newton. I really didn't know about Newton's Laws, so I knew the concept, but I didn't understand it. I just assumed that it doesn't make sense, you know, because if I walk and speed up and slow down, I am an object in motion, but I don't always stay in motion, so I never understood it, you know. I didn't have knowledge of any forces really. I never thought of it that way. I was never taught about it.
>
> Q: You just hadn't put it all together, maybe?
>
> Jeffrey: Yeah, I just never even cared to think about it. I didn't understand the importance of forces.

Jeffrey's levels of advancement for Point-of-Interest 1 are displayed in Tables 22 and 26.

Second Point of Interest

The second point of interest for Jeffrey came after the first exam and class introduction of force and motion concepts and while in the midst of class discussions on energy and momentum concepts. At the second point of interest Jeffrey had a sophisticated understanding of motion concepts. He continued to have a grasp of the basic definitions of position, velocity, and speed; choosing and setting an origin; the differences amongst velocity, speed, and acceleration; and the kinematical equations of motion for constant acceleration. He was further able to correctly explain and analyze the specific positions, velocities, and speeds in Exam 1 and performed simple calculations with the kinematical equations of motion for constant acceleration, in this case, a deceleration due to an arresting cable on the deck of the aircraft. Moreover, Jeffrey had little trouble with the signs or directions of axes within the Exam 1 question.

It should be noted that the second interview with Jeffrey was quite different from the first interview in terms of forces and force concepts. Due to the fact that energy and momentum concepts were being discussed at the time in classroom, many of Jeffrey's answers to questions during this interview centered on energy and momentum ideas, as opposed to force and motion concepts. However, his fundamental interpretations of force and motion concepts were apparent within these explanations. In fact, his capability to incorporate force and motion ideas within a framework of energy and momentum concepts assured a clear grasp the basics of those ideas where:

> Q: So how would you stop it [an object]? What would you have to do to stop an object if it's moving?
>
> Jeffrey: Have an impulse [force over a time period] on it.

Hence, in order to change the motion of an object, an outside agent would have to apply an impulse, i.e. an outside force applied over period of time. In Interview 2, Jeffrey was also requested to describe a collision between two objects in terms of forces, i.e. a collision between a small and a large mass. Jeffrey had a difficult time reconciling energy and momentum ideas with earlier force concepts.

> Q: Okay, so that would be, maybe, momentum language right? So how would you say it in in force language?
>
> Jeffrey: Force language? [Pause] You would probably have kinetic energy acting on it I would say.

> Q: Kinetic energy acts on it [Pause]. What does that mean?
>
> Jeffrey: So, I am trying to think of this in energy terms. So, an object has mass obviously, and when it is moving, has kinetic energy and when this object acts of another object, it transfers the kinetic energy.
>
> Q: So what's a transfer of kinetic energy for you?
>
> Jeffrey: What do you mean?
>
> Q: We have a special case.
>
> Jeffrey: Collision?
>
> Q: Well, for momentum definitely it would be collision. I think we used the word "work."
>
> Jeffrey: Oh yeah.
>
> Q: We said it had something to do with energy. What is your understanding of work?
>
> Jeffrey: Force applied over a distance.

Jeffrey was therefore adept at connecting forces with energies if prompted. Also, he recognized that the transfer of energy was work and work depended on the exertion of force over a distance. However, in many ways, Jeffrey's Exam 1 allowed for a better understanding of Jeffrey's knowledge of motion and force concepts due to the fact that the only concepts on which being tested, at the time, were force and motion concepts. During this exam, he is asked to analyze the motion of an aircraft as it lands on the deck of an aircraft carrier. He successfully analyzed the problem and was able to calculate the constant acceleration of the aircraft from the given one-dimensional kinematical equations of motion for constant acceleration.

Jeffrey had a moderate understanding of Newton's First Law at Point-of-Interest 2. In Exam 1, Jeffrey noted that stationary object will not move unless there is a net outside force placed on it. He thus had advanced from an Aristotelian notion of motion towards a Galilean notion of motion. He also correctly discerned that objects with bigger masses, i.e. with larger inertias, will change their motion less readily than smaller objects with lesser amounts of inertia. In his response to the exam question, Jeffrey added that large objects could also be accelerated greatly if a large force happens to be given on it by an outside agent, say by an arresting wire.

Jeffrey had a moderate understanding of Newton's Second Law at Point-of-Interest 2. He was able to use the second law equation, both in composing force diagrams and in analyzing the mathematical relationship for the given motion in Exam 1. Further, he was able to analyze and describe the various forces on an aircraft while it is being decelerated by the arresting wire. He explained that the vertical forces are in equilibrium when the aircraft is moving horizontally, i.e. the vertical motion is not changing. He further successfully used a free-body-diagram to interpret forces on Exam 1.

Jeffrey had a basic understanding of Newton's Third Law at Point-of-Interest 2. On Exam 1, Jeffrey confused "equal and opposite" and the equilibrium of external forces in a certain direction. He incorrectly noted that if aircraft lands horizontally onto the deck of an aircraft carrier, the downward force of gravity is equal to the upward force from the ground onto the aircraft due to Newton's Third Law. Therefore, he still held a nonconventional notion of Newton's Third Law.

Jeffrey's levels of advancement for Point-of-Interest 2 are displayed in Tables 22 and 27.

Third Point of Interest

The third point of interest for Jeffrey came after the second exam and the classroom introductions of force, motion, energy, momentum, and rotational concepts. At the third point of interest Jeffrey had a sophisticated understanding of motion concepts. He continued to show a sophisticated understanding of the basic definitions of position, velocity, and speed; understanding of setting an origin and directions for axes and vectors; differences amongst velocity, speed, and acceleration; and lastly a thorough understanding of the kinematical equations of motion for constant acceleration.

In Exam 2, Jeffrey was asked to interpret and analyze the vertical motion of an object falling through a known distance, using energy and momentum concepts: Dan the Bank Robber fleeing the police by jumping off of a building and subsequently hitting an airbag. In his response, he successfully integrated notions of object position, velocity, and acceleration within this "vertical" motion, including relating positional change with energy transfer and velocity change with change in an object's momentum during a collision. Jeffrey further correctly described the accelerated motion of this object as it fell vertically near earth.

In Interview 3, Jeffrey defined motion in terms of rotational motion. He described how linear motion involves the "progress" of an object in which an object moves along an axis and thus away from a starting point, while for rotational motions, objects return to their starting point, i.e. "square one," asserting:

> I would say the biggest difference is just the fact that your placement or position [Pause] in linear motion. You are always getting farther and farther away from the origin they started at. Whereas, in a rotation, you are pretty much always going back [to the starting point]. Every time you're making a full rotation, you are back to *square one* where you started. So you are not making progress in position. (Interview 3)

When asked if rotational motion is any different than linear motion, the following ensued:

> Jeffrey: Well, I guess positions are a big difference because you are not really making much progress except with respect to the center axis [in rotational motion].
>
> Q: Right.
>
> Jeffrey: [Pause] They are very similar except the direction you're going, I would say. And the forces kind of change because you add a centripetal force when you're going to rotation, to keep it moving in a circular motion. [Long Pause] They are very similar, in a lot of ways.

Jeffrey further discussed what a centripetal force was for him. He explained a sample motion of a mass on a string and then related it to linear motion, stating:

> Normally I would say get a string and tie an object to the end of it. It [centripetal force] would then be the pulling of the string, usually with your hand and pulling the string so that the force [on the

> object] is always pulling it towards your hand. So, that's kind of unique because the force direction is always moving but at the same time always towards the center of the motion. Whereas, with a linear motion usually the force is moving the object forward.

Jeffrey had a moderate understanding of Newton's First Law at Point-of-Interest 3. Jeffrey defined force as, "a push or pull" or "anything that really accelerates an object or moves it" (Interview 3). Jeff was able to define Newton's First Law for linear motion and also to extend its applicability to a rotational example, a teeter totter. Jeffrey discussed the magnitudes of forces within this rotational example, i.e. an example where forces are applied at varying distances from a point of rotation, i.e. a fulcrum, in order to affect a rotational equilibrium. He noted in Interview 3 that in order to continue this state of rotational equilibrium for the teeter totter, the magnitude of a force must increase if you are closer to the fulcrum of the "teeter totter."

> Jeffrey: So I was just thinking about the amount of force that is required to lift heavy objects.
>
> Q: So why do you think that it's a large force?
>
> Jeffrey: Yeah, I would say it's a large force because you are very close to the fulcrum of the axis, the torque is a lever arm times force so if one is bigger the other has to be smaller and vice versa so there's a correlation.

He explained this as continuing a motion, in this case a rotational motion, by applying a balanced set of torques about an axis. This answer demonstrates that Jeff is able to extend the applicability Newton's First Law of Motion to a case where there is a rotational analog. Unfortunately, Jeff later confuses the application of Newton's First Law and the notion of "equal and opposite forces" when describing equilibrium, c.f. below.

Jeffrey had a sophisticated understanding of Newton's Second Law at Point-of-Interest 3. In Exam 2, Jeffrey interpreted the example of Dan the Bank Robber fleeing the police by jumping off of a building and then hitting an airbag. Jeffrey described Dan's "vertical" motion in terms of energy and momentum with forces playing an outsized role. Jeffrey explained that as Dan fell, collided with an airbag, and rose to a certain height, he was experiencing outside forces, which caused his energy and momentum values to change. His analysis of the motion demonstrated a sophisticated understanding of how applied forces can impact numerical values for energy and momentum at given points of the motion and that changes in these values affected Dan's motion.

Jeffrey had a moderate understanding of Newton's Third Law at Point-of-Interest 3. Jeffrey defined and applied Newton's Third Law in the complicated example from Exam 2. He clarified the change in motion of Dan the Bank Robber using momentum and impulse concepts:

> When Dan jumps, he will experience Newton's Third Law which is whenever an object (Dan) exerts a force on a second object (airbag on the ground), the second object exerts an equal and opposite force on the first.… During the collision, energy is transferred between Dan and the bag, and Dan bounces back up. (Exam 2)

In other words, when Dan interacts with the bag, Dan and the airbag exchange equal and opposite forces, thus there exists an energy transfer to cause Dan to bounce back upwards. Therefore, he was able to both identify Newton's Third Law and use it in a complicated example. During interview 3, Jeffrey provided a definition of force and then correctly stated that a given object would not necessarily move because of an application of an external force. But, he then reasoned incorrectly that an object's lack of motion was attributable to Newton's Third Law, i.e. due to equal and opposite forces, like the interaction between a supporting force and a person's weight force.

> Jeffrey: Force is anything that really accelerates an object or moves it. It doesn't always move it just because you can apply a force, because [Pause] the equal and opposite force could be enough to result in no movement.
>
> Q: So when you say equal and opposite you mean?
>
> Jeffrey: Like Newton's Third Law. If I push on a wall, I'm applying a force on the wall as the wall applying a force in my hand
>
> Q: Yeah.

> Jeffrey: Or if I'm standing and my weight applies a force on the ground, and the normal force is supporting me.
>
> Q: So I hear you saying that the weight force between you and earth, you are being pulled down?
>
> Jeffrey: Yeah.
>
> Q: And between, you know, you and the ground, the ground is pushing you up. That's what I'm hearing you say.
>
> Jeffrey: Exactly.

When queried about how the physics of motion might apply to his chosen field, Jeffrey explained that forces affect how the body moves and changes its motion. In Interview 3, Jeff discussed the forces of muscles being transmitted through tendons. This related to his chosen field of physical therapy in two ways: application of force by a muscle's tendon and the therapeutic use of ultrasound waves. He included brief explanation of how the body applies force through tendons and heat therapies, like ultrasound.

> Q: Why is a tendon sort of important?
>
> Jeffrey: A tendon? Well, all the strength of the muscle is going straight through into the tendon, so there is a lot of force being applied. One tendon, usually tendons are fairly strong, and they can withstand a lot of force. But, on the other spectrum, obviously people can tear theirs when they are getting all that force going through it.
>
> Q: It's hard to heal maybe?
>
> Jeffrey: Yeah. And then you mentioned you had an ultrasound done, using the longitudinal waves to penetrate through the muscle to see it. On the other spectrum to heal it, where I would be using it more to increase the blood flow and stuff.

Jeffrey's levels of advancement for Point-of-Interest 3 are displayed in Tables 22 and 28.

Jeffrey's Force and Motion Concept Evaluations

The pre- and post-instruction administrations of the Force and Motion Concept Evaluation (FMCE) for Jeffrey occurred before and after course instruction on motion and force concepts. The results for Jeffrey are shown in Figure 6 below.

Jeffrey's performance–like all of two other participants–on the pre-instruction evaluation was quite weak with an overall pre-score of 21.6% (The Physics Education Research Laboratory, 2012). Jeffrey scored low on all individual clusters results, except graphs of forces and velocity. Thus, Jeff had some prior knowledge of graphing of forces and velocities before entering the class.

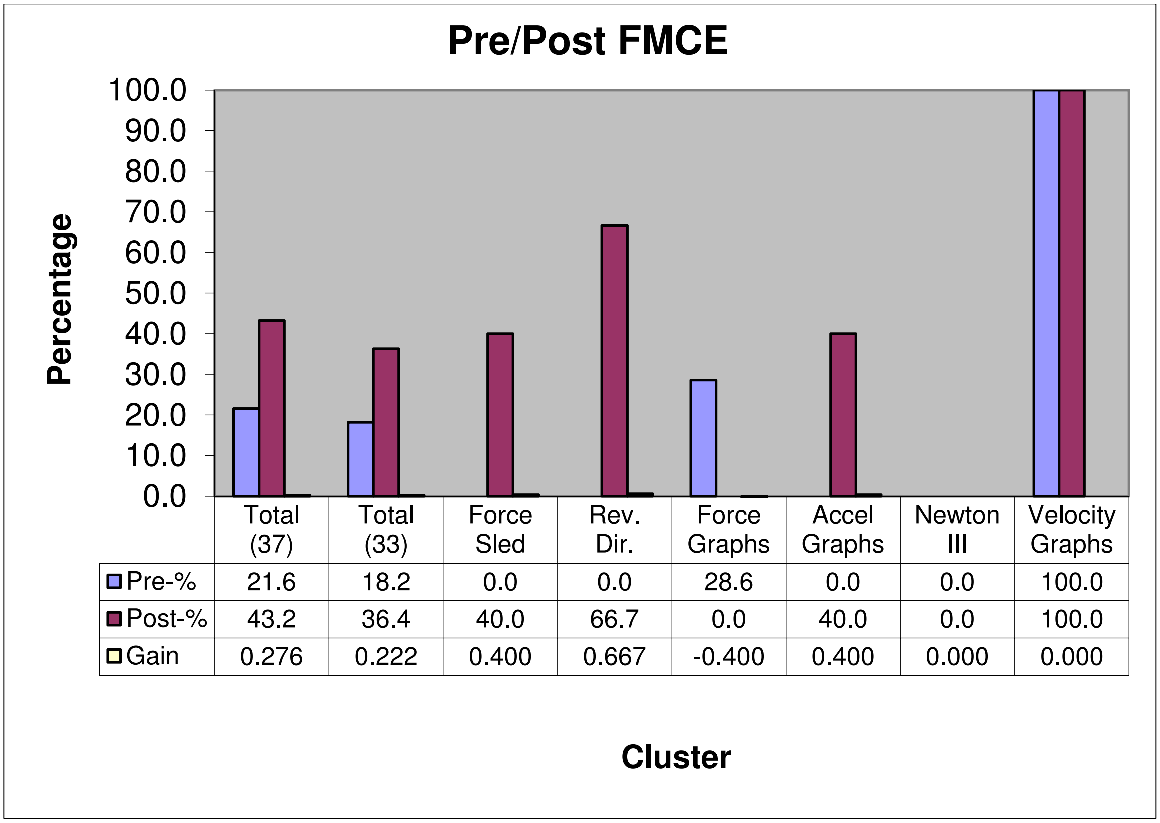
Like the other participants, the after-instruction results were more promising. Jeffrey made progress on many clusters as displayed below. His overall gain[22] for all questions was 27.6% with large advancements on "Force Sled," "Reversing Direction," "Acceleration Graphs." Interestingly, he made negative progress on "Force Graphing" questions, while making no progress on "Newton's Third Law."

Jeffrey's Maryland Physics Expectation Survey

The pre- and post-instruction administrations of the Maryland Physics Expectation Survey (MPEX) for Jeffrey occurred before and after course instruction on motion and force concepts. The results for Jeffrey are shown in Table 23 below.

---

[22] Gain is a measure of the normalized gain: What percentage of the possible improvement did they attain? $Gain = \frac{Post-\%-Pre-\%}{(100-Pre-\%)}$



	Total (37)	Total (33)	Force Sled	Rev. Dir.	Force Graphs	Accel Graphs	Newton III	Velocity Graphs
■ Pre-%	21.6	18.2	0.0	0.0	28.6	0.0	0.0	100.0
■ Post-%	43.2	36.4	40.0	66.7	0.0	40.0	0.0	100.0
□ Gain	0.276	0.222	0.400	0.667	-0.400	0.400	0.000	0.000

Figure 6. Jeffrey's Performance on Force and Motion Concept Evaluation (FMCE) Results for Pre- and Post-Instruction

Table 23 displays Jeffrey's pre- and post-assessment changes in each of the categories. Jeffrey's "Overall" favorable score moved slightly upwards from 74 to 82, while his unfavorable score inched downwards from 15 to12. This indicates a slight improvement in overall favorable attitudes towards learning physics.

