Direct, Hands-on Or Inquiry Instruction A Study Of Instructional Sequencing And Motivation In The Science Classroom

Jamie Vander Wiede
University of Central Florida

DIRECT, HANDS-ON OR INQUIRY INSTRUCTION: A STUDY OF INSTRUCTIONAL SEQUENCING AND MOTIVATION IN THE SCIENCE CLASSROOM

by

JAMIE VANDER WIEDE
B.S. Florida State University, 2004

A thesis submitted in partial fulfillment of the requirements
for the degree of Master of Arts in Applied Learning and Instruction
in the School of Teaching, Learning, & Leadership
in the College of Education
at the University of Central Florida
Orlando, Florida

Summer Term
2011

ABSTRACT

Currently, a debate exists between the strengths and weaknesses of direct and inquiry instruction. Inquiry instruction is related to positive effect on learner motivation whereas supporters of direct instruction point to its ability to adequately support learners' working memories (Hmelo-Silver, Duncan, & Chinn, 2007; Kirschner, Sweller, & Clark, 2006; Kuhn, 2007; Sweller, 1988). This study examined the possibility of combining the best features of both inquiry and direct instruction by sequencing them together. A two-part lesson on electrical circuits was presented in three separate sequences of instruction to middle school students to determine if differences in student motivation and academic achievement emerge depending on whether a guided inquiry lab followed or preceded direct instruction. Results indicated equal levels of perceived competence by students across all instructional sequences and greater interest/enjoyment and perceived autonomy support when the instructional sequence began with a guided inquiry lesson. No significant differences in achievement were reported among the sequences.

Keywords: direct instruction, inquiry instruction, sequencing, motivation, working memory

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS/ABBREVIATIONS

AAAS	American Association for the Advancement of Science
IE	Interest/Enjoyment
NRC	National Research Council
PAS	Perceived Autonomy Support
PC	Perceived Competence
S1	Sequence 1
S2	Sequence 2
S3	Sequence 3

CHAPTER ONE: INTRODUCTION

The question of how instructional design affects student learning has fueled a controversial debate within the field of educational psychology between the benefits and weaknesses of direct and inquiry instruction (Hmelo-Silver, Duncan, & Chinn, 2007; Kirschner, Sweller, & Clark, 2006; Kuhn, 2007; Schmidt, Loyens, van Gog, & Paas, 2007). National calls for reform in science education seek to improve science literacy through the use of inquiry-based learning environments (American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC], 1996). Inquiry-based learning utilizes an investigative approach where students develop experiments to collect data in an attempt to construct knowledge and understanding prior to learning concrete facts about a science concept (Minner, Jurist Levy, & Century, 2009). Simply, the goal of inquiry is to have students actively participate in discovering the nature of science in addition to learning science content. Proponents of inquiry tout its ability to motivate and engage students while increasing achievement in science (Hall & McCudy, 1990; Kyle, Bonnstetter, & Gadsden, 1988; Leonard, 1983). Research has shown that motivated students demonstrate greater cognitive engagement which is related to deeper conceptual understanding (Ames, 1990; Hidi & Renninger, 2006; Komarraju & Karau, 2008; Pintrich, 2003; Pintrich & Schunk, 2002).

However, recent studies have shown that more traditional direct instructional techniques such as lectures and textbook assignments continue to dominate the majority of science teaching (Hudson, McMahon, & Overstreet, 2002; Weiss, Pasley, Smith, Banilower, & Heck, 2003). Reasons for this may include financial commitments to more traditional instructional materials, lack of professional development for educators, inability to implement the generally more time-intensive inquiry activities, inadequate classroom management skills, as well as a tendency to teach as one has been taught (Anderson, 2002; Beck, Czerniak & Lumpe, 2000; Eslinger, Hofstein & Walberg, 1995; Lawson et al., 2002; Welch, Klopper, Aitkenhead, & Robinson, 1981; White & Frederiksen, 2008). Some critics of inquiry instruction have also questioned its ability to adequately support student learning based on its heavy reliance on problem solving (Kalyuga, 2007; Kalyuga, Chandler, Touvin, & Sweller, 2001; Kirschner, et al., 2006; Paas & Van Merrienboer, 1994; Sweller & Cooper, 1985). Such researchers feel students' working memories are overtaxed in attempting to design scientific investigations while also simultaneously trying to learn new science content during inquiry activities.

Past work comparing direct and inquiry instructional methods often pit one technique against the other in an attempt to determine a clear winner and have delivered mixed results (Blanchard, 2006; Chen & Khlar, 1999; Kirschner et al., 2006; Klahr & Nigham, 2004). Such direct comparisons do little to advance the field to a deeper understanding of how such techniques work separately to achieve similar goals. Often, contrasting perspectives of instruction have much to offer and the goal is to use the advantages of both techniques to work toward an integrative approach of improved learning and instruction. This study suggests that the strengths associated with both direct and inquiry instruction can be maximized through specific sequencing of techniques rather than selecting one over the other. The current research seeks to answer the question as to whether the motivation and critical thinking associated with inquiry-based learning and the heavy guidance during learning in direct instruction can somehow be used together to maximize achievement and understanding.

From a practical perspective, classroom educators would benefit from empirically supported and well-reasoned arguments on whether instructional techniques can be used in sequence to influence motivation and achievement. Any significant findings on the potential effectiveness of sequencing in influencing students' motivation and achievement would not require educators to abandon their current pedagogies as would be the case in research that looks to find a single superior teaching method. Additionally, field researchers would also benefit from the theoretical perspective that the simple sequencing of instruction itself might lead to differences in motivation and achievement as directions for future research. This study seeks to determine how direct and inquiry instruction can be used together in varying sequences to maximize the benefits associated with both instructional methods. The following section reviews the literature on direct and inquiry instruction.