In the post-assessment, he exhibited a mix of favorable and unfavorable responses with a perfectly favorable score in only one category, "Concepts." Between pre- and post-assessments, he showed an increase in favorable and a decrease in unfavorable scores in "Independence," "Coherence," and "Concepts." However, he displayed a decrease in favorable and an increase in unfavorable scores in the categories of "Reality," "Math-Link," and "Effort."

Table 23. Jeffrey's MPEX Pre- and Post-Assessment Results for Each Category

Cluster	Status	Pre Score	Post Score	Change	Strength	Expert Opinion
Overall	Favorable	74	82	+	Small	Toward
	Unfavorable	15	12	-	Small	
Independence	Favorable	50	83	+++	Large	Toward
	Unfavorable	17	17	0	Zero	
Coherence	Favorable	60	80	++	Moderate	Toward
	Unfavorable	20	20	0	Zero	
Concepts	Favorable	80	100	++	Moderate	Toward
	Unfavorable	20	0	--	Moderate	
Reality	Favorable	100	75	--	Moderate	Away
	Unfavorable	0	25	++	Moderate	
Math-Link	Favorable	60	40	--	Moderate	Away
	Unfavorable	20	40	++	Moderate	
Effort	Favorable	100	80	--	Moderate	Away
	Unfavorable	0	20	++	Moderate	

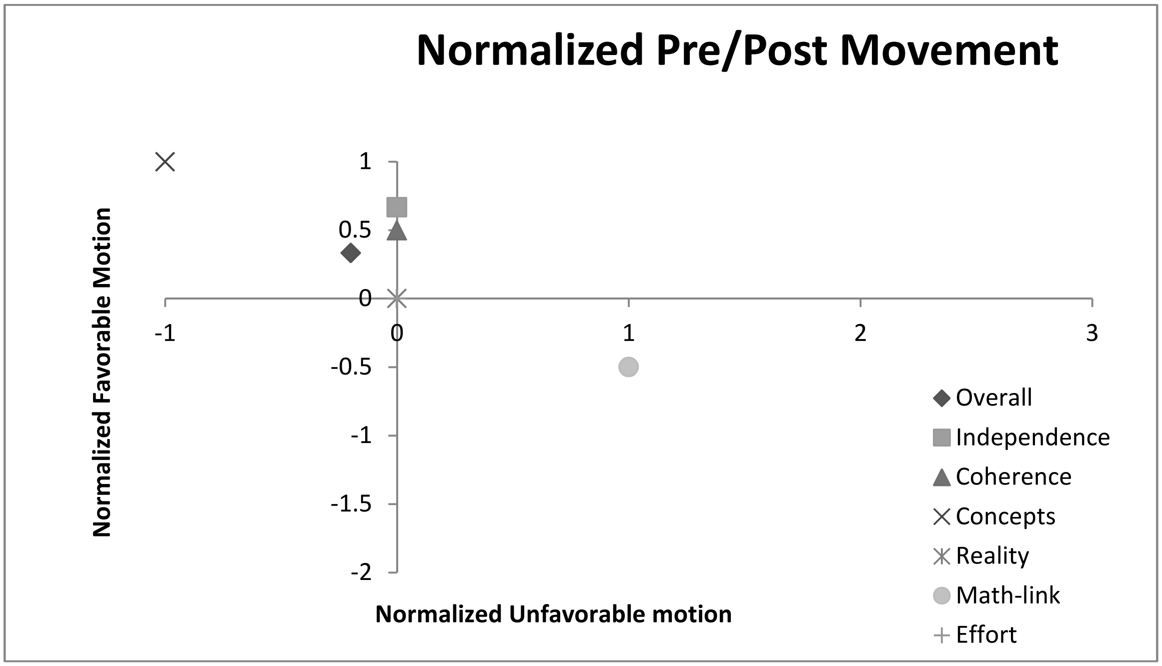


Figure 7. Jeffrey's Normalized Pre- and Post-Assessment Movement for Each of the Categories

Like Lauren, Jeffrey exhibited a positive normalized change, in the second quadrant, in his “Overall” score and for the “Concepts” category. He also became more favorable in “Coherence” and “Independence,” but at the same time showing no overall movement unfavorable for those categories. Jeffrey showed a normalized unfavorable increase in the “Math-Link” category, while in “Effort” he remained relatively constant, c.f. Figure 7.

George’s Development in Force and Motion Concepts

Introduction to George’s Development in Force and Motion Concepts

George’s progress within force and motion concepts is described in the following sections. George represents a high-level of preliminary conceptual knowledge of motion and force concepts in this dissertation. Within kinematical concepts, George moved from moderate to sophisticated to sophisticated levels of proficiency. With Newton’s First Law he moved from moderate to moderate to sophisticated. With Newton’s Second Law he advanced from moderate to moderate to sophisticated. And with Newton’s Third Law he progressed from moderate to moderate to moderate. Force and motion learning progressions for George are shown in Table 24. Levels of advancement for all research subjects for each point-of-interest are displayed below in Tables 26, 27, and 28 along with a summary table, Table 29.

First Point of Interest

At the first point of interest George had a moderate understanding of motion concepts. These included the basic definitions of position, velocity, and speed; understanding of setting an origin and direction for axes and vectors; the differences amongst velocity, speed, and acceleration; and a basic understanding of kinematical equations of motion for constant acceleration. George also had a sufficient grasp of the differences between velocity and acceleration concepts.

Table 24. Force and Motion Learning Progressions for George

Point-of-Interest	Concepts of motion, including position, velocity, and acceleration	How net external force causes changes in motion 1st Law	Relationships of changes in motion to applied forces and the mass of the object 2nd Law	How forces between two different bodies relate 3rd Law
1	Moderate	Moderate	Moderate	Moderate
2	Sophisticated	Moderate	Moderate	Moderate
3	Sophisticated	Sophisticated	Sophisticated	Moderate

George did not define motion as changes in an object's position, per se, but instead utilized velocities and accelerations concepts to hint at motion and invoke force concepts.

> Q: What are the basics of motion to you?
>
> George: I think the basics of motion are the three laws of motion, of course. So, the first one is that inertia, that objects in motion tend to stay in motion in a straight line and objects at rest stay at rest. [Asking himself] What is it? The second law is that forces cause acceleration. And that you can still have a constant speed and not necessarily be accelerating. No force was the cause of that because you can still be going straight line without force. (Interview 1)

For George, forces and motion were intertwined, and forces cause objects to change their motion, i.e. he had the scientifically accepted Galilean understanding of motion. George also defined forces by relating them to changes in motion.

> Q: What's a force to you?
>
> George: Force is just, I don't know how to describe it. It's just a change in motion. (Interview 1)

He also held that knowing about forces was important in biology and therefore vital for him in his chosen field of dentistry.

> Q: Do you think there is a standard core of force concepts that all students in this course should all take away with them? Do you think there are standard things that students should take away with them from physics as far as forces goes?
>
> George: Yeah, it's important to know what forces are [Pause].
>
> Q: How are they important for biology?
>
> George: For biology, well, I can relate to my field, dentistry, because the drill and rotation, in particular. As it spins in a circle, it spins at a certain rate, has to apply a certain amount of force to the enamel, which is the hardest surface and the human body. That's how I look at it and maybe how hard it is to pull a tooth out or something [laughs]. It is difficult to pull a tooth out.
>
> Q: So you see some connection to your field right away and some things that you need to know. What do you think is a successful way for you to learn those things? Is there a successful way to learn those things?
>
> George: Learn those things? I think there is, I mean, if I just practice doing it.

During interview 1, George was asked to describe the motion of an object, including the object's position, velocity, and acceleration, initially moving at 55mph and slowing to a stop in a time of five seconds. He had little trouble defining position, velocity, and acceleration and stated the directions and signs for each if given an example.

> Q: So you do you think it is increasing its position or decreasing its position?
>
> George: I think it's increasing its position [pointing to the paper].
>
> Q: Do you think it's increasing or decreasing its speed?
>
> George: It is decreasing its speed.
>
> Q: Do you think it's increasing or decreasing its velocity?
>
> George: It's decreasing its velocity.
>
> Q: Do you think its acceleration is positive or negative?

> George: Negative.

He also noted that his understanding of the differences between speed and velocity and velocity and acceleration were fuzzy, but that his effort at remembering and employing the mathematical relationships had help him recognize the differences.

> George: Well, on the difference between speed and velocity, the difference between velocity and acceleration and [Pause]. I didn't really think about the differences. I don't know. I thought that all objects fall at the same acceleration. I thought it was speed, I guess, instead of acceleration. But I never knew that before really.

George was also queried about how the velocities change and to calculate the average acceleration of the object.

> Q: So it starts at some rate, and it ends at rest, so tell me a little bit about the motion.
>
> George: It's decelerating. It's traveling in a positive direction but is losing speed constantly, at a rate of 11mph each second so there might be some resistance.
>
> Q: I hear you saying that it depends on what's happening between here and there, between the starting and the ending point, doesn't it? And it affects the motion? What is?
>
> George: The more vertical it is, the more force gravity will have on it. It will accelerate faster but…
>
> Q: What are the forces here?
>
> George: Decelerating forces.
>
> Q: Which way would it be on your picture here? How would you diagram the deceleration?
>
> George: There would have to be something getting in the way of this, friction between the tires or if it's really not aerodynamic, it's slowing down because of with the wind.
>
> Q: So how does Newton's First Law come into this?
>
> George: If it's a heavier object, I mean if it's more massive object, it's going to be harder to stop.

He was thus capable of calculating, in his head, the average acceleration of the object, related forces to that average acceleration in a certain direction, and also linking the motion to outside forces present in the system.

George also had a moderate understanding of Newton's First Law at Point-of-Interest 1. He could easily recite Newton's First (and Second) Laws in Interview 1. He clearly understood the concept of inertia and how it affected motion and that it was not necessary to have a net force to have motion, i.e. he had a Galilean understanding of forces; Interestingly, however, later in that same interview, he included that "forces cause objects to move."

George had a moderate understanding of Newton's Second Law at Point-of-Interest 1. Accordingly:

> Q: How does Newton's Second Law come into it?
>
> George: Ah, I keep forgetting that one. What is it? [Pause] Newton's Second Law.
>
> Q: So forces relate to acceleration, right?
>
> George: Force and acceleration. Okay, so the only force acting on it [a slowing object] is a resistance force. It had an initial force, but it's not acting on it anymore.

He initially had trouble remembering Newton's Second Law, yet he was able to explain that if object is slowing down, i.e. decelerating, there must have been some kind of force acting on a given object to slow it down. He also stated that there must have been an initial force to cause it to start to move, which is not necessarily the case. In another example, when asked about a parachute falling under the influence of gravity, George was clearly able to talk about the drag force increasing as the object's speed increases. But, he was not sure about how this occurs so that the object achieves a terminal velocity, i.e. eventually increases its velocity through a fluid until the resistive drag force balances the weight force, and dynamic equilibrium is achieved.

> Q: What about the drag force [on the parachutist]?
>
> George: The drag force. The faster it goes, the more drag force is going to have.
>
> Q: So how is that going to affect the acceleration?

> George: Well, there's a ratio between the drag force and the mass, I think [Pause]. It always evens out to 10 meter per second squared.
>
> Q: I see.
>
> George: This ratio, the more heavier the object, the more air resistance it has, the faster it accelerates. They cancel each other out
>
> Q: Oh, they cancel out, okay.

George had a moderate understanding of Newton's Third Law at Point-of-Interest 1. He could recite the third law, "every action has an equal and opposite reaction" and could utilize it in a given situation, if prompted. When George arrived in the physics course, he stated that he knew Newton's Third Law the best until he was confounded by the defining of "systems."

> Q: For you as you're growing in your knowledge, what did you start out with? What was your understanding of forces when you first came in? Has it changed?
>
> George: Well, things changed, but I knew the third law of motion. That's the one I understood the most. But when you [teacher] put different systems on the board, and you make the dotted line on one part of the system that you could have and if you enclose the entire system, it doesn't move because they are moving in opposite directions. I don't know.

George's levels of advancement for Point-of-Interest 1 are displayed in Tables 24 and 26.

Second Point of Interest

The second point of interest for George came after the first exam and class introduction of force and motion concepts and while in the midst of class discussions on energy and momentum concepts. At the second point of interest George had a sophisticated understanding of motion concepts. He displayed an excellent understanding of the basic definitions of position, velocity, and speed; differences amongst velocity, speed, and acceleration; choosing and setting an origin and directions of vectors; and the kinematical equations of motion for constant acceleration. In Exam 1, he clearly had the ability to analyze the motion of an aircraft as it lands on an aircraft carrier and successfully applied the one-dimensional kinematical equations of motion for constant acceleration to solve for acceleration if positions and velocities were known.

George defined motion in Interview 2 as, “changing of position and position is where an object is located or how it’s, how it’s organized.” When queried about how his ideas how changed about motion, he was quick to cite equations:

> Q: How have your ideas of motion changed since maybe August? Has there been a change in them?
>
> George: I’ve learned a lot of stuff about them. I’ve learned a lot of equations that I can use.
>
> Q: So it’s all about equations?
>
> George: Actually, when I kind of think about it when I am driving or when I am moving. I can figure out forces and possible scenarios that I will or won’t have to deal with, but I can also calculate stuff I want to.

He therefore invoked mathematics, i.e. mathematical relationships, when asked about motions, and thus felt that the ability to calculate a given physical quantity, say velocity, along with the general explanations of individual motions were important to him. He again mentioned how rotations are vital for his intended field of interest, dentistry.

> Q: Now you’re into dentistry? Do you see any crossover into dentistry, for motion and position?
>
> George: I mean dentistry involves a lot of machines and machinery, especially the drill and other kind to gadgets we have. And the drill is important because different bits of the drill spin at different rates, while they do different things, based on their size and motions.
>
> Q: So rotations I hear you saying?
>
> George: Yeah.

George had a moderate understanding of Newton’s First Law at Point-of-Interest 2. He defined force in terms of energy in Interview 2. He stated:

> Force is when you apply or transfer energy to some other object. I mean that is when you can use forces to calculate some things.

> [Pause] So like gravity, we can have a force on an object and causes changes in the motion of other objects.

Moreover, he continued to orient his understandings around notions of energy, i.e. with concepts he was using in his biology classes where:

> Q: Which do you think is more fundamental for you: energy or forces?
>
> George: For me, energy.
>
> Q: If I break science into forces or energy or both, what would you say?
>
> George: Energy definitely [Pause] because I use energy a lot in advanced cell biology and chemistry classes.
>
> Q: So, you see it as, you know, energy causing forces maybe? And how do you see that relating to forces? So when we talked about forces…
>
> George: Like a direct relationship with forces because energy is moving objects and objects that are moving have force.

(Once again, invokes the necessity of having a force for motion, a common misconception.) Also, he was able to relate that a body with a constant velocity, i.e. in a uniform state of linear motion, must have an equilibrium of forces.

> Q: So if you're moving in a constant velocity, what do you know?
>
> George: Well, what's happening is that the forces are canceling each other out so you are not having a net increase of forces positively and negatively. The motion remains the same.

George therefore continued to hold an overall Galilean understanding of motion.

George had a moderate understanding of Newton's Second Law at Point-of-Interest 2. In Exam 1, George easily found the net force on a body in horizontal motion when its mass and acceleration were known. He also easily invoked the second law equation and demonstrated that the vertical forces must be balanced while the aircraft is moving horizontal motion, i.e. not changing its vertical motion. He successfully utilized a free-body-diagram to interpret outside forces on an object in Exam 1.

George had a moderate understanding of Newton's Third Law at Point-of-Interest 2. When he had doubt on forces and the Third Law, George invoked a "find-an-equation" approach.

> Q: Two objects come into contact, what happens with their forces?
>
> George: Well, you'd have to, you can use it equation to see the movement.

But, he also was quick to explain, if prompted, that the forces between the objects are "equal and opposite."

> Q: Let's say how much force would the small one give to the large one versus the force on the small one due to the large one? [Pointing] So if you had forces [Diagramming vectors], how would these forces [Pointing to the left vector] and this force [Pointing to right vector] compare?
>
> George: They would be equal and opposite.

George also easily discussed the motion of a car in contact with a road in terms of forces. He incorrectly explained, however, that to speed up a car, the tires must put more force on the ground than the ground puts on the tires, an obvious inconsistency with the Third Law of Motion.

> Q: So if you have an object moving, moving at given a value, 55 mph. Tell me about the forces.
>
> George: You can have the forces of the engine pushing it. Well, that doesn't push it, but the wheels push against the ground?
>
> Q: So if we were speeding up, what would that mean?
>
> George: That means the engine is working faster, the car is pushing harder against the ground than the ground is pushing on the car.

He also approached the physical example by creating a "system." He correctly explained that for a system to change its motion there must be an outside force. Therefore, the choice of system is a big difference.

> Q: I notice that you made a differentiation between the force of the engine and the force on the ground. Can you tell me a little bit more about that?
>
> George: Well, that's more like *systems*.

> Q: Okay.
>
> George: The car is a system. For a system to change its motion it has to have an outside interaction so what's happening is that the engine is turning the wheels. Now I really don't know how [laugh]. But an outside force has to press against the whole system to change its motion so that's why the wheels are what is pushing against the ground, not the engine on the ground.
>
> Q: So the wheels push against the ground. What does that do?
>
> George: Well, basically you have the wheels pushing against the ground, the ground is pushing against the wheels.
>
> Q: How do you know that?
>
> George: From the Third Law.
>
> Q: So it's the ground pushing against the car, not the car pushing on the ground?
>
> George: Yeah. But then you also can have resistance of friction so the air can get in the way or there might be bumps on the road that slow the car down, and if the tires are not smooth enough, they could have a lot more friction [Pause] and like the shape of the car affects the aerodynamics of it.

George's levels of advancement for Point-of-Interest 2 are displayed in Tables 24 and 27.

Third Point of Interest

The third point of interest for George comes after the second exam and after classroom introductions of force, motion, energy and momentum concepts. At the third point of interest George had a sophisticated understanding of motion concepts. He continued to show a sophisticated understanding of the basic definitions of position, velocity, and speed; understanding of setting an origin and directions for axes and directions of vectors; differences amongst velocity, speed, and acceleration; and lastly a thorough understanding of the kinematical equations of motion for constant acceleration.

In Exam 2, George was asked to interpret and analyze the vertical motion of an object falling through a known distance, using energy and momentum concepts: Dan the Bank Robber fleeing the police by jumping off of a building and subsequently hitting an airbag. In his response, he successfully integrated notions of object position, velocity, and acceleration within this motion, including relating positional change with energy transfer and velocity change with change in an object's momentum during a collision. George correctly described the accelerated motion of this object as it fell vertically near earth. He also correctly stated that the gravitational force of the Earth caused Dan's kinetic energy to change while falling and returning upwards after a collision with an airbag at ground level:

> Since his velocity is increasing as he falls due to the work that gravity does on him to make him cover a distance, his kinetic energy is also increasing. Once he reaches the bottom of the fall, he has his maximum kinetic energy (Exam 2).

George had a sophisticated understanding of Newton's First Law at Point-of-Interest 3. George was successful in defining the First Law in multiple ways. In Interview 3, which occurred after classroom introduction of energy, linear momentum, and rotations, George was quick to define the First Law, "For every action there is a reaction." He discussed how forces relate to rotational forces, i.e. torques, explaining that forces are similar to torques: forces cause motions to change in a "line" while torques cause general changes in rotational motion. And he continued to define forces as he had done previously, "something that gives changes in motion." Further, he defined mass or inertia in terms of a measure of "forward" inertia. Moreover, in Exam 2, George wrote:

> This is due to Newton's First Law, which states that an object in motion will remain in motion or in a linear path unless acted upon by an outside force.

George had a sophisticated understanding of Newton's Second Law at Point-of-Interest 3. In Exam 2, George reasoned correctly that the gravitational force of earth would cause an object to accelerate at a constant rate, in lieu of air resistance. He further noted that the external force of an airbag will cause Dan's motion to vary because the outside force is no longer exclusively from gravity but rather from the massive interaction between Dan and the airbag. Therefore, the different amount of external force from the airbag would cause a large change in the motion, i.e. a large change in the object's velocity. Hence, although George does not explicitly state that mass is equal to force times acceleration, he does imply that the external forces are proportional to the resulting motion changes.

George had a moderate understanding of Newton's Third Law at Point-of-Interest 3. George discussed equal and opposite forces in Exam 2. George wrote that when Dan jumps from the roof of the building, he alters his motion because experiences an equal and opposite force as he jumps from the roof. He wrote, "Since Newton's Third Law states that every <u>action</u> has an equal and opposite <u>reaction</u>, the roof pushes back on him and he is propelled into the air." This external force occurred over "a short amount of time" and therefore puts an external impulse on Dan, causing his "momentum to change."

During an office visit during the term, George asked about equal and opposite forces for a case with gravity. He was confused on how motion can occur given the fact that the forces are "equal and opposite."

> Q: So, if you tell me that the forces are balanced between two objects, opposing forces, you have to tell me why. You would say it's, Newton's Third Law, right? Two bodies in contact, they give equal and opposite forces.
>
> George: I remember in class you said not to use Newton's Third Law or something.
>
> Q: I said collisions are when you have two bodies in contact, guess what? Equal and opposite forces. So this is the name of the game, Newton's Third Law.
>
> George: What about an object falling [as an object falls under the influence of gravity]? I'm not sure about that.
>
> Q: So what's the interaction?
>
> George: There's gravity pulling you down, and there's really no opposite interaction.
>
> Q: Yet there is. You are coming in contact with air so the [Pause] well there's two interactions, you and earth, earth pulls up on you, and you pull out on Earth. Guess what? We don't care about the pulling up on the Earth! The other one, we're pushing down on the air, guess what? Air pushes back up on us!

Hence, whenever there's an interaction, there are equal and opposite forces, but how a system is affected by those forces is dependent on which forces are *external* to that system. George then queried about how motion can change even though the forces are equal and opposite,

> George: I understand that. What is kind of confusing is that if you are having equal and opposite pushes, then how can you even change the motion?
>
> Q: Yeah, well, it depends on your system. So you have a body falling, she is falling towards Earth. The earth pulls down on her, she pulls up on earth, guess what? These are equal and opposite. What you're saying is that there is no net change in something here. That's what you're saying. But if you just focus on her, remember what the Orange and Apple example? Remember? So here the net force on her is definitely unbalanced so something is changing. So you have to define the system and also see if you have a time elapsing. Yeah, the crux of this is that it depends on how you set up the system of interest.

Finally, when asked how the physics of motion might apply to his chosen field, George was quick to point out specific examples from laboratory: construction and motion of cardboard rockets and the vertical dropping of egg,

> Q: Tell me one of the things from physics experiences have influenced you? Maybe random things come to mind?
>
> George, I don't know [Pause] I like when we made the rockets. That's what I like and when we did the egg drop too. I thought that that was probably just as cool.

George's levels of advancement for Point-of-Interest 3 are displayed in Tables 24 and 28.

George's Force and Motion Concept Evaluations

The pre- and post-instruction administrations of the Force and Motion Concept Evaluation (FMCE) for George occurred before and after course instruction on motion and force concepts. The results for George are shown in Figure 8 below.

George's performance–like all of two other participants–on the pre-instruction evaluation was quite weak with an overall pre-score of 16.2% (The Physics Education

Research Laboratory, 2012). George scored surprisingly low on all individual clusters results, except graphs of velocity. Thus, George may have had some prior knowledge of graphing of velocities. (It should be noted that the low level of initial understanding of these concepts raises suspicions that George did not take the first assessment of the FMCE seriously.)

Like the other participants, the after-instruction results were far more promising. George made large gains on many clusters, as shown below. His overall gain[23] for all questions was 58.1% with large advancements on “Force Sled,” “Acceleration Graphs,” and “Newton’s Third Law.” Interestingly, he made no progress on “Reversing Direction” questions.

George’s Maryland Physics Expectation Survey

The pre- and post-instruction administrations of the Maryland Physics Expectation Survey (MPEX) for George occurred before and after course instruction on motion and force concepts. The results for George are shown in Table 25 below.

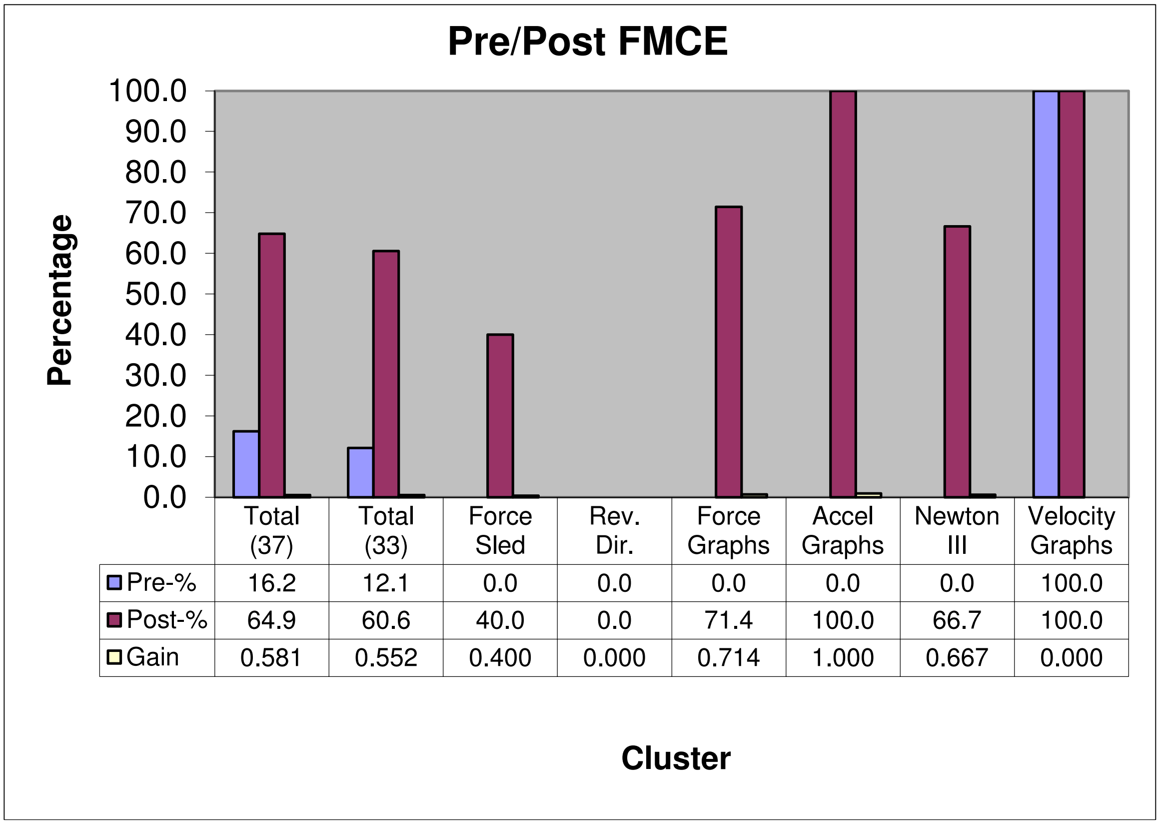
Table 25 displays George’s pre- and post-assessment changes in each of the categories. George’s “Overall” favorable score moved slightly upwards from 59 to 65, while his unfavorable score remained constant at 32. This indicates a little overall improvement in favorable (or unfavorable) attitudes towards learning physics.

In the post-assessment, he exhibited a large mix of favorable and unfavorable responses with no categories scored perfectly favorable. Between pre- and post- assessments, he showed very little change in favorable and unfavorable scores. He displayed an increase in favorable and a decrease in unfavorable in three categories, “Overall,” “Concepts,” and

---

[23] Gain is a measure of the normalized gain: What percentage of the possible improvement did they attain? $Gain = \frac{Post-\%-Pre-\%}{(100-Pre-\%)}$

"Effort." The "Independence" category remained exactly the same with "Math" showing a slight increase in unfavorable and "Coherence" showing a slight decrease in favorable.



	Total (37)	Total (33)	Force Sled	Rev. Dir.	Force Graphs	Accel Graphs	Newton III	Velocity Graphs
■ Pre-%	16.2	12.1	0.0	0.0	0.0	0.0	0.0	100.0
■ Post-%	64.9	60.6	40.0	0.0	71.4	100.0	66.7	100.0
□ Gain	0.581	0.552	0.400	0.000	0.714	1.000	0.667	0.000

Figure 8. George's Performance on Force and Motion Concept Evaluation (FMCE) Results for Pre- and Post-Instruction

Table 25. George's MPEX Pre- and Post-Assessment Results for Each Category

Cluster	**Status**	**Pre Score**	**Post Score**	**Change**	**Strength**	**Expert Opinion**
Overall	Favorable	59	65	+	Small	Toward
	Unfavorable	32	32	0	Zero	
Independence	Favorable	50	50	0	Zero	Zero
	Unfavorable	50	50	0	Zero	
Coherence	Favorable	60	40	--	Moderate	Away
	Unfavorable	40	40	0	Zero	
Concepts	Favorable	60	80	++	Moderate	Toward
	Unfavorable	40	20	--	Moderate	
Reality	Favorable	100	75	--	Moderate	Away
	Unfavorable	0	25	++	Moderate	
Math-Link	Favorable	80	80	0	Zero	Away
	Unfavorable	0	20	++	Moderate	
Effort	Favorable	60	80	++	Moderate	Toward
	Unfavorable	40	20	--	Moderate	

George exhibited a positive normalized change, in the second quadrant, in only one category, the "Effort" category. All other categories showed little or no net overall movement. In essence, this means that George had very little change between pre- and post-assessment of physics attitudes, c.f. Figure 9. It would be safe to say that George's beliefs and attitudes about physics changed very little during his coursework in physics.

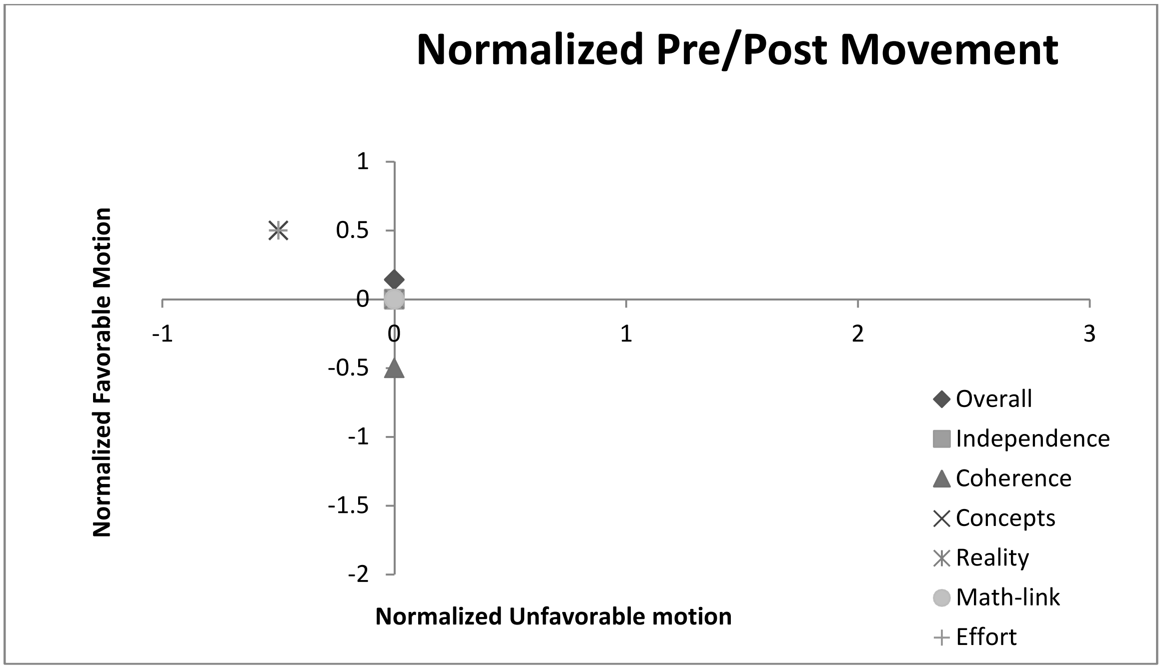


Figure 9. George's Normalized Pre- and Post-Assessment Movement for Each of the Categories

Cross-Case Analysis of Participants

Introduction

A cross-case analysis of how each research participant progressed in force and motion concepts and their use of interactive technologies, like DyKnow and tablet PCs, will be examined. This analysis is imperative to help reconcile how student understanding of in force and motion concepts might be connected to the overall utilization of interactive technologies.

First, levels of proficiency for each participant at each point of interest are shown in Tables 26, 27, and 28. (Nota Bene: Expanded tables for levels of proficiency for each participant are shown in Appendix C.) At Point-of-Interest 1, learners had varying levels of proficiency for the different conceptual categories. Only Jeffrey had a crude understanding of Newton's Third Law while George had a moderate level of understanding for all categories.

Table 26. Levels of Proficiency for Each Participant at Point-of-Interest 1

Point-of-Interest 1	Concepts of motion, including position, velocity, and acceleration	How net external force causes changes in motion 1st Law	Relationships of changes in motion to applied forces and the mass of the object 2nd Law	How forces between two different bodies relate 3rd Law
Lauren	Moderate	Basic	Moderate	Basic
Jeffrey	Moderate	Basic	Moderate	Crude
George	Moderate	Moderate	Moderate	Moderate

At Point-of-Interest 2, more sophisticated levels of understanding were attained. No "crude" levels are shown and only two "basic" levels are prominent. These include Lauren and Jeffrey for the Third Law category.

Table 27. Levels of Proficiency for Each Participant at Point-of-Interest 2

Point-of-Interest 2 (after Exam 1)	Concepts of motion, including position, velocity, and acceleration	How net external force causes changes in motion 1st Law	Relationships of changes in motion to applied forces and the mass of the object 2nd Law	How forces between two different bodies relate 3rd Law
Lauren	Sophisticated	Moderate	Sophisticated	Basic
Jeffrey	Sophisticated	Moderate	Moderate	Basic
George	Sophisticated	Moderate	Moderate	Moderate

At Point-of-Interest 3, one "expert" level of understanding was attained by Lauren and concepts of motion. George continued to hold a moderate understanding of the third law of motion.