CHAPTER TWO: LITERATURE REVIEW

Guidance in Direct and Inquiry Instruction

Instructional techniques cover a wide spectrum of guidance, with direct instruction considered most structural as students' behaviors are usually controlled by specific instructions from the teacher. Common direct instructional techniques include the use of lectures, note-taking, textbook readings, and worked examples with learning goals often being seen as product-oriented (Anderson, 2002; Kyle et al., 1988; Von Secker & Lissitz, 1999). Product-oriented instruction is concerned with an end result or an outcome as evidence that learning has occurred (Merriam & Caffarella, 1991). In direct instruction, teachers act as transmitters of information and students play the role of passive recipients of knowledge or direction followers. A typical scenario of product-based direct instruction may be represented by a teacher conducting a lecture on how sunlight helps plants grow through the process of photosynthesis. Students may take notes, complete worksheets or watch videos on the topic. A test may then be given on that material and students will demonstrate their ability to recall and apply material covered in class.

It is important to note that while direct instruction is often pictured as passive, it can also be represented in a more active environment (Cobern et al., 2010). "Hands-on" lab experiences are highly guided in nature as they often ask students to follow predetermined set problem-solving procedures. For example, a scripted or procedural lab would include a set list of materials to be used and a cookbook-like recipe that students would follow. To use the example from before, a highly guided hands-on lab on plant growth may ask students to determine whether the amount of sunlight affects how high a plant will grow in 30 days time. Procedures may look like this: "Plant one bean seed in three identical pots that contain the same amounts and type of soil and label them Plant #1, Plant #2 and Plant #3. Put Plant #1 out in direct sunlight for four hours each day and Plant #2 out in direct sunlight for only two hours each day. Plant #3 should receive no sunlight on any day. Give each plant 10mL of water each day for 30 days. Record the height of each plant every day at the same time for 30 days." In this example, all students would replicate identical experiments based on the instructions provided and would all collect the same data regarding the specific question of how the amount of sunlight affects plant growth.

Learners in direct instruction are often all treated as "blank slates" that possess no existing foundation for a given domain (Kayluga, 2007; Lord, 1997). In contrast, inquiry-based learning falls within the theoretical jurisdiction of constructivism, in which learners are thought to actively create knowledge through experiences and must work to integrate new information with their own level of existing prior knowledge (Lord, 1997; Minner et al., 2009). While inquiry activities commonly contain specific learning objectives just as in direct instruction, they are also process-oriented in that they value the experiences by which students come to understand and investigate these ideas rather than just focus on the outcome (Merriam & Caffarella, 1991). Students participating in inquiry learning may be asked to design testable questions, formulate hypotheses, develop valid investigative approaches, make observations, and synthesize data to develop and defend evidence-based conclusions (Anderson, 2002; Ertpinar & Geban, 1996; Hofstein, Nahum, & Shore, 2001). Inquiry activities are unique in that they places the student in the center of the problem-solving space and ask them to develop their own solution method without relying on specific, step by step directions (Egleston, 1973).

It is also important to acknowledge that the degree of guidance within the inquiry spectrum varies dramatically with pure discovery being the least guided interpretation of the pedagogy (Minner et al., 2009). Pure discovery learning is best exemplified through a science fair project scenario where students select their own research question, design their own experiment, obtain relevant data, analyze results, and make their own conclusions. For example, students may decide to conduct an experiment to see if the type of music played to a plant will affect the rate at which it grows. It is up to the student to determine the independent, dependent and controlled variables, as well as interpret their results. Students in pure discovery situations sometimes fail to observe or internalize the desired concepts given the invalidity of their experimental design or because of a lack of discussion, feedback and reflection (Klahr & Nigam, 2004; Mayer, 2004). Pure discovery is also typically very time-intensive when compared with more guided instruction in order to allow students to explore at their own pace. Often, teachers are required to follow set curriculum guidelines as set forth by their school districts and do not have the option to extend instruction on a particular topic based on the rate at which students learn.

Teachers who embrace inquiry in their classrooms more commonly choose guided inquiry activities over pure discovery learning (Hmelo-Silver et al., 2007). Guided inquiry is just as it sounds; it provides students with more structure and guidance in an effort to lessen the amount of solution methods a student may choose when solving a problem. Generally, this allows guided inquiry activities to take less time to implement than pure discover activities. Using the example of the music and plant experiment, a guided inquiry version of the investigation is exemplified by the following mission: Students are asked to design an experiment to determine whether the type of music played to a pea plant will affect its rate of growth over a 30 day period. Here, students are given a dependent variable to measure (plant height) as well as the length of time the experiment will last. However, it will still be up to the student to make choices in their design. For example, will they use seeds or plants that have already sprouted? Will they think to control all other variables other than music (sun light, water, soil)? Will they decide to have a control plant in which no music is played? In this example, it is important to note that teachers who tend to use guided inquiry often do not intend, nor do they want identical experimental designs or even successful designs from each student or lab group in the class. Often, discussion of such successes and failures in the varying experimental designs of students that encourage and develop critical thinking skills which is one of the main goals of inquiry learning (Martin-Hansen, 2010).

The issue of amount of guidance during instruction is important in that individuals have a very limited capacity of actively processing and making sense of new information in their working memories (Sweller, 1988). The working memory is best described as the place where conscious processing of information occurs. When individuals attempt to learn new information, much of their working memory capacity is used for the construction of schemas. Schemas are domain-specific, mental representations of concepts and ideas that learners construct and continuously rearrange as they gain knowledge (Chi, Feltovich, & Glaser, 1981). One strength of direct instruction is its ability to support individuals who are learning new material as they can use the majority of their working memory resources on schema construction rather than using them for other activities such as problem-solving (Kalyuga et al., 2001). The heart of inquiry, even guided inquiry, is embedded in the act of problem solving which some researchers feel is the major weakness associated with inquiry instruction (Kalyuga, 2007; Kalyuga et al., 2001; Kirschner, et al., 2006; Paas & Van Merrienboer, 1994; Sweller & Cooper, 1985). Learners in inquiry-based environments, they argue, must allocate the majority of their working memory resources for problem solving, rather than for schema construction of the new material hoping to be learned. Students who attempt to solve problems without having sophisticated schemas to draw knowledge must use their limited working memory resources for both selecting and implementing problem solving strategies as well as for attempting to make sense and organize the new information behind the learning objective. Learning under such conditions can a frustrating experience for the learner as the task may simply be out of reach (Sweller, 1988).