Table 28. Levels of Proficiency for Each Participant at Point-of-Interest 3

Point-of-Interest 3 (after Exam 2)	Concepts of motion, including position, velocity, and acceleration	How net external force causes changes in motion 1st Law	Relationships of changes in motion to applied forces and the mass of the object 2nd Law	How forces between two different bodies relate 3rd Law
Lauren	Expert	Sophisticated	Sophisticated	Moderate
Jeffrey	Sophisticated	Moderate	Sophisticated	Moderate
George	Sophisticated	Sophisticated	Sophisticated	Moderate

A summary table for the overall progressions of each research subject at each particular point-of-interest along with his/her initials level of conceptual development in force and motion concepts is displayed in Table 29. As can be seen in the table, all students generally advanced in the different categories, some starting at a very low level and advancing to high-level and some beginning at a higher level and not advancing considerably. For example, Jeffrey began at a moderate level of understanding of concepts of motion yet only progressed to a sophisticated level, i.e. one level of progression higher. On the other hand, Lauren started at a basic level for Newton's First Law and advanced to a sophisticated level of understanding. In only one category and for only one participant, Lauren, is the level of "expert" attained. In all categories, students advanced in expertise in each category, except George who made very little progress on Newton's Third Law, staying at the "moderate" level. Moreover, all learners ended with a moderate understanding of Newton's Third Law. Generally, students held a lower level of understanding for the final category–Newton's Third Law–than any the other categories.

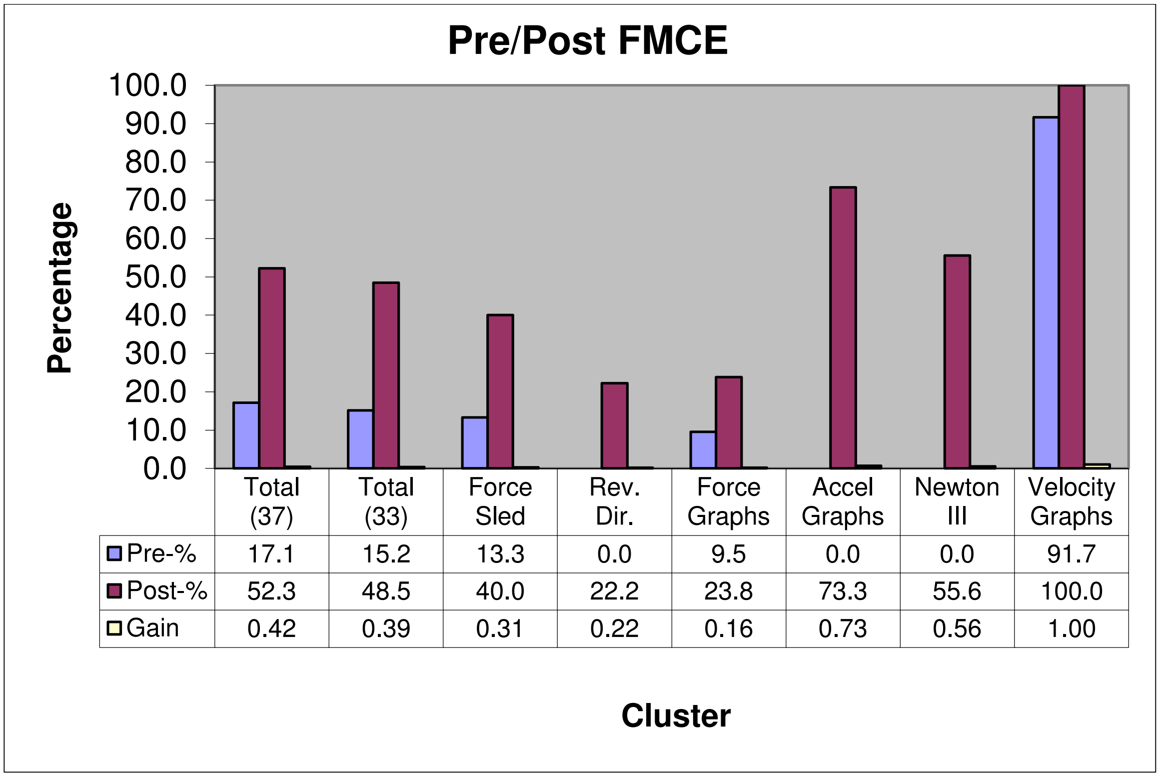
Table 29. Overall Progressions of Research Subjects at Each Point-of-Interest

Research Subject	Point-of-Interest	Concepts of motion, including position, velocity, and acceleration	How net external force causes changes in motion 1st Law	Relationships of changes in motion to applied forces and the mass of the object 2nd Law	How forces between two different bodies relate 3rd Law
Lauren	1	Moderate	Basic	Moderate	Basic
	2	Sophisticated	Moderate	Sophisticated	Basic
	3	Expert	Sophisticated	Sophisticated	Moderate
Jeffrey	1	Moderate	Basic	Moderate	Crude
	2	Sophisticated	Moderate	Moderate	Basic
	3	Sophisticated	Moderate	Sophisticated	Moderate
George	1	Moderate	Moderate	Moderate	Moderate
	2	Sophisticated	Moderate	Moderate	Moderate
	3	Sophisticated	Sophisticated	Sophisticated	Moderate

Overall Force and Motion Concept Evaluation (FMCE)

Results

Figure 10 shows the overall pre- and post-instruction results of the student participants on Force and Motion Concept Evaluation (FMCE). The initial scores of the three participants were an extremely low 17% and mid-level 52% for pre- and post-instruction administrations, respectively, with an overall gain of 42% between assessments. Generally, student participants achieved gains in all categories, including large gains in “Acceleration Graphs,” and “Newton’s Third Law.”



	Total (37)	Total (33)	Force Sled	Rev. Dir.	Force Graphs	Accel Graphs	Newton III	Velocity Graphs
🟦 Pre-%	17.1	15.2	13.3	0.0	9.5	0.0	0.0	91.7
🟥 Post-%	52.3	48.5	40.0	22.2	23.8	73.3	55.6	100.0
🟨 Gain	0.42	0.39	0.31	0.22	0.16	0.73	0.56	1.00

Figure 10. Participants' Performance on Force and Motion Concept Evaluation (FMCE) Results for Pre- and Post-Instruction

(It must be noted that the sample size of N=3 participants must be taken into account. Therefore, gains on all categories are not necessarily *statistically significant*; however, indications of direction of progression can be established.)

From Table 30, all individual learners made gains in the "Overall" and "Acceleration Graphs" categories. Lauren gained in the "Velocity Graphs" category while Jeffrey and George remained perfect in that category. Lauren made no progress in several categories, and Jeffrey made no progress on "Newton's Third Law" category. On the other hand, George gained in all categories except "Reverse Direction." One student, Jeffrey, lost ground on "Force Graphs" category.

Table 30. Overall Gains or Losses for Each Research Participant on the FMCE

Participant	Overall	Force Sled	Reverse Motion	Force Graphs	Acceleration Graphs	Newton' III	Velocity Graph
Lauren	40%	0%	0%	0%	80%	100%	100%
Jeffrey	27%	40%	67%	-40%	40%	0%	0%[24]
Matthew	58%	40%	0%	71%	100%	66%	0%[25]

It must be noted that the administrations of the FMCE and MPEX were one of a limited number of multiple-choice-type assessments that student participants encountered throughout the term. Clearly, the strategies for answering multiple-choice questions, or other more objective-based assessments, are far different than more subjective instruments, like writing artifacts or student presentations. Thus, it is hard to compare the relatively poor results in the study to other similar assessments.

Overall Maryland Physics Expectation Survey (MPEX) Results

Table 31 displays the overall pre- and post-assessment changes (N=3) from the MPEX. The changes are displayed in each of the categories, using the sign convention from Table 20. The students' "Overall" favorable score moved slightly upwards from 66 to 75, while their unfavorable scores lowered slightly from 19 to 16. This indicates a slight overall positive increase, i.e. towards a more expert attitude in physics. A "towards" ("away") attitude change is defined as an increase (decrease) in favorable scores paired with a decrease (increase) in unfavorable scores for the category. A positive (negative) change in favorable paired with a positive (negative) change in unfavorable is deemed "ambivalent."

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[24] Began as perfect score

[25] Began as perfect score

In the post-assessment, they exhibited a large mix of favorable and unfavorable responses. They responded with no categories perfectly favorable, though the "Reality" category started out with no unfavorable scores. There was an increase in favorable and decrease in unfavorable, indicating a positive change in attitudes, in the "Overall" score and "Concepts" category, c.f. arrows in Figure 11. Student attitudes became more negative–away from expert opinion–for "Math-link" and "Reality" and slightly away in movement for "Effort." Other scores were more ambivalent, yet they showed a slight indication towards or away from expert opinion. The favorable score for "Independence" went up, while the unfavorable remained the same. "Coherence" category became more ambivalent with favorable and unfavorable scores showing a decrease. "Math" category became drastically more unfavorable, c.f. arrows on Figure 11.

Table 31. Overall MPEX Pre- and Post-Assessment Results for Each Category

Cluster	**Status**	**Pre Score**	**Post Score**	**Change**	**Strength**	**Expert Opinion**
Overall	Favorable	66	75	+	Small	Towards
	Unfavorable	19	16	-	Small	
Independence	Favorable	56	72	++	Moderate	Towards
	Unfavorable	22	22	0	Zero	
Coherence	Favorable	67	53	--	Moderate	Ambivalent
	Unfavorable	27	20	-	Small	
Concepts	Favorable	53	93	+++	Large	Towards
	Unfavorable	27	7	--	Moderate	
Reality	Favorable	100	83	--	Moderate	Away
	Unfavorable	0	17	++	Moderate	
Math-Link	Favorable	60	53	-	Small	Away
	Unfavorable	7	27	++	Moderate	
Effort	Favorable	80	73	-	Moderate	Away
	Unfavorable	20	20	0	Zero	

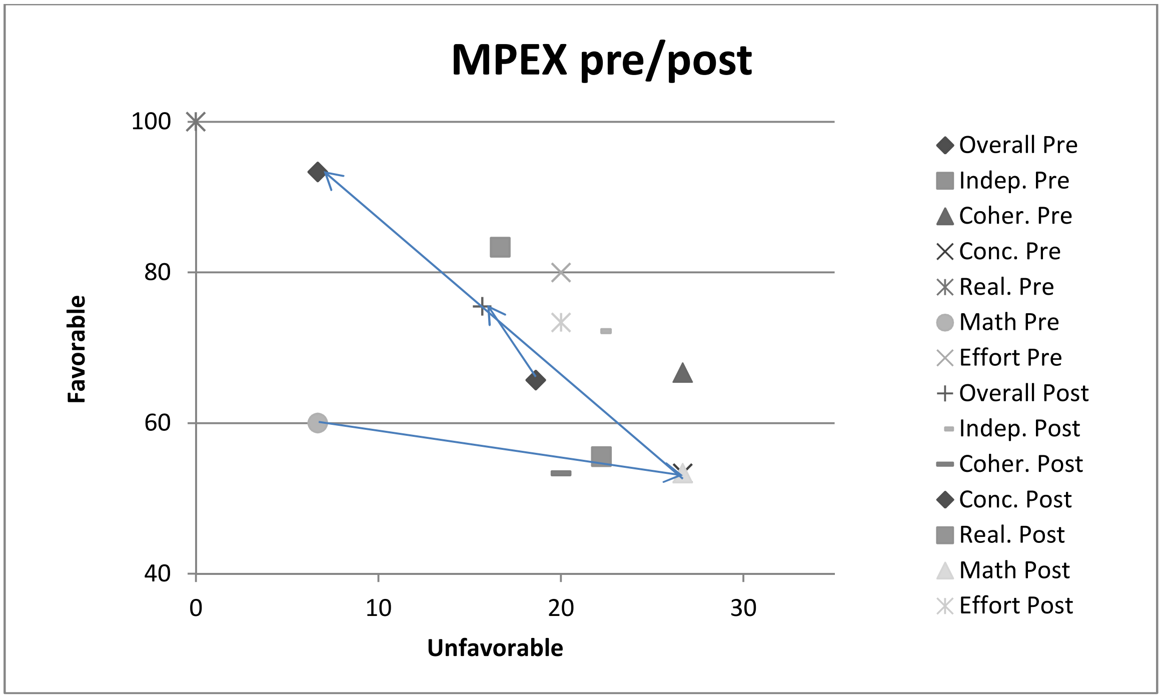

Figure 11. Overall Distribution of MPEX Pre- and Post-Assessment (Arrows show movement for “Overall” scores and “Concepts” and “Math” categories)

Overall students exhibited a positive normalized change, in the second quadrant, in their “Overall” score and for the “Concepts” category. This indicates a positive change in attitudes toward physics overall and towards concepts in general. They also became slightly more favorable in “Independence”, while at the same time showing no normalized movement for “Reality.” However, “Math” category became drastically more unfavorable, c.f. dot to the far-right in Figure 12.

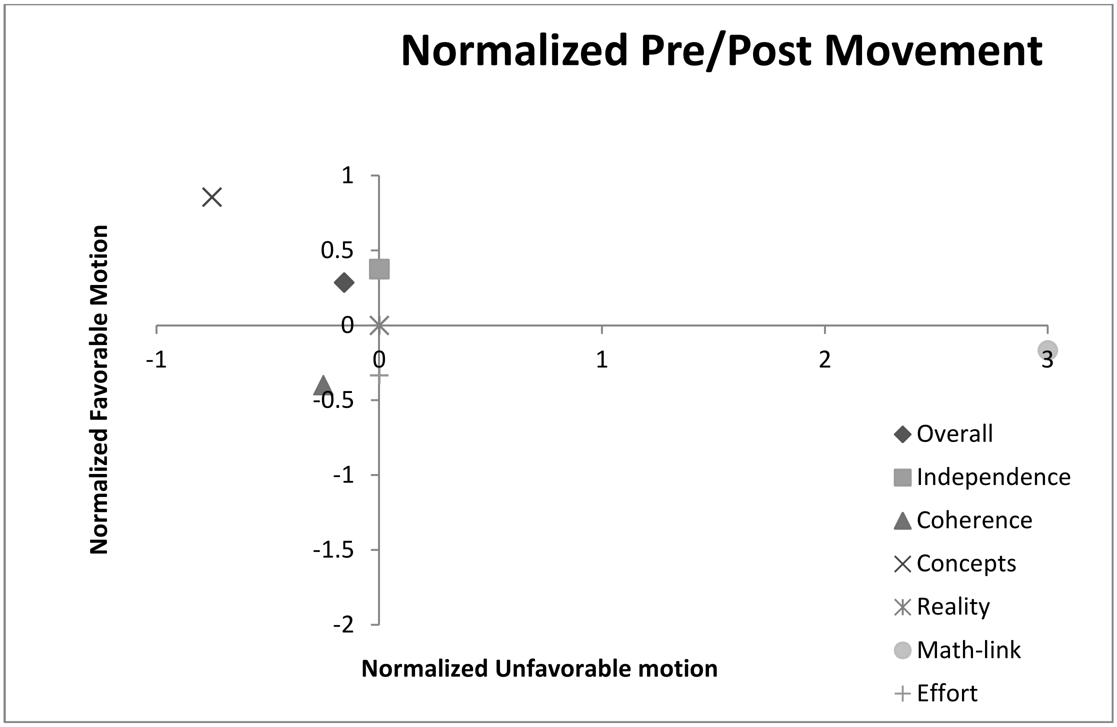

Figure 12. Overall Student Normalized Movement between MPEX Pre- and Post-Assessments

Table 32 displays the individual directions of MPEX scores toward or away from expert attitude about physics. All students, though George's gain is small, move towards expert's attitude about physics in the "Overall" category. Also, all students move towards expert attitudes on "Concepts." Lauren and Jeffrey gained "Independence" while George changed little. Jeffrey moved towards experts on "Coherence" while Lauren was ambivalent and George moved away from experts. For "Reality" and "Math-Link," Lauren remained the same while Jeffrey and George moved away from experts. Lastly, for "Effort," all participants diverged with Lauren, Jeffrey and George, ambivalent, away, and towards expert opinion, respectively.

Table 32. Overall Change in MPEX Score for Attitudes Towards Physics for Each Participant

Participant	Favorable, Unfavorable, Direction	Overall	Independence	Coherence	Concepts	Reality	Math-Link	Effort
Lauren	F	+++	+++	---	+++	++	+++	++
	U	-	0	--	--	0	--	++
	Gain	Toward	Toward	Ambivalent	Toward	Toward	Ambivalent	Ambivalent
Jeffrey	F	+	+++	++	++	--	--	--
	U	-	0	0	--	++	++	++
	Gain	Toward	Toward	Toward	Toward	Away	Away	Away
George	F	+	0	--	++	--	0	++
	U	0	0	0	--	++	++	--
	Gain	Toward	No Change	Away	Toward	Away	Away	Toward
Overall	Gain	Toward	Toward	Ambivalent	Toward	Away	Away	Away

General Characteristics for Each Research Participant

In Table 33, the type of learner, learning style, notion of ideal science classroom, and opinion of group learning for each research participant are listed. Each individual participant is different for each category, as expected. Each individual is a somewhat dissimilar learner, possessing a varying learning style, idea of ideal classroom, and opinion towards group-type learning.

Lauren was an auditory and kinesthetic learner. She studied by looking over PowerPoints, repeating points over and over, and knew she knew something if she could repeat to other people. Her ideal classroom had lots of hands-on activities and opportunities to interact. But she was ambivalent towards group learning, and she felt that learning in a group depended on group members.

Jeffrey varied from Lauren in his learning. He was strongly visual and kinesthetic learner and recognized that he knew something if he can reproduce it. He did this by getting a general grasp of the overall concepts and then going into detail a few chunks at a time and then moving on. He was extremely mathematical, liked to engage, and was quick to vocalize his learning. He enjoyed working in small groups in order to make sure if he wasn't missing something important for his learning and queried his group mates to get reassurance.

Table 33. Cross-Case Analysis of Learning in the Science Classroom for Each Participant

	Type of Learner	Learning Style	Ideal Science classroom	Opinion Towards Group Learning
Lauren	Auditory, Kinesthetic	Looked over PowerPoints Repeated points over and over Had to be able to say back to other people	Lots of hands-on activities and opportunities to interact	Ambivalent towards Learning depended on the quality individual group members
Jeffrey	Visual, Kinesthetic	Knew something if he could reproduce it in a different manner Got a general grasp of the overall concepts and then went into detail, starting with a few chunks of time and then moved on Vocal and quick to engage other learners	Mathematical with repetitions Being able to verbalize, explain meanings behind equations and critically think	Working with others was valuable in case he is missing something Asked a lot of questions to get reassurance in group
George	Visual and "individual"	Buildup of ideas Starting out with less knowledge and then gain knowledge Studied his notes and PowerPoints and came up with questions he needed to ask the teacher	Liked lots of PowerPoint slides with content Relished fun classroom activities Preferred little or no group work Constant testing of content helped learning	Had distaste of group work Felt he has a burden to carry in groups

George was a visual and highly independent learner. For him learning was building up of ideas by starting out with less knowledge and then gaining knowledge. He studied his notes and PowerPoints and came up with questions he needed to ask the teacher. He preferred having lots of PowerPoint-type content slides and little or no group work and valued the constant retesting of his knowledge during class.

Table 34 shows each research participant's general impression of DyKnow; opinion of collaborative/sharing; use of tablet PCs, screen, stylus, and drawing; use of class notes and Moodle; and opinion of polling, surveys, websites, and simulations.

Lauren enjoyed everything about DyKnow and felt that interactions on DyKnow helped her learning. She valued the ability to write on and control what was happening on the projected screen for all student learners to see. She didn't perceive any big difference between tablet PCs and personal computer but she valued the ability to write on the screen if she chooses or to type in text boxes. Also, she utilized Moodle regularly, and it was essential for her because she could access her class notes online. Polls, surveys, websites, and simulations kept her attention, and she believed fostered interactions within the classroom and served as conversation starters for her.

Jeffrey loved DyKnow and thought it was very efficient and organized with many tools and strengths. He valued being able to view what others were doing and acknowledged that DyKnow forced students to be prepared to interact during class. He appreciated using tablet PCs, including their portability, though many times he interacted only with his stylus on the screen. He especially liked to write and draw mathematical or equation forms. He stated he accessed Moodle occasionally to view class notes, and they

Table 34. Cross-Case Analysis of Facets of Interactive Technology for Each Participant

	General impression of DyKnow	Collaborative control/Sharing	Opinion of Tablet PCs, Screen, Stylus, Drawing	Opinion of Class notes, Moodle	Opinion of Polling, Surveys, Websites, Simulations
Lauren	“Liked everything” about DyKnow Interactions on DyKnow helped her learn	Liked the ability to write on and control what is happening on the projected screen	Felt that PCs and tablets are basically the same Likes the ability to write on screen Chose to type in text boxes	Moodle was very important Accessed past class notes posted on Moodle regularly	Kept her attention and fostered interactions Served as conversation starters
Jeffrey	“Loved” DyKnow Very efficient and organized Had many strengths and tools	Valued being able to see what others are doing Forced student learners to be prepared	Liked tablet PCs and their portability Sometimes interacted with screen Liked drawing diagrams and writing equations	Accessed and used class notes periodically on Moodle Triggered “connections”	Kept him on track Assisted in showing the teacher what students know about the course material Pushed him to continue reading outside of class
George	“Awesome” Very efficient and organized Liked answer boxes and interactive questioning	Appreciated how and in what ways stake-holders could put ideas on the board and change them in real-time	Liked tablet PCs Felt tablets go hand-in-hand with DyKnow Liked portability Continually drew and doodled	Believed they are very valuable and used them often	Kept students’ attention Helped learn what is necessary for testing Forced him to be prepared for class and could be competitive

helped him trigger his “remembrances.” Polls, surveys, websites, and simulations kept him on track and also pushed him to continue his reading outside of the classroom. Further, he stated that they aided the teacher in comprehending what students knew about the material.

George thought DyKnow was awesome. He believed it was efficient and organized, and he especially valued its ability to allow students to respond within gray boxes and its capability to employ interactive questioning. He further appreciated the software's ability to project student ideas on the overhead screen and then subsequently change them in real-time. He also enjoyed using the tablet PCs and felt they went hand-in-hand with DyKnow though the technology made it easy for him to constantly doodle and draw on his individual DyKnow slides. Moodle held value for him in accessing course notes while at the same time the interactive elements of the course kept his attention, helped him learn what was necessary for testing, and fed his competitive spirit by forcing him to be prepared for class.

Table 35 lists the level of student use or indications of student preference for each technological aspect along with whether the element is oriented towards the individual, group or both, type of scaffold afforded with technology, and the type of teacher feedback.[26] Each aspect is rated from low to moderate to high, depending upon each student's use of that aspect and/or indications of relative importance for each student learner.

Various elements of technology rated *high* for all research participants. These include elements of overall use of DyKnow, preformatted class slides, preformatted class evolution, the ability to control content on overhead screen, and DyKnow Server/Moodle course page. A number of elements are rated *low* by all participants. This include the use of preformatted list of objectives, directed submission of student work on DyKnow slides, displaying and sharing of student work, and use of replay on DyKnow. For the remainder the elements, except for polling, the participants agreed to a fair extent, ranging from low and moderate or moderate and high responses. (This implies that the

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[26] Also see Table 15

participants saw DyKnow in a similar way: some elements were important and other elements were not so important.) As a consequence, some of the strategies for teacher scaffolding and feedback imbedded within each aspect of technology were more significant for student learners than other strategies. And since students had a preference for one over another, their utilization of technology and its accompanying teaching strategy then differed for each student.

The question then remains: How does a student's general preference for, and use of, various features of interactive technology affect his/her learning in motion and force? Obviously, this is a difficult question to answer given the myriad variables involved in ascertaining conceptual development. Yet, some general features for each of the participants are relevant as discussed in the next section, c.f. below in Overall Findings.

Table 35. Level of Use of Aspect or Indications of Student Preference for the Elements of Technology

Use of Aspect	Lauren	Jeffrey	George	Individual, Group, or Both	Type of Scaffolding Afforded by the Technology	Type of Feedback
DyKnow Interactive Software	High	High	High	Both	All types	All types
Tablet PC	Moderate	High	High	Both	All types	All types
General use of pre-formatted class slides	High	High	High	Both	All types	All types
Use of preformatted list of objectives	Low	Low	Low	Both	Attention	Interactive, Timely
Use of preformatted class evolution	High	High	High	Both	Interaction, Attention, Visible knowledge	All types
Directed and spontaneous student inking/drawing and filling text boxes on slides	Moderate	High	High	Individual	Interaction, Attention, Visible knowledge, Procedural steps and modeling knowledge	Interactive, Targeted
Directed and spontaneous electronic submission of student work on DyKnow slides	Low	Low	Low	Individual	Attention, Visible knowledge, Procedural steps and modeling knowledge	Assessment, Timely/Corrective
Teacher displaying and sharing of individual student or group work	Low	Low	Low	Group	Interaction, Attention, Visible knowledge, Procedural steps and modeling knowledge	All types

Individual student ability to control content on individual tablet screen including color, shapes, and text boxes on slides	Moderate	Moderate	High	Individual	Visible knowledge, Procedural steps and modeling knowledge	Interactive
Student group control of individual DyKnow slides	High	High	Low	Group	Interaction, Attention, Visible knowledge, Procedural steps and modeling knowledge	All types
Student ability to control content on overhead screen	Moderate	High	High	Both	Interaction, Attention, Visible knowledge, Procedural steps and modeling knowledge	All types
Replay on DyKnow slide	Low	Low	Low	Individual	Visible Knowledge, Procedural steps and modeling knowledge	Timely
Polling and surveying of students	High	High	High	Group	Interaction, Attention, Visible knowledge	Timely/Corrective
Imbedded websites and software and teacher restriction of browsing	Low	Low	Moderate	Individual	Attention, Websites and learning software	Interactive, Timely/Corrective
DyKnow server and Moodle course website	High	High	High	Individual	Websites and learning software	Assessment, Timely/Corrective

Major Findings

Introduction

In this section a number of overall findings related to the research questions will be presented. To address the findings and research questions, a general description of each research participant's experience within the technology-enhanced environment was articulated above. This included the individual utilizations of DyKnow and tablet PCs and teaching practices within a specific science classroom, one which embraces social constructivist teaching and learning philosophies. Further, in-depth explanations for each participant's development in force and motion concepts and changes in beliefs/attitudes also were provided.

From these explanations, three major findings related to the research questions will be reported. First, distinct indications of learning within force and motion concepts were clear for the research participants along with a general favorable shift in attitudes and beliefs about physics. Second, the ways in which interactive technology was utilized by the students within this setting depended on the each individual learner. As a consequence, the utilization of interactive technology by the instructor for feedback and scaffolding activities relied, not only on teacher strategies and the types of available technologies, but also on student learners and their individual enlistment of those technologies. Lastly, there was a positive impact on learning of force and motion concepts for research participants within the setting. Thus, the impact of the use of interactive technology on force and motion conceptual development for research participants was evident. This was especially true for concepts impacted by teaching techniques that matched prior student learning experiences, like those fostering content delivery and student interactions. And, as a corollary to this, the elements of interactive technology which were scaffolded to "elicit attention" and increase "student interactions" were the most successful for student learning of low-level concepts; elements related to making "knowledge visible and modeling knowledge" and "procedural steps" were most successful for student learning for high-level concepts.

First Finding

First Finding: As the course progressed, student learners evolved in their beliefs/attitudes about physics and also advanced in levels of proficiency in force and motion concepts. Each individual participant evolved differently. Finding #1 relates to Research Question #1.

It is clear that student learners do not come to a physics course as blank slates (NRC, 1996; NRC 2000). When students arrive within a course, they bring a set of preliminary beliefs and attitudes about science, prior understandings of science concepts, and repertoire of learning strategies honed and tempered through prior experiences. And it is also evident that teachers can affect student learning through structured class activities and discussions. At the same time it is the hope of all science teachers not only that each student's conceptual understanding and ideas about science progress but also that their attitudes and beliefs about science move towards those of science experts. This movement may then positively affect student science literacy, motivation to learn in science in the future, and subsequent individual career paths. For this study, student beliefs/attitudes and ideas about force and motion concepts all shifted. This included their ideas about science, understanding of science concepts, and their enlistment of interactive technology.

Student Change in Attitudes/Beliefs Toward Physics

Since student expectations and beliefs about science affect learning (Redish et al., 1998, Shanin, 2009), an understanding of how students developed in their beliefs/attitudes concerning physics was noteworthy. As discussed in the above narratives and as seen in Tables 21, 23, and 25, each individual research participant's beliefs/attitudes concerning physics changed during his/her ongoing experience in the course. Individually, the normalized pre- and post-assessment shifts in the Maryland Physics Expectation Survey (MPEX) for each of the attitudinal categories are shown in Figures 5, 7, and 9. Each individual, as expected, moved in varying attitudinal directions. Lauren moved either "towards" expert beliefs or was "ambivalent" in her beliefs in Table 21 while George shifted very little in his beliefs about physics, as in Table 25. Jeffrey advanced towards experts in roughly half of the categories whereas he moved away in the other half in Table 23.

It is apparent that during the course, as a whole, the researcher participants' beliefs about physics also shifted as can be seen in Table 31. Their overall beliefs progressed from more "novice" ideas to more "expert" ideas about physics with small changes overall for pre- and post-assessments, signifying slight movements in all categories in Figure 12. Generally, student attitudes/beliefs towards physics moved slightly towards expert's beliefs in the "Overall" and "Independence" responses along with a moderate-to-large favorable movement for the "Concepts" category. Consequently, according to Redish et al. (1998) and Sahin (2009), student learners evolved from receiving information to reconstructing one's own understanding, i.e. became more "independent," and that their beliefs about conceptual knowledge shifted from seeing physics as a set of formulas towards viewing physics as a set of concepts that underlie formulas, i.e. became more "conceptual" in their understandings about physics.

On the other hand, as a whole, student attitudes/beliefs shifted slightly away from experts opinion on "Reality," "Math-Link," and "Effort." Thus, learners overall evolved in their beliefs away from expert opinion in those areas. This means that their beliefs became more unrelated to experiences outside the classroom, i.e. their beliefs about physics shifted away from a link to real-life experiences. Also, they became more concerned with mathematics as a tool for calculating with numbers, i.e. moving towards use of mathematics as a calculational tool rather than representing information about physical phenomena. Lastly, they became less willing to think carefully about what they're doing, i.e. gave less effort to careful consideration of physical phenomena overall.

Student Conceptual Development in Force and Motion

Concepts

Students also made advances in conceptual understanding of force and motion. As can be seen in Tables 26, 27, 28, and also in the summary Table 29, student participants improved in their assigned levels of proficiency for concepts related to general motion, Newton's First, Second, and Third Laws. In general, participants moved from lower levels like "crude" and "basic" towards more "moderate" and "sophisticated" levels of understanding. Individual movement in those categories was, as expected, non-uniform and dependent upon the individual. Students arrived in the course with higher levels of proficiency for general motion concepts, like kinematics, than for most force concepts, and also most students had lower levels of proficiency for Newton's Third Law at each point-of-interest than for the other categories. Further, students exited the course with the almost uniformly "sophisticated" understanding of force and motion concepts. The only exception was for Newton's Third Law which had a lower level of understanding, near to a "moderate" level of understanding. Thus, it appeared that student learners have a more difficult time with concepts related to Newton's Third Law. This supports Brown's (1989) contention that student learners enter physics courses with poorly developed notions of Newton's Third Law and that these preconceptions are persistent and difficult to overcome during instruction. Unfortunately, the lack of progress with Newton's Third Law can also retard progress on other force and motion concepts too. But, as Brown writes, "If students can gain a deep conceptual grasp of Newton's third law, they are in a much better position to answer both qualitative and quantitative questions involving forces" (p. 365).

The overall results of the Force and Motion Concept Evaluation (FCME), Figure 10, also shifted. As can be seen in the figure, in nearly every category, student learners made gains. These gains were across the board and moderate to large in extent, including large gains in ideas related to forces, reversing direction, graphs of acceleration, and Newton's Third Law. And although student learners in general started out at very low levels of understanding for all the concepts, their progress was noticeable in the assessment. (It should be stated that this type of assessment was one of the only multiple choice assessment of the course for student learners.)

Individually, student also made gains on force and motion concepts on the FMCE, as can be seen in Figures 4, 6, and 8. As expected, individual learners progressed in varying conceptual categories. Lauren achieved large gains in the graphing of acceleration and Newton's Third Law. Jeffrey made gains in forces, changes in motion, and graphing of acceleration, except for Newton's Third Law questions. Moreover, George made the most strides of the three participants in his understanding for this artifact, progressing on nearly every concept in the assessment. However, it should be noted that George may not have taken the first assessment administration seriously, skewing the relative differences in the assessment, or perhaps he was just a better test-taker of multiple-choice-type assessments than the other two participants on the final assessment.

Second Finding

Second Finding: How interactive technology was employed by the student depended on the student learner. The utilization of interactive technology for teacher feedback and scaffolding relied, not only on teacher strategies and the types of available technologies, but also on student learners and their individual employment of those technologies. Finding #2 relates to Research Questions #1 and #2.

When the students entered this technology-enabled learning environment, they entered a new paradigm–a science course based on a social constructivist, technology-enhanced teaching philosophy. Faced with this, as in all courses, students adapted. As can been seen from Finding #1, individual learners evolved in their beliefs/attitudes about physics and also grew in their understandings of force and motion concepts. The general learning characteristics for each individual and their reactions to interactive technology can be seen in the above individual narratives and in Tables 16, 17, and 18.

At the same time, they also adjusted to this technology-enhanced science course by displaying inclinations for some aspects of technology, and not for others, and acclimating to its uses in various ways. Some elements of interactive technology, including DyKnow, simply weren't utilized by student learners in the way that the teacher had intended them to be used. Some elements were more important for them and thus were utilized by students more frequently and with more success. Other elements, especially those not emphasized by the teacher, were enlisted less frequently or ignored completely. And though student learners collectively encountered the same elements within the course and had no problems with new technology–they grew up with technology and were, relatively speaking, technology experts, these differences in individual preferences for and use of the various elements of technology then affected learning. And in the process, the learners themselves altered that same course environment as a consequence, including the ways in which the teacher subsequently structured activities within that classroom based.