This scenario is often the case in pure discovery learning, given that students do not have the skills or background knowledge to apply to the situation and therefore are unable to adequately grasp the concepts being presented (Mayer, 2004). However, proponents of guided inquiry do not consider it to be minimally guided due to the large and flexible amount of scaffolding available within the instruction (Hiebert, Fennema, Fuson, Human, & Murray, 1996; Hmelo-Silver et al., 2007; Schmidt, et al., 2007). Unlike in pure discovery learning, guided inquiry commonly uses deliberate instructional scaffolding strategies such as the designing of manageable tasks that fit within students' zones of proximal development (Hardy, Jonen, Möller, & Stern, 2006; Hmelo-Silver et al., 2007; Vygotsky, 1978). Quality guided inquiry tasks are purposefully designed to be as specific and clear as possible so students are aware of the expectations and limits associated with each task as well as being difficult enough to engage learners' sense of challenge. Other scaffolding strategies include providing a pre-determined selection of materials to be made available to students while problem solving in an effort to limit possible solution methods. Teacher interaction is also a commonly used scaffolding strategy in guided inquiry tasks as instructors can use questioning techniques to help uncover student thinking, model appropriate and useful questioning, and provide guidance to those students who may need it (Hmelo-Silver et al., 2007).

In summary, instruction matters in its effect on student achievement (Von Secker & Lissitz, 1999). Direct instruction better supports working memory when compared with pure discovery learning but inquiry that is appropriately guided has also be shown to support working memory. However, the debate of how much guidance should be used during instruction will only be truly beneficial if students are willing to actively engage with the material being presented. The issue of how to best support the working memory during learning is suddenly of no value to a student who is unmotivated to participate in the lesson. Acknowledging that learning does not occur within a cognitive vacuum, areas beyond guidance and working memory must be considered when discussing the strengths and weaknesses of instructional techniques. The following section will compare motivational differences across the pedagogies.

The Influence of Direct and Inquiry Instructional Methods on Motivation

Motivational research has evolved from being seen as solely a characteristic of the learner to being seen as a reciprocal relationship between learner behavior, their environment, and the task at hand (Kuhn, 2007). Kuhn (2007) described motivation as "not residing within the individual but in the interaction between the individual and the subject matter" (p. 109). In other words, motivation is not a fixed trait that a learner will decide to turn on or off at their liking, rather, motivation can be activated or stifled depending on the educational context and task at hand. However, it is not just the content itself that is or is not inherently motivating; more relevant to this study is that the way in which content is presented to the learners can also have have strong motivational implications (Ames, 1992; Hiebert et al., 1996).

Research has shown that motivated students demonstrate greater cognitive engagement often leading to deeper conceptual understanding when compared with those students who are not motivated (Ames, 1990; Hidi & Renninger, 2006; Komarraju & Karau, 2008; Pintrich, 2003; Pintrich & Schunk, 2002). Direct instructional techniques such as lectured note-taking or worked examples are often based on a "teacher-centered instructional agenda" that defines not only what students should think or do but when and how (Reeve, Jang, Carrell, Jeon, & Barch, 2004, p. 148). As a result of the lack of intrinsic motivation in students in controlling environments, teachers generally rely on the use of extrinsic means of motivation such as controlling, directive language. While direct instruction is beneficial in that it places a low demand on working memory during learning, it can also fail to motivate students at the same time due to the controlling nature of the technique.

Autonomy is one component of the triarchic *self-determination theory*, which proposes that individuals are most motivated when they feel they are acting out of their own will (Ryan & Deci, 2000). Teachers who are autonomy-supportive work to nurture students' inner motivational resources by focusing on student interests and providing opportunities for choice-making (Reeve et al., 2004). Characteristics of autonomy-supportive instructional behaviors include taking time to hear students' perspective and encouraging students to work at their own pace (Reeve et al., 2004). Students who perceive their teachers as providing autonomy-supportive classrooms have been found to demonstrate higher conceptual understanding and academic achievement as well as have increased student curiosity, interest and appetite for academic rigor in class (Boggiano, Flink, Shields, Seelbach, & Barrett, 1993; Grolnick & Ryan, 1987; Ryan & Grolnick, 1986; Tsai et al., 2008).

Learner autonomy is stifled in classrooms where instructors are perceived to be controlling as these instructional behaviors interfere with a student's natural desire to work at their own pace (Assor, Kaplan, Kanat-Maymon, & Roth, 2005; Tsai, Kunter, Ludtke, Trautwein,

& Ryan, 2008). Direct instructional techniques fail to meet students' inner need for choice by binding them to specific pacing or directions. Inquiry activities, on the other hand, release students from set problem-solving procedures by encouraging creative thinking and alternate explanations. However, while motivation may be higher during inquiry instruction due to increased levels of perceived autonomy, that same increased level of freedom may prevent students from finding adequate solution methods on their own due to the sheer number of solution methods possible. Failure to adequately find a favorable solution method may cause students to become frustrated and de-motivated due to its interference with another component of self-determination theory, perceived competence. Deci and Ryan (2000) suggested that individuals are most motivated when they believe they posses the ability to be successful at a given task. If there is no guidance given to a student who is unable to find an acceptable solution method on their own, they are likely to feel incompetent to solve the problem, become de-motivated, and ultimately give up. Here again, it is important to acknowledge that guided inquiry activities use scaffolding techniques to try to find the motivational balance between increasing a students' sense of perceived autonomy while still helping them feel capable of the given problem.

The role of interest is related to self-determination theory (Reeve, 2002). Interest is defined as a state of positive affect and concentration and fuels intrinsic motivation. Intrinsic motivation resides within the individual as opposed to some external source such as the promise of reward or threat of consequence (Hidi & Renninger, 2006). Students who are interested in what they are learning report higher levels of autonomy, pay greater attention, process information more deeply, and demonstrate greater academic achievement (Mayer, 1998; Renninger, Hidi, & Krapp, 1992). While interests do vary from individual to individual, certain environmental aspects have been found to increase situational interest in learners regardless of differences in individual preference, which makes it relevant to the discussion of instruction (Ames, 2002; Tsai et al., 2008). Students in low autonomy-supported environments are associated with lower levels of reported interest and enjoyment whereas autonomy-supportive environments have been found to be one of the main factors in increasing interest and enjoyment (Reeve, 2002; Ryan & Deci, 2000). The tendency for direct instruction to use controlling or directive language has been found to result in lower interest and enjoyment among students and have even been known to cause negative emotions such as anxiety and frustration (Assor et al., 2002; Assor et al., 2005; Reeve & Jang, 2006).

In summary, students are most motivated to learn in classes in which they perceive instructors to be autonomy-supportive and report interest in classes in which they do not feel controlled (Deci & Ryan, 2000). Student-centered inquiry instruction works by facilitating students' need for autonomy in the classroom, whereas the controlling aspects associated with most direct instruction stifle student motivation. However, the same freedom associated with inquiry-oriented activities may not provide enough guidance and place too heavy a demand on students' working memories thereby lowering their levels of perceived competence for the task. The questions remain: Is the increased autonomy and interest associated with inquiry instruction of greater benefit in producing higher academic achievement than direct instruction? Do students feel more competent during direct instruction due to its low demand on the working memory? Or better yet, can both direct and inquiry instruction be combined in an effort to benefit from both the cognitive and motivational aspects associated with each technique? The following study attempts to answer such questions.

CHAPTER THREE: METHODOLOGY

The following study compared three instructional sequences for a middle school science lesson on electrical circuits by using varying sequences of lecture, scripted and guided inquiry labs (see Table 1). Each sequence covered the same amount of class time, used the same lab materials, had identical learning objectives and completed identical pre and post assessments on electrical circuits (see Appendix A). Sequence 1 (S1) began with a 45-minute lecture comparing series and electrical circuits followed by a 45-minute scripted lab the following day that directed students to create and compare series and parallel circuits. Sequence 2 (S2) was done in the reverse order with the scripted lab occurring on the first day followed by the lecture on day two (see Appendix B). Sequence 3 (S3) began with an inquiry lab on the first day where students were given missions to solve but did not give directions for how to go about solving them (see Appendix C). Students then listened to the same lecture as the other sequences on day two. Identical lab materials were made available to students regardless of whether they were participating in the inquiry or scripted lab. Materials included two light bulbs, one wires, and two D batteries in battery holders.

Table 1: Instructional Sequences for Circuits Lesson

	Day 1 of lesson (45 minutes)	Day 2 of lesson (45 minutes)
Instructional Sequence 1 (S1)	Lecture	Scripted Lab (set procedures provided)
Instructional Sequence 2 (S2)	Scripted Lab (set procedures provided)	Lecture
Instructional Sequence 3 (S3)	Inquiry Lab (no set procedures provided)	Lecture

The instructional sequences were designed in such a way that all science content and time on teaching were identical with the independent variable being the sequence in which the instruction is presented. S1 (lecture prior to scripted lab) reflects the way science is done in the majority of public schools where students receive information on the material during the lecture and then apply such knowledge to a lab environment afterwards. S2 (scripted lab prior to lecture) was created in order to determine whether it is merely the hands-on experience prior to the lecture that makes any potential difference in motivation or achievement or if it is truly the aspect of inquiry prior to direct instruction that is the cause. S3 (inquiry lab prior to lecture) was developed to represent how most guided inquiry is done in the classroom today, where students will only be presented with detailed information regarding a concept after they have had a chance to investigate and consider the ideas for themselves beforehand (Hastings, 2006).

Research questions included:

1) Does variation in instructional sequence influence perceived autonomy support, perceived competence and interest/enjoyment?
2) When controlling for existing knowledge, does instructional sequence influences achievement?

It was predicted that higher levels of perceived autonomy support would be reported during the inquiry lab in S3 when compared with the scripted lab in S1 and S2. However, this lack of direction and subsequent larger toll on working memory may cause students to report lower levels of perceived competence during the inquiry activity when compared with the highly guided nature of the scripted lab in S1 and S2. Additionally, it is hypothesized that the highest levels of interest/enjoyment will also be reported in S3 during the inquiry lab due to the predicted heightened levels of perceived autonomy. Finally, I predicted that students in S3 will demonstrate the highest academic growth due t enhanced motivation.

Participants

The study took place in two 7th grade physical science teacher's classroom at a public middle school in central Florida. A total of 12 intact class periods (six advanced and six regular) were used in the study for a total sample of n =178. One advanced class and one regular class were randomly assigned to each instructional sequence. Both teachers have taught for the same number of years and have both participated in similar professional development workshops during their teaching careers. Both teachers instructed a total of six class periods a day, three of which were advanced class periods and three of which were considered regular class periods. Both teachers had previous experience in teaching electrical circuits to 7^{th} graders and were comfortable with the scientific content of the material as well as with common student misconceptions pertaining to circuits. At the time of the study, students had not had any formal school training on the topic of electrical circuits.

Procedures and Instrumentation

Students were given a seven-item pretest the day before instruction began that covered characteristics of series and parallel circuits (see Appendix A). The assessment was pre-evaluated and approved by a county science representative. For each sequence, two 45-minute class periods were used in consecutive days to present the materials on circuits in three separate instructional sequences. S1 (n= 60) consisted of a lecture on day one, followed by a scripted lab on day two. S2 (n=60) was done in the reverse order and consisted of the scripted lab on day one, followed by the lecture on day two. S3 (n=58) has students participate in an inquiry lab on day one, followed by a lecture on day two. On both days and immediately following instruction, students were given a 17-item motivational self-survey (see Appendix D) developed using questions from Deci and Ryan's Intrinsic Motivation Inventory (IMI) and Learning Climate Questionnaire (LCQ). The survey sought to assess self-reported levels of perceived autonomy support, perceived competency and level of interest/enjoyment after each portion of the instructional sequence. The reliability for the motivation battery showed a Cronbach's alpha = 0.84 for perceived autonomy support; 0.84 for perceived competence; 0.94 for interest/enjoyment. Students were then given the post assessment at the beginning of the class period on the day after instruction ended for all sequences.