Each learner drew on different elements of technology as can be seen in Tables 34 and 35. Some overall results stand out. First, in general, students reacted positively to technology, like DyKnow Interactive software and tablet PCs. All student participants valued DyKnow and appreciated what the technology allowed. This included the portability of the tablets, ability of students to write with a stylus on individual tablets and class overhead screens while using DyKnow, their ability to interact with other student learners through DyKnow, and the general availability of science content across DyKnow servers and the Moodle course website. Students further found value in having PowerPoint-like content displays and also welcomed immediate access to lecture printouts and course files on Dyknow/Moodle. Second, the activities designed by the teacher to promote active learning, including structured DyKnow activities and those related classroom feedback, were greeted differently by each student. Some scaffolded activities with DyKnow were rated highly by student learners. These included the use of a preformatted "class evolution;" directed and spontaneous student inking/drawing and filling in text boxes, i.e. the so-called "gray area" prompts; student ability to control content on both individual and overhead screens, as directed by instructor; and polling/surveys. Other activities designed by the teacher were not received so highly, however. These included the use of a list of objectives to start class, immediate electronic submission of student work, teacher sharing of individual student group work, the use of replay on DyKnow, imbedding of websites/simulations, and restriction of student browsing on the Internet.

Tellingly, the research subjects responded in various ways depending on their learning preferences. As can be seen in Tables 16, 17, 18, and 35, the learning characteristics of each participant and their reactions to each aspect of technology varied. For example, Lauren favored group learning and reacted favorably towards those elements that were more "group" or "both" group and individually oriented. These included use of class evolution, student group control of individual DyKnow slides, student control what's happening on the projected class screen, and polling/surveying of students. In other words, Lauren found value in those facets of the environment that enabled her to *interact with others* and to observe and engage with other students' ideas and opinions. On the other hand, George favored more individual-type learning and responded favorably to more "individual" elements of technology, like directed and spontaneous student inking and filling in text boxes, student ability to individually control content on each tablet, use of embedded websites and software, and employment of DyKnow server and Moodle course website. Thus, he was attuned to those facets that enabled him to *experience, review, rehearse, and individually test* his evolving knowledge. Lastly, Jeffrey exhibited preferences for both group and individual learning, and thus was more mixed in his preferences. He favored some elements, and not others, enjoying group-centered activities while also appreciating activities that emphasize individual learning.

These individual student preferences then affected teacher utilization of these technologies. Not surprisingly, the use, or non-use, of technology by the research participants could not have easily been deciphered by the instructor. In other words, it was not obvious at the time which aspects of the technology were being utilized by students. Hence, even though all students actively participated together in the classroom setting, technology was employed differently by all, and instructor awareness and questioning of student learners through interactions with the learner was then necessary to gauge student utilization of technology and learning. Thus, the teacher-student interactions were vital in this technology-enhanced environment.

Third Finding

Third Finding: After factoring in individual preferences, the overall use of interactive technology, including DyKnow Interactive Software, positively affected individual student learning within force and motion concepts. Specific uses of DyKnow that led to increased conceptual development included PowerPoint-like content delivery for low-level concepts and the formation of student groups to foster interaction and feedback opportunities for higher-level concepts. Finding #3 relates to Research Questions #1 and #2.

Corollary: Elements of interactive technology which were scaffolded to elicit attention and making knowledge visible were the most successful for student learning of *low-level content. Elements related to increasing student interactions and modeling knowledge/procedural steps were most successful for student learning of high-level content. Finding #4 relates to Research Questions #2.*

As was stated in Findings #1 and #2, student learners grew in their conceptual understanding of force and motion concepts, and individual participants had various preferences for and practices with interactive technology. Since student employment of the elements of interactive technology varied depending on each individual's preferences for technology, then presumably, the imbedded teaching strategies utilized with technology, i.e. with DyKnow, like scaffolding activities and continual feedback, had varying effects for each individual even though they are in the *same* learning environment. If Finding #2 holds, then student learning was more or less successful as indicated by use of the aspect or student preference for that aspect, as can be seen in Tables 29 and 35. The question then becomes, "What were the connections, if any, between how individual students utilized technology and their subsequent learning within force and motion concepts?"

Obviously, many factors influenced student conceptual development within this environment.[27] The level of content knowledge played a role for each individual, as did student prior experiences in science, and the model of learning applied by the teacher within this environment. Broadly, indications of student development in force and motion concepts depended on the level of content, whether high or low, teacher structuring of activities using technology, and the teacher's ongoing assessment of learning. In turn, these then influenced how each individual student progressed in the various categories of force and motion concepts, c.f. Table 29.

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[27] It should be noted, however, that the disentangling of cause-and-effect in the study is difficult given the qualitative methodology utilized in the study.

Past experience in science without a doubt shaped learning. Clearly, the research participants had prior involvements in other science areas before entering this course. And for the most part, according to the participants, these learning experiences coalesced around the traditional use of a teacher-distribution-of-knowledge model or transmission-type of teaching practice (Gunel, 2008). This involved the repeated use of PowerPoint slides or longhand notations on whiteboards, leading to content distribution and rehearsal of concepts. In this type of learning environment, learners first engaged and experienced the content offered by the teacher. Then, students interacted and reviewed this content individually. Finally, individual learners rehearsed content for later replication and redistribution. Learning in this model than revolved around absorption of expert opinion through lecture or reading, subsequent individual internal dialogue, and replication of knowledge for assessment purposes (NRC, 1996). Although these experiences included some elements of active learning processes, like student groupings, usually the distribution of low-level content to student learners, like definitions, descriptions, and lists, was a main goal of the teaching.

Since the students' prior learning experiences have been those of content distribution, it was first expected that the content delivered through teaching methods and assessed with methods related to this traditional dissemination of content would be most readily learned (Tobin & Tippins, 1993). Hence, it was reasonable to conjecture that students will have honed those specific skills must useful for rehearsal and replication of content material. And it also was probable that learners developed in those areas where they had with more existing knowledge. This would be attributable to the fact that delineating and distributing the definitions for concepts about which students have had prior knowledge, like motion, would have been easier for the student learners to understand than more complex concepts, like applying problem-solving strategies. Indeed, both appeared to be true. To investigate this, one could look at concepts that students comprehended somewhat well initially along with those that would have been most impacted with any traditional transmission-type approaches utilized in the course and then decipher if there are connections.

Students began with rudimentary understandings of physics from past experiences. Specifically, they entered the course with some low-level knowledge of motion and force definitions, as seen from initial assessments like the Force and Motion Conceptual Evaluation. Low-level concepts–based loosely on the categories in Bloom's Taxonomy of Questioning (Krathwohl, 2002)–were defined by the researcher as information that needed to be identified or recognized and then subsequently repeated, memorized, listed, and/or recalled. As can be seen in Table 29, students arrived in course with moderate to sophisticated levels of understanding of the kinematical knowledge, including position, velocity, and acceleration, and some definitional understanding of Newton's Second law, $F = ma$. This included definitions of the motion concepts and the listing of equations for force or motion. (On the other hand, for Newton's First and Third laws, Lauren and Jeffrey began with crude or basic understandings while George began with a moderate understanding of both laws.)

How student learners came to know these ideas was up for debate. Perhaps, student might have been exposed to operational types of physics knowledge in related natural-science classes, like biology and chemistry, serving as a basis for their respective subjects. Or students might have encountered the idea of Newton's Second Law and memorized it and applied it in simple cases within other settings, like in high school physics courses. Further, the relation between distance, rate and time for non-accelerated motion, $Distance = Rate \cdot Time$, is well known. In any case, the basic knowledge of basics of motion was apparent. And they indeed exited the course with even higher levels of understandings of those specific conceptual areas after instruction in those areas. Therefore, student advancement by the prior criteria would have been expected in these areas.

Aspects of technology applied in the course that most represented content distribution included aspects of DyKnow elements structured to increase “attention” and make “knowledge visible.” Various elements of DyKnow were articulated and utilized by the teacher to distribute content and elicit student attention. Several examples stood out. First, the employment of pre-formatted DyKnow content slides assumed the most PowerPoint-like status and was thus the most transmission-like application of DyKnow in the course. Low-level definitional ideas related to motion and other concepts were easily transmitted to student learners via the preformatted DyKnow slides. This was very similar to more traditional means of content transmission: Student learners were exposed to new ideas through the dissemination of concepts–knowledge made visible on tablet screens or on the overhead screen. The DyKnow content slides then were a powerful learning aid for studying and rehearsal of concepts, according to learners, and gains in recall of definitional forms were apparent on the course assessments, like exams and homework artifacts. Second, the inclusion “gray” areas within those preformatted slides served to elicit student attention. As structured by the teacher, these gray areas were filled in by the student learner as various concepts were discussed. Therefore, in order to fill in these areas, students must have been engaged and responsive within class discussions. All student learners remarked positively about the gray areas, as they had experienced this method of content distribution in the past. Third, the ability for student learners to augment and modify existing content in DyKnow, i.e. individual student control of content on the DyKnow slides, was also vital. Like the gray areas, the ability for students to modify course content with their styluses within the DyKnow while they participated in course conversations appeared to lead to advances in conceptual development for low-level forms of content. This helped learning for student in two ways by: (1) forcing learners to augment slides within ongoing conversations and (2) facilitating the utilization of DyKnow slides for rehearsal and review for grading assessments and as means from which to study for course examinations and homework artifacts. Lastly, polls/surveys were very beneficial for student learners. All research participants had prior experiences with polling and surveying in other courses, and all responded favorably to their usage in the course. According to the learners, both polls and surveys assisted to keep the attention of student learners and helped them to focus on new ideas. They also as a means for students to compare individual student progress in low-level concepts. Although the depth of the conceptual development for each use of these uses of DyKnow was limited, they were highly rated and utilized continually by the research subjects.

It should also be noted that in the dissemination model teacher feedback had a limited role in learning, however. The method, in general, wasn't as successful for concepts that were not easy to memorize, couldn't be memorized, or required more conceptual linkages. For these higher-level concepts, like those listed in Table 36, learning was not as successful. That is, for higher-level concepts that required manipulation, application, critique, analysis, judgment, and/or prediction, students would have had more difficulties with this model. This was especially true for problem-solving and mathematical manipulation. Moreover, students who were accustomed to the dissemination model (and had not encountered a conceptual conflict model) would have had troubles with learning these types of concepts. For example, the concepts and applications of Newton's First and Third laws along with applications of Newton's Second Law were, and are, complex and required much more thought that simple memorization or identification. Further, students did not come to the course with very high levels of understanding of these two specific laws beyond their mere definitions or problem-solving with mathematics, aside from some limited problem-solving in their general chemistry courses. In addition, the manipulation of equations related to Newton's Laws or kinematics, or indeed of any other mathematical form, to make judgments or predictions, were higher-level examples. Truly, memorizing equations was much different than having the ability to manipulate and interpret the mathematical forms of force and motion.

Table 36 shows the levels of content, based loosely on Bloom's taxonomy, applicable scaffolding strategy, and features of DyKnow which helped to augment student conceptual development in those areas.

Table 36. Levels of Content and Applicable Features of DyKnow

Types of Content	Features of Content Type	Examples of Content-type for Force and Motion	Examples of Force and Motion Concepts	Applicable Strategy and Feature(s) of DyKnow
Low-Level	Memorizing, Recalling, Classifying, Identifying	Definitions, Lists, Descriptions	Kinematics, Definition of Newton's Second Law	Eliciting Attention Making Knowledge Visible (1) Pre-formatted Slides (2) Gray-Areas (3) Student control of individual slides (4) Polling/Surveys
High-Level	Manipulating, Applying, Critiquing, Analyzing, Judging, Predicting	Consensus making, Problem-solving, Manipulating Math forms,	Newton's First, Newton's Third, Application of Newton's Second Law	Increasing Interactions Modeling procedural steps and knowledge (1) Class Evolution (2) Student group control of slides (3) Ability to control overhead screen (4) Replay on DyKnow

During their experience in this course, many activities then went beyond the simple distribution of content, addressing higher-level concepts. Indeed, a conceptual development model of learning (Posner et al., 1982) was encountered by student learners to forge understanding about science concepts. The goal of this constructivist-type learning environment was to foster *conceptual change* through constant assessment of student learning. This course was organized by scaffolding activities and teacher feedback processes with the assistance of interactive technology in order to perpetuate conceptual change across student learners within the setting. In particular, the intent was then to create *conceptual conflict*, offer correction to student learning, and challenge students to review and evaluate their learning individually and socially. This usage could be especially valuable in science where technology could assist in creating conceptual conflict leading to accommodation of new science ideas and concepts, like with force and motion concepts in physics (Hewson & Hewson, 1984; Meyer & Moreno, 1998; Tobin & Tippins, 1993).

New and unique activities using interactive technology assisted student learning for higher-level concepts. In Table 13, the general types of scaffolding with different intents are listed. These different intents can enhance learning by allowing constructivist learning techniques to occur along with the use of technology. In Table 36, examples of high-level content and intent of teacher scaffolding are also displayed. These include consensus making, problem-solving, and manipulating mathematical forms, like equations. Aspects of technology used in the course that most addressed high-level content included DyKnow elements scaffolded to increase "interaction" and show "procedural steps and modeling knowledge."

Several examples are relevant for high-level concepts. First, beginning each class experience with an "evolution" acted as a means for creating interaction amongst learning stakeholders. This was a highly rated activity in which student learners were required to respond to a prompt, submit response, and that engage in class discussions. Usually the question related to a low-level content area, such as definitions; however, the resulting discussion from these prompts for student learners to engage and interact within the classroom setting. The teacher then utilized a blank DyKnow slide on which to write common student responses, organized around unified themes and visible to all stakeholders. Oftentimes, the resulting discussions went beyond the original question and into areas involving the creation of linkages amongst content areas, consensus making, and even some problem-solving, all aided by the teacher utilization of tablet and stylus.

Second, the ability for student group control of DyKnow slides was important for learning. Within DyKnow, teachers have the ability to group student learners into various groupings, including pairs, groups of three, etc. Within these groups, students then had the ability to collaboratively control their group's slide from their individual table PC, thereby communicating and interacting with each other within the technology. With this ability, the teacher could then create various activities within these student groups, initiating the discussion and engagement of high-level ideas, like problem-solving and linking of course concepts. For example, various activities were constructed in which student learners were required to collaboratively solve examples using Newton's Second law. The teacher first displayed an example of a step-by-step solution using Newton's Second Law. Student groups were then arranged, often by random selection, and a DyKnow slide with a related physical example requiring a numerical answer was then displayed. Student groups then needed to interact to solve the problem, requiring problem-solving skills and the use of tablet, styluses, calculators, and course textbooks. As student groups collectively solved these problems, the instructor then had the ability to draw from their work and distribute each individual group's progress to other groups via the overhead screen. According to all learners, this type of activity was both effective and efficient. It was effective in that it required learners to interact, hone their problem-solving abilities and then agree upon a common answer. In other words, it required interaction and the displaying of procedural steps to find a common answer. Further, it was efficient due in that there were no papers exchanged or shifting of seats or any general movement within the classroom. Thus, it was quick, orderly, and centralized through the technology.

Third, along with student collaborative control, students had an even greater ability: the ability to control the overhead screen for all student learners and teacher. This was different than collaborative control, for an individual student had the ability to control the content for *all* student learners throughout the classroom. Once given control from the instructor, the individual student could add, annotate, or otherwise modify content on the overhead for all to view. For example, the teacher could augur interactions and model procedural steps by creating activities where student learners needed to fill in the steps in a given problem or create links amongst various concepts. Using DyKnow, a slide could be constructed with steps missing within a sample problem or with linkages not visible to students. Student learners would then be asked to fill in the blanks or add the required link using their individual tablet and stylus. In this way, creating interactions and the modeling of procedural steps were combined into a single DyKnow-enhanced activity. Student volunteers or students chosen through random selection could then be called upon to display their responses and argue their accuracy or correctness before the whole group.

Fourth, replay on DyKnow was moderately effective for learning. A wonderful feature of DyKnow was its ability to replay procedural steps within the application. In other words, the individual marking of steps using the stylus could be replayed, step-by-step, for the student learner. These steps could be the teacher's or student's steps depending on how the technology was used. For example, the teacher could distribute a DyKnow slide all student learners in which the teacher had solved a problem using his stylus. These teacher steps could then be replayed by the students independently within the DyKnow application. Therefore, the modeling of procedural steps and knowledge could be done effectively through a simple use of the application. This ability was rated lower by student learners than some other features of DyKnow. In fact, until told of it, Lauren was surprised that DyKnow had the ability to replay her stylus strokes! Jeffrey and George both knew of the capability but enlisted it infrequently. This was most likely due to the fact that the instructor did not emphasize this capability within the application and further did not specifically structure frequent uses of this capability within the classroom setting. Thus, it was not used effectively by the instructor or students within this setting. Moreover, in many ways, as discussed above, problem-solving activities were relegated to a second tier of learning in favor of more conceptual development type activities. Consequently, student learners place much more emphasis on activities that developed connections or linkages amongst concepts than on activities with problem-solving elements. This can also be seen in the way student attitudes on the MPEX about the link between mathematics and physics moved away from experts. This non-emphasis of problems-solving in general coupled with the underuse of the DyKnow replays during classroom experiences could have contributed to this apparent movement away from expert opinion.