A school coworker with no previous knowledge of the study completed a formal observation of both teachers during each sequence to control for fidelity in teacher behavior. A checklist developed by a local school district determined that no difference was reported among teachers or among sequences for enthusiasm, subject matter knowledge, clarity of instruction, or standard of student behavior (see Appendix E).

Curriculum

Electrical circuitry is considered to be part of the standard 7th grade science district curriculum regardless of whether students are in advanced or regular science classes. All three sequences shared identical learning objectives relating to the material as determined by Orange County Public School science task analyses and the Sunshine State Standard (SC.7.P.11.2). The lecture given on day one for S1 and on day two for S2 and S3 were identical as were the scripted labs given on day two of S1 and day one of S2 (see Appendix B). The inquiry lab (see Appendix

C) contained no set procedures for how to construct each type of circuit though it provided the same materials from the scripted lab for the students to use. Based on Cohen's moderate to large effect size of 0.33, a level of significance of .05, and a power of 80%, a sample size of 95 participants were required to detect practical significance of learning gains as detected by pre and posttest scores.

CHAPTER FOUR: RESULTS

Motivation

A MANCOVA analysis was conducted for day one and day two separately, both controlling for the effect of teacher as covariate to test whether the combination of instructional sequencing and teacher have an effect on motivation. There was a significant effect for sequences at the multivariate level for day one, Wilks's $\lambda = .91$, $F(6, 344) = 2.89$, $p = .009$ as well as day two, Wilks's $\lambda = .88$, $F(6, 344) = 3.96$, $p = .001$. There was no effect found in motivation between teachers at the multivariate level, Wilks's $\lambda = .96$, $F(3, 172) = 2.58$, $p = .06$). For day one, there were significant differences found among teachers for perceived autonomy, $F(1, 174) = 4.62$, $p = 0.33$ but not for perceived competence or interest/enjoyment. For day two, there was a small effect found among teachers on perceived competence, $F(1, 174) = 7.57$, $p = .007$, $\eta^2 = 0.04$ but not for perceived autonomy or interest/enjoyment.

For day one, there were significant differences found among sequences, $F(2, 174) = 2.77$, $p = .048$, for perceived autonomy. Post hoc analysis for day one showed that S2 ($Mean_{S2} = 5.19$, $SD_{S2} = 0.99$) and S3 ($Mean_{S3} = 5.62$, $SD_{S3} = 0.96$) were different in their effect on student perceived autonomy, $p = .014$; $CI(95\%) = -.81, -.09$, with students in S3 reporting higher perceived autonomy than students in S2. There was no effect found for perceived autonomy between S1 ($Mean_{S1} = 5.45$, $SD_{S1} = 1.03$) and S2 or between S1 and S3. Significant differences were also found among sequences for interest/enjoyment, $F(2,174) = 6.82$, $p = .001$. Post hoc analysis for day one showed that both S1 ($Mean_{S1} = 5.11$, $SD_{S1} = 1.27$) and S3 ($Mean_{S3}= 5.80$, $SD_{S3} = 1.15$) were different in their effect on student interest/enjoyment, $p = .005$; $CI(95\%) = -1.12, -.20$, with students S3 reporting higher interest/enjoyment than students in S1. S2 ($Mean_{S2}$

= 5.20, SD_{S2} = 1.33) and S3 were also different in their effect on interest/enjoyment, $p = .014$; *CI*(95%) = -1.03, -.12, with students in S3 again reporting higher interest/enjoyment levels when compared with students in S2. There were no significant differences found for interest/enjoyment between S1 and S2. Figure 1 shows students' reported perceived autonomy support (PAS) and interest/enjoyment (IE) levels among the instructional sequences for day and day two. Perceived competence was not included in the graph as no significant difference was reported among sequences for either day.

For day two, there was a effect of less than .07 found among sequences, $F(2, 174) = 2.77$, $p = .06$, found for perceived autonomy. Post hoc analysis for day two showed that S2 ($Mean_{S2}$ = 4.86, SD_{S2} = 1.44) and S3 ($Mean_{S3}$ = 5.40; SD_{S3} = 1.13) were different in their effect on student perceived autonomy, $p = .02$; *CI*(95%) = -1.03, -.09, with students in S3 reporting higher perceived autonomy than students in S2. There was no effect found for perceived autonomy among S1 ($Mean_{S1}$ = 5.14, SD_{S1} = 1.29) and S2 or among S1 and S3. As in day one, there were no significant differences found among sequences for perceived competence for day two. Significant differences were found among sequences, $F(2,174) = 6.82$, $p = .001$, for student interest/enjoyment. Post hoc analysis indicated that S1 ($Mean_{S1}$ = 5.11, SD_{S1} = 1.63) and S2 ($Mean_{S2}$ = 4.08, SD_{S2} = 1.66) were different in their affect on student interest/enjoyment, p = .001; CI(95%) = .44, 1.61, with students in S1 reporting higher levels on interest/enjoyment than students in S2. S2 and S3 ($Mean_{S3}$ = 4.90, SD_{S3} = 1.56) also had an affect on student interest/enjoyment, p = .005; CI(95%) = -1.43, -.25, with students in S3 reporting higher interest/enjoyment than students n S2. There were no significant differences in interest/enjoyment found between S1 and S3.

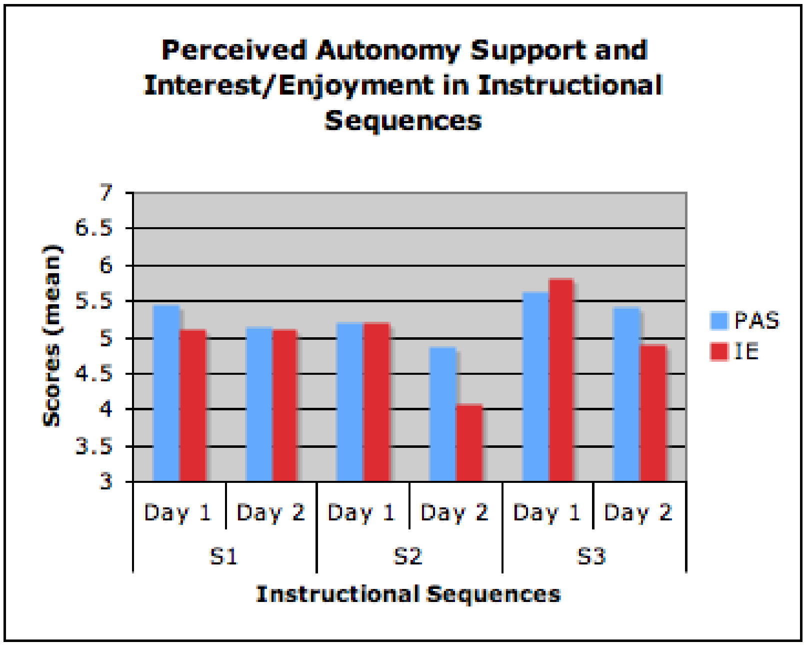


Figure 1: Student perceived autonomy support (PAS) and interest/enjoyment (IE) for day one and two of each instructional. S1 = lecture prior to scripted lab; S2 = scripted lab prior to lecture; S3 = inquiry lab prior to lecture.

Achievement

An ANCOVA analysis was conducted controlling for the effect of the pretest as a covariate to test whether the combination of instructional sequencing and teacher have an effect on posttest scores. While there was a significant difference found among teachers, $F(1, 171) = 4.72$, $p = .03$, the combination of sequence and teacher did not have a significant effect on posttest scores, $F(2,171) = 1.11$, $p = .33$. There were significant differences found between sequences, $F(2, 171) = 4.56$, $p = .01$, for posttest scores. Post hoc analysis indicated that S1 ($Mean_{S1} = 6.08$, $SD_{S1} = 1.10$) and S2 ($Mean_{S2} = 5.52$, $SD_{S2} = 1.07$) were different in their effect on posttest scores, $p = .003$; $CI(95\%) = .21, .98$, with students in S1 reporting higher posttest averages than students in S2. No significance was reported for the difference in posttest scores between S2 and S3 ($Mean_{S3} = 5.84$, $SD_{S3} = 1.09$) or S1 and S3. There were no significant differences between either teacher’s classes in regards to school environment, socioeconomic status, male-female ratio, or prior achievement scores in math and reading.

CHAPTER FIVE: DISCUSSION

Past studies have shown that strengths associated with inquiry instruction include increased achievement, enhanced critical thinking skills and promotion of positive attitudes toward science when compared with varying direct instructional techniques such as lectures, worksheet or textbook-oriented classes (Ertpinar & Geban, 1996; Hall & McCudy, 1990; Hofstein, et al., 2001; Kyle et al., 1988; Leonard, 1983). As was confirmed in this study, students participating in autonomy-supportive classrooms in S3 reported higher interest than in classroom environments where they feel more controlled in S1 and S2 (Tsai et al., 2008). On day one, students participating in the inquiry lab (S3) reported higher levels of perceived autonomy support than did students working on the procedural lab (S2). Students in the inquiry lab (S3) also reported the highest levels of student interest and enjoyment among all of the sequences. It is, perhaps, unsurprising that students participating in the inquiry lab (S3) would report higher interest or enjoyment when compared with students who are sitting more passively while listening to a lecture (S1). However, it is interesting to note that while two sequences of students were participating in hands-on lab activities (S2 and S3) and that both activities contained identical learning objectives and materials, the students participating in the inquiry lab (S3) reported significantly higher interest/enjoyment levels than the students working in the scripted lab (S2). This confirms the hypothesis that students enjoy activities more when they are not restricted to following set problem-solving procedures and are able to experiment more freely (Ryan & Deci, 2000).

On day two, students in S2 and S3 listened to identical lectures on circuits. The students who had participated in the inquiry lab the day prior (S3) reported significantly higher interest/enjoyment and perceived autonomy support during the lecture than the students who had participated in the scripted lab the day before (S2). This means that not only did students enjoy the inquiry version of the lab more than the procedural version but that the students in the inquiry group enjoyed the exact same lecture more as well. Again, and perhaps unsurprisingly, students working on the scripted lab (S1) reported significantly higher interest and enjoyment than the students who were listening to the lecture in S2. However, no significant difference was reported in perceived autonomy support or in interest/enjoyment between the students participating in the scripted lab (S1) and the students in S3 who were listening to the lecture and had previously participated in the inquiry lab the day prior.

Additionally, on either day and among all of the sequences, no significant difference in perceived competence was found. Unlike what many cognitive theorists have found in previous studies comparing inquiry to direct instruction, students reported feeling as capable of success during the guided inquiry lab as they did during the lecture and scripted lab (Kalyuga, et al., 2001; Kirschner et al., 2006; Paas & Van Merrienboer, 1994). These results suggest educators should not avoid inquiry in the classroom based on the idea that students will feel not feel capable of reaching the learning goals associated with the activity due to the over taxation of their working memory. Rather, this finding lends support to the idea that guided inquiry activities that are appropriately scaffolded allow students to feel just as competent during the activity as they would during direct instruction. Scaffolding techniques used in this study during the inquiry activity include specific wording of the mission to be solved, restricting use of available materials, use of peer support and interaction with the instructor during problem solving.

These findings highlight the main goal of the study which sought to discover whether specific sequencing of instruction alone could positively affect student enjoyment. Should an educator wish to edit their curriculum given these findings, they would not have to add or eliminate any content from their teaching objectives nor would they have to find extra time during the school year to attempt to use guided inquiry in the classroom. Having to adjust either of those factors would likely result in a teacher simply deciding not to implement the recommended finding as such changes are often impossible to make given the large amount of outside demands in public education. Rather, the significance of this study is the idea that a simple adjustment to the order in which a lesson is presented can significantly affect student enjoyment and interest. This finding is highly practical in the sense that the same amount of material can be covered in the same amount of time but result in a more positive effect on student motivation.