Limitations of the Findings

Several limitations of these findings stem from setting of the study, initial research questions, and methods used. First, this study occurred in one particular university-level physics course and focused on three individual learners, representing low-, middle-, and high-levels of initial understanding of force and motion concepts. This study involved marrying interactive technologies, like DyKnow and tablet PCs, with social constructivist teaching practices in a single setting. Therefore, this study was located in a very specialized environment and with a very specific catalog of teaching strategies and technologies. The results of the study then are not necessarily generalizable to other venues with differing teaching strategies and technologies. Particularly, practitioners in classrooms centered around traditional, transmission of content methodologies must be wary of the overall findings of this study.

Second, student motivation and beliefs about science can be particularly difficult to pin down. Many of the conclusions drawn within the study about student motivation and belief in science must be viewed with a note of skepticism. Actual motivation and beliefs of student learners, in particular, can only come from indirect measurements, like interviews and assessments products. Interviews within this study were between researcher and subject, and although the implicit relationship between the two was one of trust and friendliness within a small community (everyone goes be their first names), unequal power dynamics were most assuredly in play. Consequently, how students self-report their so called “motivation” and “beliefs” about physics must be called into question given the fact that the person to whom they were reporting was their instructor and therefore the person who reports their individual grades.

Lastly, the research methods employed, namely a qualitative, multiple-case-study methodology, do not lend themselves to generalizability across different classrooms, c.f. Chapter 3. Though the descriptions of each individual research case were rich and abundant in detail and findings for each case and across cases were sound, the small population of research participants puts in doubt the ability for reader to generalize these descriptions and results to other settings beyond case-specific situations.

Summary of Chapter

In this chapter, multiple elements related to the research questions were discussed. This included a comprehensive description of a typical class from the teacher’s perspective, general descriptions of each research participant and his/her uses of interactive technology, in-depth explanations of each participant’s development within force and motion concepts, cross-case analyses of student progress in force and motion concepts and utilization of technology, and lastly, a discussion of overall findings. This study found that three important findings that influence learning in the classroom: (1) student learners evolved in their self-reported attitudes about physics and advanced in their levels of proficiency in force and motion concepts; (2) the ways in which interactive technology was employed by the student learners depended on the individual learner along with subsequent changes in teacher utilization of the technology; and (3) the overall application of interactive technology positively affected individual learning within force and motion concepts. Scaffolding of activities to elicit student attention and make knowledge visible aided for learning low-level content; For high-level content, activities designed to model procedural steps and increase interactions were more successful.

CHAPTER FIVE

DISCUSSION

Introduction

This chapter summarizes the findings of this dissertation and discusses the implications for the utilization of interactive technology, like DyKnow Interactive Software and tablet PCs, within constructivist-type science classroom. A summary of the findings will be presented related to the research cases and research questions. This will include descriptions of the three major research findings. Finally, an overall discussion of findings with implications for teaching and future research will also be described. This will include specific tactics for scaffolding activities and auguring teacher feedback with interactive technology and also connections to relevant research literature.

Summary of Findings

In summary, the findings of this dissertation offer some detail into the experiences of three research participants in an introductory university physics course and provide some insight into the employment of interactive technologies, like DyKnow and tablet PCs, within a constructivist-type, introductory physics classroom. First, the general experience of three student learners during four months of intensive physics experience was detailed. This included individual conceptual development in force and motion concepts and their overall experiences while using DyKnow and tablet PCs. Next, instructor use of DyKnow Interactive Software with tablet PCs, and specific activities designed to scaffold learning and facilitate student interactions were also described. Lastly, the conceptual framework invoked within this dissertation recognized that student learners learn effectively through social interactions and that technology can act as a means of facilitating interaction and scaffolding of activities.

The first research question for this dissertation considered how the technology components of a university-level physics course, impacted students' learning in motion and force concepts. Overall, as stated in Finding #1, student learners advanced in their understanding of motion and force concepts, while also at the same time reacting very positively to the elements of DyKnow and tablet PC technologies within the classroom. Since student expectations and beliefs about science affect learning (Redish et al., 1998; Shanin, 2009), measures of student expectations and beliefs were also considered. Generally, students' attitudes and beliefs towards physics moved towards expert opinion, as measured by the MPEX assessment, indicating a positive overall movement for student learners. Individual interviews with research participants also provided insight in to their individual, self-reported motivation to learn and their beliefs about science. And though it was difficult to disentangle how the various elements of interactive technology and beliefs affected student conceptual development, positive reactions to technology paired with self-reported movements towards experts in beliefs and attitudes coincided with broad gains in motion and force conceptual development, as in Finding #3.

The second research question for this dissertation involved how students used interactive technology in combination with purposeful teacher feedback and scaffolding while learning within motion and force concepts. Finding #2 indicated that the employment of interactive technologies alone without specific teacher strategies was not enough. The engagement of technology hence relied on the choices and preferences of student learners and subsequent teacher structuring and restructuring of classroom activities. Therefore, structuring feedback opportunities to increase teacher-student interactions was important so that teachers could continuously assess student development while also refining classroom activities based on student progress.

Findings #2 and #3 indicated that the intention of the scaffolded activities depended on the level of concept that was being taught. Scaffolding activities to increase attention and make knowledge visible were important for learning low-level concepts while using interactive technology. Also, the scaffolding of activities that fostered interactions within the classroom and also that modelled knowledge and procedural steps for student learners were significant for development of higher-level concepts. Examples of those types of strategies and opportunities were discussed in the findings.

Discussion of Findings

This dissertation first identified student learning within force and motion concepts and also general improvements in self-reported student attitudes/beliefs during instruction. Several points of interest throughout the term were identified, and individual student learning within force and motion concepts articulated. These descriptions suggested that within this unique environment, advances in student conceptual development and the convergence self-reported student attitudes about physics towards expert opinion were assisted by the enlistment of specific teacher pedagogies and elements of interactive technology. This supports the contentions of Berque (2006a), Hennessy, Deaney, & Ruthven (2005), and Simoni (2011) that the employment of interactive technologies with specialized approaches can support student learning in science class, in particular physics classrooms. In particular, these supports include allowing students to work at their own pace (Rogers & Cox, 2008), providing for instantaneous teacher feedback and teacher communication to students and proactive guiding of student activities (Bodenheimer et al., 2009; Hennessy, Ruthven, Deaney, 2005; Schroeder, 2004), having the ability to solve and analyze problems requiring sketches and mathematical formulas (Enriquez, 2010), and augmenting student motivation and engagement within science disciplines (Amelink et al., 2012; Dertling & Cox, 2008; Dickerson et al., 2009; Evagorou & Acraamidou, 2008). The use of interactive technologies to allow for sharing of resources, which enabled joint problem solving cross learners and enhanced faculty student interactions, also lent itself to the overall positive progressions of student learning within this setting (Chickering & Ehrmann, 2008).

Second, although all student learners participated in the same technology-enabled environment, individual students utilized technology in manners corresponding to their individual preferences. Consequently, the unfolding of classroom activities depended on students–who were in charge of the enlistment of technology and the pace of learning, not the instructor. This challenges the traditional notion of teacher-driven instruction and instead was more suits an emerging notion of student construction of knowledge within a classroom setting. Also, this implies that student motivation and beliefs about science learning should have an impact on the enlistment and pace of learning within the classroom. This matches several authors' contentions (Amelink et al., 2012, Lui et al, 2011) that student engagement and self-motivation is colored by and enhanced within learning environments using interactive technologies, like tablet PCs. Moreover, as expected, instructor utilization of feedback and scaffolding strategies evolved as his awareness of individual student uses of these elements of technology progressed (Chi, 1996; Lin & Dwyer, 2009; Yip, 2004). The instructor's construction of activities and reactions during classroom activities then changed based on student progress, not only in conceptual ideas, but also in preferences for and enlistment of technology. This included the use of technology for offering immediate teacher feedback (Roschelle et al., 2007) and for creating more frequent student interactions through the creation of multi-student and whole-class groupings (Woodruff & Meyer, 1997). Further, the teacher scaffolding of activities to affect individual student learning, blending different classroom resources, was enabled by the interactive technology (Ge & Land, 2003; Grincewisz et al., 2011; Lin & Lehman, 1999; Zydney, 2010).

Third, the type of learning process and the level of content made a difference in this dissertation. Structuring activities to elicit student attention and also designing PowerPoint-like displays of content to make knowledge visible for student learners were most successful for lower-type processes and physics content, like definitions and theories. These involved low-level learning processes, like memorizing, recalling, classifying and/or identifying material, and specific physics concepts, like ideas related to general motion or Newton's Second Law. Student abilities to experience lectures with many different software applications (Dertling & Cox, 2008), follow progressions of material as it is written (Stickel & Hum, 2008), switch between applications during lectures, and change inking styles (Biswas, 2007) offered distinct advantages within this context. In general, this content delivery matched student prior experience in other science courses and was complementary to their accustomed, self-reported learning styles. For these types of processes, the design of preformatted DyKnow slides and slides with "gray areas" elicited student attention and served as a means of content delivery. The student control of individual slides through DyKnow and the ability to ink and modify content with the tablet PC allowed for further student reflection on their learning knowledge (Biswas, 2007; Lumkes, 2009). Polling/surveys also permitted for student identification of their knowledge base and functioned as a means for comparing emerging individual student ideas to those of others (Sneller, 2007).

On the other hand, for higher-level learning processes, like consensus making, problem-solving and/or manipulating mathematical forms, and more complex physics concepts, like applications of Newton's First and Third Laws, a different set of strategies were more successful and involved different type of scaffolding of activities with technology. These were more "constructivist" in nature and included increasing student interactions within the classroom and also modeling procedural steps. In this way, various activities and elements of technology could be taken advantage of and could be combined to facilitate learning. For these higher level processes, teacher construction of class discussion questions, creation of student groups, collaborative control of DyKnow slides and overhead screen, and the use of replay on DyKnow were fruitful. Class "evolutions" and student groupings delivered with DyKnow and designed by the instructor allowed for frequent and efficient interactions in the classroom (Steinweg et al., 2010). This helped to foster learning through conceptual conflict in which student learners could interact, make misconceptions known, and air subsequent critiques of others' ideas (Theys et al., 2005). Collaborative control of DyKnow slides allowed for comparison of ideas and consensus making through the technology platform and to the class as a whole. To a lesser extent, the use of replay on DyKnow helped to display and model procedural steps within problem-solving settings, both for individual students and for the whole class of learners.

In summary, interactive technology, in particular DyKnow and tablet PCs, can act as a locus point about which student learners and the instructor can interact (Amelink et al., 2012; Berque, 2006a; Biswas, 2007; Dickerson et al., 2009; Evagorou &Acraamidou, 2008; Price & de Leone, 2008; Pryor & Bauer, 2008). Both individually and in groups, different teaching strategies and learning processes can be engaged with the technology, especially with platforms like DyKnow. The flexibility of the technology thus offers distinct advantages which can be leveraged with an emerging instructor expertise. And depending on a one's teaching philosophy, different ways of delivering content, auguring student interactions, and modeling knowledge can be designed using the technology.

Implications for Teaching

The enlistment of interactive technologies can have a powerful effect on learning (Hennessy, Deavney, & Ruthven, 2005; Mayer & Moreno, 1998). And for those teachers who are considering the enlistment of interactive technologies in a constructivist-type classroom, a number of relevant findings from this dissertation should be deliberated. First, it is clear within this setting that students were in control of their individual learning. Second, the teacher in this dissertation designed instructional practices based on his teaching philosophy, specific areas of science content, and available types of technologies. Lastly, the instructor responded to student enlistment and preferences for technology and designed appropriate strategies based on emerging student assessments.

Individuals In Charge of Learning

Within the setting (or any learning setting), students are in charge of their own learning and his/her engagement of learning processes, no matter what the learning method or setting (Bettencourt, 1993; Roschelle et al.,2007; Wells & Arauz, 2006). In classrooms of the past, this learning was chiefly done via the traditional method of content delivery, using simple technologies, like chalkboards and thick textbooks. Student learners within these highly teacher-structured settings were thus charged with encountering, pondering, and rehearsing expert opinion, mainly as solitary individuals. The effectiveness through which students learned was then proportional to the amount of individual effort and energy devoted understanding the ideas of experts, as interpreted through individual instructors and their assessment methodologies.

Within current classrooms, however, contemporary teaching practices no longer view learning is as an individual act, but rather as collective consensus-making across learning stakeholders (Hennessy, Deaney, & Ruthven, 2005). Advanced technologies currently exist, which can aid individual student learning through progressive teaching methods (NRC, 1996; NRC 2000). Moreover, it should be noted that learning can still be accomplished with just about any teaching strategy, including traditional teaching methods, and through varying technologies even if they are rudimentary or used haphazardly. This applies as long as the technology is understandable to student and they are able to adapt to its use (Mayer &Moreno, 1998): case-in-point, ordinary content delivery through PowerPoint, which displays science content on PC screens. But, the efficacy of the learning surely also depends upon the instructor and his or her careful, considered employment of interactive technologies. This enlistment must be consistent with his/her teaching and learning philosophy, i.e. must have the ability to maximally enhance learning (Lumkes, 2008), and be understandable to the instructor (Selwyn, 2013).

Teacher Design of Instructional Practices

Though the students are in charge of their learning, teacher's construction of activities with technology and responsive feedback within the classroom is also very important (Jang & Stecklein, 2010; Li et al., 2010). Those strategies must first come from the teacher's teaching philosophy, which is in turn impacted by one's prior teaching experiences and educational background. Then, guided by this philosophy and aware of available technologies, specific curricular strategies can evolve, which take advantage of and purpose each element of technology.

Yet, even though the teacher directs the environment, it is apparent that all learners interact in the same teacher-directed environment and that the students themselves are the ones who are actually in control of their own learning within this setting. As a consequence, to impact student learning, teachers must structure activities with the realization that not all learners value, or even care to use, a given piece of technology or activity. In order to effectively foster learning, then, within any technology-enhanced environment, teachers first must discover, in some way, student preferences for technology while at the same time ascertaining their pre-existing conceptual frameworks. This could be accomplished by questioning student learners about what their prior experiences with technology have been, including comfort with new types of technology, past experiences and exposures to various types of technology in other courses, and how subsequent learning occurred in previous settings. Instructors could accomplish this by design preliminary activities with a variety of formats, examine what works, and re-emphasize those elements that suit the varying learner preferences within the class. This involves both configuring activities beforehand and then constantly assessing student learning, i.e. teacher scaffolding and feedback. This can result in creating activities with individual preferences in mind, and then as situations progress in class, rapidly augmenting or modifying teaching practices to response to incoming student feedback. Further, teachers must continually adapt to rapidly changing individual preferences for technology while at the same time frequently assessing and challenging students' existing conceptual frameworks. Understandably, it is imperative to not only leverage those features of technology which match student preferences and prior learning experiences but also to work with or modify those aspects that are not as important to student learners. This goes to the heart of student-centered learning: student control of learning combined with proactive teacher facilitation of course events.

Strategies for Interactive Technology

Teachers must emphasize the use and efficacy of different technologies in order for their successful enlistment within the science classroom. It is clear that students will only use and employee those elements of technology that are important to them, in lieu of teacher direction or threat. Moreover, students will not respond favorably to restrictions within technology, like on web browsing, and many may not continue using technology beyond garnering course points under duress in a "use-for-points" system. Therefore, teachers must not only have effective strategies for teaching with technology but must also introduce those strategies and their intent to student learners so that student learners can successfully activate those technologies for their learning.

Instructor choices of technology definitely carry weight too. Just because a technology has many features does not mean a teacher should or have to use them all. And just because an application has a capability doesn't mean students will utilize it: there must be a reason for them to use it! Cleary, instructors must choose the appropriate hardware and software for each teaching method (Lumkes, 2009). Given a set of options, different available technologies should be sampled. They then should be selected based on a teacher's teaching philosophy and also on the general logistics of the classroom. This includes availability of funding, decision-making process, and available interactive technologies and how these components compare to the teaching philosophy of each individual teacher. For instance, if a teacher holds a constructivist mindset and has the funding and the independence to choose a set of interactive technologies, the specific choice of technologies should complement and augment a constructivist-type classroom. In this dissertation, DyKnow interactive technology along with tablet PCs was utilized in a constructivist-type setting with specific instructor strategies for learning. In different classrooms with comparable funding, alternative options might make more sense. And this, in fact, may include ordinary table computers instead of tablet PCs, increased whiteboard space for collaborative work, or a greater selection of laboratory equipment.

The biggest decision ironically is whether to engage technology at all. According to the findings, the collective use of the various technologies did help students progress in their learning. These technologies were efficient and cost-effective, in general. However, many of the scaffold activities used in this dissertation were specific to the DyKnow program and tablet PCs. (And even then, the list of features not employed frequently by students was long.) Frankly, many of the decisions made in using technology could have also applied to ordinary classroom activities without technology, like physically arranging students in small groups within the classroom, simply talking to collaborate and negotiate results, or employing handouts to facilitate problem-solving activities.