Despite the fact that students report higher levels of motivation during guided inquiry activities, teachers are often reluctant to shift their teaching styles from traditional to inquiry-based for a variety of reasons (Lord, 1997). One main reason is that while teachers may read and even agree with theoretical findings, teachers often make decisions based on the day-to-day practical factors associated with running a classroom (Anderson, 2002). Inquiry-based classroom environments are often more demanding in terms of classroom management as students are often participating more actively in debate while problem solving (Anderson, 2002; Hofstein &Walberg, 1995). Appropriate debating techniques must be explained and modeled for students before jumping into an inquiry-style curriculum. Teachers must feel comfortable and have practice with these practical classroom management matters before they are likely to adopt a new pedagogy (Anderson, 2002). Even more, switching teaching styles often requires a shift in deeply-held beliefs about the purpose a teacher serves. Teachers who view themselves in the traditional role as dispensers of information may have a hard time shifting to the belief that students should uncover and experiment with concepts themselves through experimentation.

Additionally, teachers in inquiry-based classroom environments often face unforeseen questions from students that may make the teacher uncomfortable if they do not feel capable of answering the questions (Welch et al., 1981). In inquiry situations, as control is shifted from the teacher to the student, teachers must be more flexible and willing to expect the unexpected than they would during direct instruction. If a teacher is not completely comfortable in understanding the content they are teaching, releasing this control is a formidable task.

The results of this study showed that the students who began with the lecture and followed up with the scripted lab (S1) demonstrated significantly higher gains on posttest scores when compared with the instruction done in the reverse order (S2). No significant differences in posttest gains were reported between students who received an inquiry lab followed by a lecture (S3) with either of the other sequences. These results suggest that while students may achieve the smallest gains when participating in a scripted lab before a lecture, it would not make a significant difference should a teacher begin a lesson with a lecture or with an inquiry lab depending on their particular preference. Though the results of this study did not indicate that students in the inquiry group demonstrated higher academic gains despite their increased perception of choice and interest and enjoyment, previous studies have shown that students with autonomously supportive teachers (rather than controlling ones) demonstrated higher conceptual understanding and academic achievement (Boggiano, et al., 1993; Grolnick & Ryan, 1987; Ryan & Grolnick, 1986).

One factor that may have influences the observed results is the brevity of student exposure to the particular instructional sequence each student was assigned to. Future research comparing the effects of instructional sequencing on students' motivation and achievement would benefit from a lengthier version of this study where students are exposed to multiple repetitions of their assigned instructional sequence within a broader unit of curriculum as opposed to a single lesson. For example, instead of one lesson comparing series and parallel circuits, it may be of greater benefit to see how students report motivation and perform academically after experiencing an entire unit on electricity containing multiple but related lessons. In that scenario, students would participate in a continuous experience within their particular instructional sequence. A longer study covering more instructional content would also allow for a lengthier and more comprehensive pre and post assessment than was used in the current study which may reveal clearer distinctions in achievement among the sequences. Additionally, a small effect among the two teachers was found with students performing higher for one teacher over the other regardless of which sequence they were in.

CHAPTER SIX: CONCLUSION

The findings of this study are highly practical in that they do not advise educators to somehow find more time during the school year in order to implement recommendations; often an impossibility for some educators. Rather, greater student enjoyment can be achieved in the same amount of class time by sequencing the order in which instruction is presented. Teachers who previously lectured before lab could simply reverse the order and conduct an inquiry lab prior to a lecture potentially increasing student enjoyment and achievement without needing to use any more valuable class time. As students often report decreasing levels of motivation and achievement as they enter adolescence, teachers and researchers must find ways to align instruction, keep students engaged in their learning, and create a positive classroom experience for students (Anderman & Maehr, 1994; Eccles, Midgley, Wigfield, Buchanan, Reuman, Flanagan, & Iver, 1993). As Dewey (1913) put best, "our whole policy of compulsory education rises or falls with our ability to make school an interesting and absorbing experience to the child'' (p. ix).

APPENDIX A: PRE AND POST ASSESSMENT

1. Three bulbs are lit in an electrical circuit. When one bulb is removed, the rest of the bulbs go out. Identify the type of circuit that is being described.

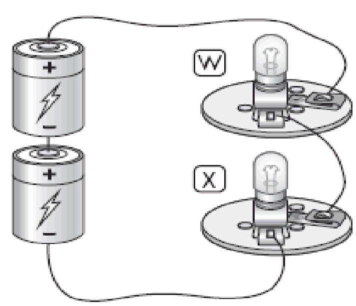
a) complete
b) parallel
c) series
d) short

2. Which of the following changes would increase the electrical current in a series circuit?

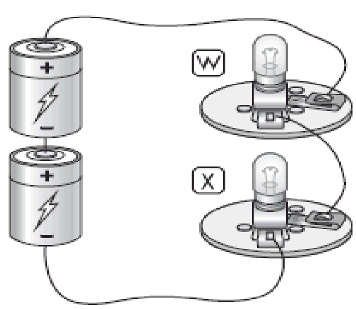
a) adding more light bulbs
b) removing one light bulb
c) adding another fuel cells
d) removing one of the wires

3. Below are two identical bulbs (W and X). They are connected to the same C-cell battery as shown in the illustration below. Assuming that the bulbs are equal, which of the following statements **best** describes what will happen when the circuit is turned on?

a) The W-bulb will be brighter than the X-bulb.
b) The X-bulb will be brighter than the W-bulb.
c) Neither bulbs will be lit because the circuit is open.
d) Both bulbs will be lit at an equal level of brightness.

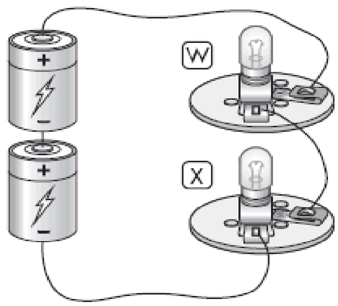


4. Examine the closed circuit diagram below. DRAW ARROWS on the diagram to show how electrons are moving through the circuit.