Implications for Future Research

The implications for future research from the dissertation are numerous. This dissertation was conducted within a very specific setting: an introductory-level university physics classroom using interactive technologies, namely DyKnow Interactive software and tablet PCs. Therefore, it is unknown how and in what ways the results of the study would look in other situations with alternate teaching philosophies, varying technologies, and in alternate levels of education. And obviously, replicating this dissertation in those settings would most likely obtain varying results. Therefore, the findings of this dissertation can be advanced in a number of ways.

The first way to extend this study in other classrooms would be modify the research questions such that different interactive technologies are enlisted. This could include, for example, the use of ordinary personal computers with DyKnow or using tablet PCs with another interactive program, like Ubiquitous Presenter. Then, if the teaching philosophies and instruction are nearly the same, then one could ascertain whether or not the utilization of varying technologies leads to comparable results. It is expected that the general findings of this dissertation would hold in those settings; however, confirmation of those findings would help to substantiate the original claims.

Another way to extend the study would be to enlist the same research questions in different levels of education, say primary or secondary levels of education, or to different areas of learning. As stated above, the use of mathematical forms within a science discipline lends itself to unique challenges. The employment of technology presumably would then vary in other content areas, ones in which there is a lesser need for manipulation of mathematical forms. Therefore, studies forged with interactive technologies, like DyKnow and with tablet PCS, in other content areas would enlighten this research.

A third area which needs to be addressed is whether scaffolding of activities, specifically modelling procedural steps, would lead to a reinforcement of student self-reported beliefs/attitudes about mathematics. In this dissertation, student learners' self-volunteered beliefs/attitudes about the link between mathematical forms and physical reality deteriorated throughout the term and thus moved away from expert opinion, as measured by the MPEX assessment and in interviews. And it was also clear that student learners' problem-solving abilities on examinations and homework activities needed continued assistance throughout the term. (This comes as no surprise in a physics course!) Further, student learners without question did not prefer the replay feature of DyKnow nor made much use of it throughout the term. Therefore, it would advantageous to explore how specific techniques could be enlisted to model procedural steps with mathematical forms. This could include significantly increasing the number of instructor-created activities or the quality of those activities within alternative technologies in order to decipher whether or not this might foster strengthening of explicit student attitudes about the link between mathematical forms and physical reality. It is an open question then whether similar instructor techniques would lead to similar positive, self-reported attitudinal changes.

APPENDIX A: EXAMPLE OF INTERVIEW PROTOCAL

Student Interview Protocol 1

Instructor Interview Protocol – Date

Student Learning Outlook/Preferences (how does this student conceive learning, learning in science?)

- What is learning to you? Is learning different in science?
- How do you learn best in general? How do you learn science best?
- In what ways do you think most students learn best?
- In what ways do you think most students learn science best?

- Do you think a particular teaching strategy can help a student learn (science)? Why or why not?
    - What is science knowledge to you?
    - How have your learning preferences changes in science?

      Study habits?
      Use of writing?
      Use of concept maps?
      Problem-solving techniques?

Knowledge (What does this student think should be learned in the course?)

- Do you think there is a standard core of knowledge that all students taking in this course should come away with?

- If yes, what do you think is a potentially successful way for students to understand that standard core of knowledge?

Instructional Strategies (how does the student react to instructional strategies?)

- What are some of the positive features for you of the teaching strategies used in physics? What are some of the negative features?
- Would you prefer simple lecture? Why or why not, explain
- Describe what you do in the small groups (in this course?). What are your reactions?
- What type of assessments (homework, quizzes, exams, papers, etc.) have you been helpful for you? Why?
- Talk about the successes and failures of the course in terms of the instruction and learning.

- Place where you think teachers should be as a group on the following continuum.

Instructor as learning facilitator   Instructor as information giver

- Place where you think students should be as a group on the following continuum

Student as receiver of knowledge   Student as constructor of knowledge

<u>Visioning (What does the student envision science learning (expectations) to be?)</u>

- What's your vision of what an ideal physics class would be. Include not only your actions and interactions, but also content and teaching strategies.

  Describe the ideal student/teacher relationship in a class like physics.

- In what way(s) is the structure and set up of physics applicable to your other classes?

<u>DyKnow Features</u> (how does the student react to Dyknow?)

- What elements of DyKnow have affected your learning?
  - Concept mapping
  - Group interactions
  - Evolutions, exit tickets
  - Meshing of web links, picture, text

- How do you use DyKnow, in and out of class?
  - Review notes
  - Inking and marking panels
  - Student collaboration

<u>Tablet PC aspects</u> (how does the student react to Tablets?) (Survey Monkey)

- What elements of Tablet PCs affect your learning?

Conceptual Interview Questions

<u>Motion and Force</u>

- What is your understanding of motion, position?
-
  - How would you define motion? Position?
  - What are the basics of motion to you?
  - Tell me about how your understanding of motion has changed.
- How would you say that motion and displacement are different, similar?
- How do the laws of kinematics enter your field of interest?
- What are some applications of motion in your field?

- Trace your learning about motion, distance, velocity, acceleration.

Forces

- What is your understanding of force?
  - What is electric charge to you?
  - In what ways are electric fields different than electric charges?
  - Tell me how your knowledge of electric charges and fields has evolved.
- What are some applications of Force in your field?
- What are some of the major concepts?
- Trace your learning in Force.

Momentum

- What is your understanding of momentum?
  - How is force different than momentum to you?
  - How do momentum affect you field?
  - What are the basics of momentum?
- What are some applications of Momentum in your field?
- What are some of the major concepts?

Rotations

- What is your understanding of rotations?
  - What is rotation to you?
  - How do rotations show up in your field?
- What are some applications of rotations in your field?
- What are some of the major concepts?

Any other comments?

Specific Event Question

Closing remarks

- Will have transcripts for you to read. Thank you.

APPENDIX B: COURSE EXAMS

Physics 110 Exam 1 **Wednesday, Oct. 10th 1-2PM, 2-3PM**

Answer the following question *clearly*, *concisely* and *thoroughly*. In your answer include your knowledge of ***position, velocity, acceleration** and **forces***. Each question has a scaled value of 100 points. Use an audience of informed peers.

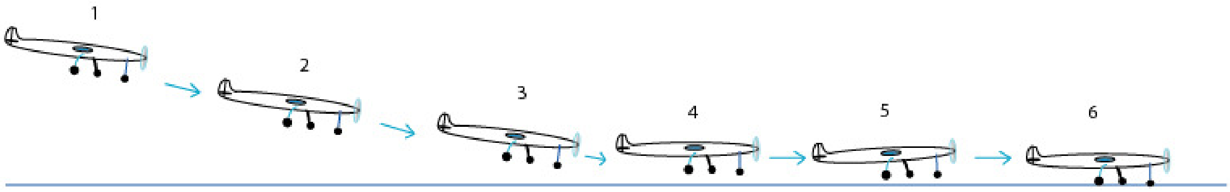
Clarke University is known as a scholarly (some would say “nerdy”) institution. You encountered an example of this at an informal get-together where the topics of interest at the punch bowl weren’t guys, girls or gossip but “aircraft carriers.” Wa-Wa-What?!

One social-butterfly-like gal was arguing (or is it flirting?) with an attractive dude saying, “You can’t be serious. When an aircraft stops on an aircraft carrier, the arresting wire system can stop a 54,000 pound aircraft travelling at 150 miles per hour in only two seconds, in a 315 ft landing area, or in scientific units, 24,500 kg aircraft travelling at 241 kilometer per hour in a 96 m landing area.”

“No!” responds the guy. “How can that be? The g-force is under 3.0g’s!”

You observe this, and pulling up a chalkboard, you butt in. What do you say?

Describe what you say to resolve their dilemma and to judge who is correct. First, describe the general motion of the aircraft as it lands on the aircraft carrier, including positions, velocities, acceleration and the various forces on the aircraft. Second, explain how and why the motion changes. Third, judge who is correct.



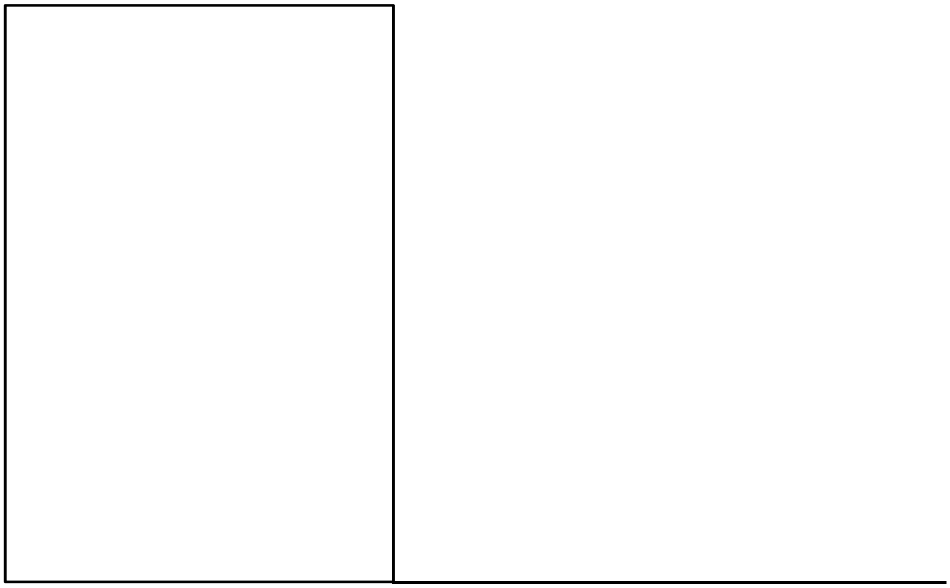
Physics 110 Exam 2 **Wednesday, Nov. 16th 1-2PM, 2-3PM**

Answer the following question *clearly*, *concisely* and *thoroughly*. In your answer include your knowledge of ***Linear Momentum*** and ***Energy***. Each question has a scaled value of 100 points. Use an audience of informed peers.

“Devious” Dan Danford has a plan. He will rob a bank. After fetching his money, he will then elude his pursuers by running to the top floor of the 45.0 m high-rise bank building. He then will jump for his freedom and bounce into a 2nd story, 15.0 m high window. Dan, though devious, is not crazy. In fact, he took physics at Clarke University, so he knows the “physics” of the fall. Therefore, he will put a large, taut, inflatable bag at the bottom of the building to insure for a bounce speed of 20m/s after he hits the airbag.

If his mass is 75.0 kg , the time of collision is 0.15s and the force of the collision is 5000 N , will he make the second story level or higher? Neglect air resistance.

First, using a diagram, describe the general motion of Devious Dan as he falls onto, and bounces up from, the airbag, including his linear momenta and energies. Second, answer how much energy must be lost in this collision if he makes it. Third, judge if he has enough energy after the collision to *complete* this motion.



APPENDIX C: EXPANDED PROGRESSIONS OF RESEARCH SUBJECTS AT EACH POINT-OF-INTEREST

Point-of-Interest 1	Concepts of motion, including position, velocity, and acceleration	How net external force causes changes in motion 1st Law	Relationships of changes in motion to applied forces and the mass of the object 2nd Law	How forces between two different bodies relate 3rd Law
Lauren	Moderate Able to define motion without prompt Understands the definitions of position, velocity, and acceleration Understands the need for an origin and axis for an object's motion Understands the differences amongst velocity, speed, and acceleration Relies on mathematical relationships to formulate motion answers Attempts to employ kinematical equations of motion Able to do a quick calculation in her head for average acceleration	Basic Cautious about describing motion and forces and uses energy to define force Has a semi-Aristotelian notion of necessary force to give motion. but she is careful to say "sometimes we know forces are acting on it, but it can still be in motion because of inertia" Understands inertia and how it affects motion	Moderate Able to use second law equation and can relate force, mass and acceleration Able to describe support forces	Basic States that "every force has like a force against it" Notes that forces balance on a single isolated object Unsuccessfully describes how tires and ground interact, saying tires pushes car forward, not the ground
Jeffrey	Moderate Not able to define motion without prompt Understands the definitions of position, velocity, and acceleration Understands the need for an origin and axis for an object's motion with prompting Understands the differences amongst velocity, speed, and acceleration Attempts to employ kinematical equations of motion and is able to do a	Basic Has a "push/pull" definition of force Has an Aristotelian notion of necessary force to give motion, "for something moving there need to be forces, pushes or pulls" Understands inertia and how it affects motion	Moderate Able to use second law equation and can relate force, mass and acceleration Relates net force to acceleration	Crude Able to define law easily but confused on 3rd law when forces tend to equilibrium Understands the interaction between the ground and a car

	quick calculation in his head for average acceleration and includes calculations for speed and velocity			
George	Moderate Not able to define motion without prompt Understands the definitions of position, velocity, and acceleration Understands the need for an origin and axis for an object's motion with prompting Understands the differences amongst velocity, speed, and acceleration Attempts to employ kinematical equations of motion and is able to do a quick calculation in his head for average acceleration and includes calculations for speed and velocity	Moderate Knows that a force doesn't need to be present to have motion, i.e. he has a Galilean notion of the connection between forces and motion States also that, "forces cause objects to move" Understands inertia and how it affects motion	Moderate Able to use second law equation and can relate force, mass and acceleration Able to use 2nd law on example but says he keeps forgetting it	Moderate Understands and can recite the 3rd law Able to apply to car and ground example

Point-of-Interest 2 (after Exam 1)	Concepts of motion, including position, velocity, and acceleration	How net external force causes changes in motion 1st Law	Relationships of changes in motion to applied forces and the mass of the object 2nd Law	How forces between two different bodies relate 3rd Law
Lauren	Sophisticated Employs and able to calculate acceleration on Exam 1 using kinematical equations of motion Able to define motion without prompt No longer relies on mathematical relationships to formulate motion answers Has difficulty with motion direction and direction of acceleration Has difficulty when velocity and acceleration are in different directions	Moderate Defines force somewhat differently than energy No longer has Aristotelian understanding of force necessary for motion. And knows that a force doesn't need to be present to have motion, i.e. a Galilean notion of the connection between forces and motion	Sophisticated Able to use second law equation on Exam 1 Successfully uses a free-body-diagram on Exam 1	Basic Continues to have difficulty with the third law States that large object exerts more force on small object than the small object exerts on the large object, i.e. interaction forces are different
Jeffrey	Sophisticated Employs and able to calculate acceleration on Exam 1 using kinematical equations of motion Able to define motion without prompt	Moderate No longer has Aristotelian understanding of force necessary for motion. And knows that a force doesn't need to be present to have motion, i.e. a Galilean notion of the connection between forces and motion.	Moderate Able to use second law equation on Exam 1 Successfully uses a free-body-diagram on Exam 1	Basic In Exam 2, says incorrectly that the ground force on a plane and its weight force are equal and opposite due to the third law (132.5)
George	Sophisticated Employs and able to calculate acceleration on Exam 1 using kinematical equations of motion Relies on calculations for explanations	Moderate Continues to hold a Galilean understanding of motion At times mentions force being necessary for motion Invokes energy to define forces	Moderate Able to use second law equation on Exam 1 Successfully uses a free-body-diagram on Exam 1	Moderate Able to talk about how engine forces relate to the interaction between the ground and the car Underscored importance of "systems"

Point-of-Interest 3 (after Exam 2)	Concepts of motion, including position, velocity, and acceleration	How net external force causes changes in motion 1st Law	Relationships of changes in motion to applied forces and the mass of the object 2nd Law	How forces between two different bodies relate 3rd Law
Lauren	Expert Consistent with her definition of motion Continued understanding of the definitions of position, velocity, and acceleration, need for an origin and axis for an object's motion Continued understanding of the differences amongst velocity, speed, and acceleration Able to differentiate between linear and rotational motions	Sophisticated Understands equilibrium and inertia Notes that forces do not need to be present to have motion Extends the application of forces to rotational motions Definition of force has progressed to "if you're pushing an object or pulling an object, you're putting a force on it"	Sophisticated Able to use second law equation and calculations are appropriate Notes it is difficult for her to employ 1st, 2nd in Physical Therapy	Moderate Able to employ 3rd Law when discussing momentum change in a complicated example from Exam 2
Jeffrey	Sophisticated Uses rotational motion to define linear motion Continued understanding of the definitions of position, velocity, and acceleration, need for an origin and axis for an object's motion Continued understanding of the differences amongst velocity, speed, and acceleration Able to differentiate between linear and rotational motions	Moderate Forces is a push or pull but continues to have a lingering Aristotelian notion of forces and motion change Extends the application of forces to rotational motions Confuses equilibrium and equal and opposite forces	Sophisticated Able to use second law equation and calculations are appropriate	Moderate Had some issues with equal and opposite and the resulting motion Confuses equilibrium and equal and opposite forces Able to employ 3rd Law in a complicated example from Exam 2
George	Sophisticated Consistent with his definition of motion Continued understanding of the definitions of position, velocity, and acceleration, need for an origin and axis for an object's motion Continued understanding	Sophisticated Forces is something that causes a change in motion Extends the application of forces to rotational motions Able to articulate 1st law in multiple ways	Sophisticated Able to use second law equation and calculations are appropriate	Moderate Able to employ 3rd Law when discussing momentum change in a complicated example from Exam 2 Had a difficult time explaining how forces can be equal and opposite and still have a

	of the differences amongst velocity, speed, and acceleration Able to differentiate between linear and rotational motions Relies on calculations for explanations		motion change Able to employ in a complicated example from Exam 2

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