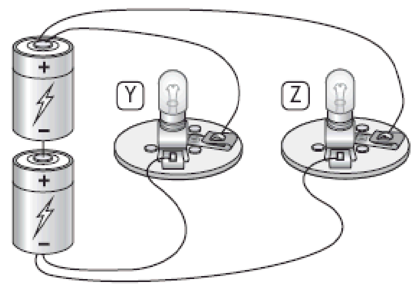


Use the following scenario and answer questions 5-7.

Mark arranged two identical light bulbs in a series circuit and two other identical light bulbs in a parallel circuit. Both circuits use two, identical C-cell batteries. He notices that the light bulbs in one of the circuits are brighter than in the other circuit.



Circuit 1



Circuit 2

5. In which circuit are the light bulbs brighter? ___________________

6. Explain what causes the light bulbs in this circuit to be brighter.

7. In which circuit would the batteries drain the most quickly? __________________

APPENDIX B: SCRIPTED LAB FOR SEQUENCE TWO (S2)

Materials:

2 D Batteries	2 light bulbs with wires on each side
2 Battery holders	1 wire

PART A:

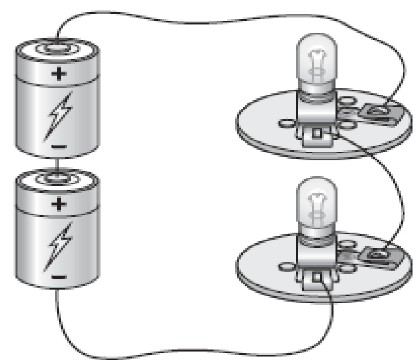
1. Arrange the materials into the following SERIES circuit arrangement so that **<u>both</u>** bulbs are lit. Notice how ALL wires are touching each other or a battery!

    a) Describe what you think the **<u>purpose</u>** of each of the following materials is:

Battery: ______________________________

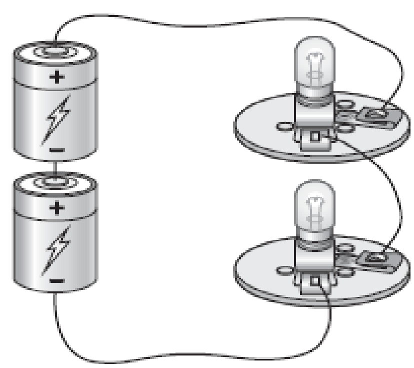
Wire: _________________________________

Light bulb: ____________________________



Series Circuit

2. DRAW ARROWS on the diagram to show how you think electrons are moving through the SERIES circuit.

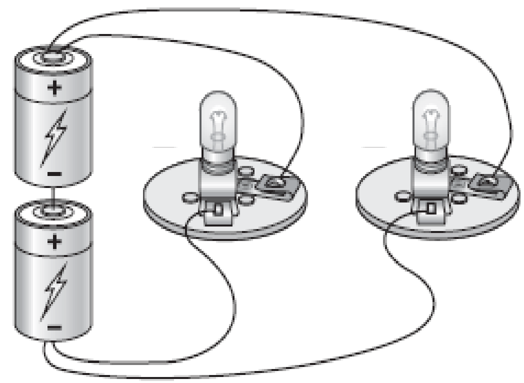


3. Remove ONE of the batteries and <u>reconnect</u> the SERIES circuit with only **ONE** D battery. What happens to the brightness of the lights when one of the batteries is removed?

4. Add the battery again so that the circuit is lit with BOTH batteries. Now, make a **break** in the circuit by disconnecting one of the wires touching the battery. What happens to both lights when the wire is disconnected? Why do you think this happens?

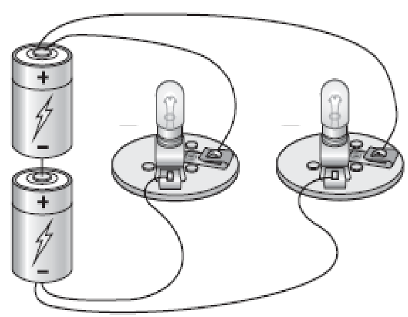
PART B:

5. Arrange the materials into the following PARALLEL circuit arrangement so that both bulbs are lit. Notice how ALL wires are touching each other or a battery!



Parallel Circuit

6. DRAW ARROWS on the diagram to show how you think electrons are moving through the PARALLEL circuit.



7. a) Does the PARALLEL circuit have **more** or **less** light than the SERIES circuit? __________

b) Why do you think the level of brightness is different between the PARALLEL and SERIES circuits? Explain your thinking.

8. Remove ONE of the batteries and <u>reconnect</u> the PARALLEL circuit with only **ONE** D battery. What happens to the brightness of the lights when one of the batteries is removed?

9. Add the battery again so that the circuit is lit with BOTH batteries. Now, make a break in the circuit by disconnecting ONLY ONE of the light bulb's wires from the battery (the other light bulb's wires should continue to touch the battery) What happens to the bulbs when the one wire is disconnected? Why do you think this happens?

APPENDIX C: INQUIRY LAB FOR SEQUENCE 3 (S3)

Materials:

2 D Batteries	2 light bulbs with wires on each side
2 Battery holders	1 wire

Missions:

1) Find a way to make BOTH bulbs light up at the same time.

2) Find a way to make BOTH light bulbs go out by disconnecting ONLY ONE wire.

3) Make one light bulb GO OUT and the other light bulb STAY ON by disconnecting ONLY ONE wire.

Draw and label your arrangements for each of the missions above.

APPENDIX D: MOTIVATION SELF-SURVEY

Please indicate how true each statement below is for you by circling 7 for “very true” and 1 for “not true at all.”

1. I feel that my teacher provides me choices and options.

2. After working at this lesson for a while, I felt pretty confident I understood it.

3. While I was doing this lesson, I was thinking about how much I enjoyed it.

4. My teacher tries to understand how I see things before suggesting a new way to do things.

5. This activity did not hold my attention at all.

6. I am satisfied with my performance in this lesson.

7. I would describe this lesson as very interesting.

8. My teacher showed confidence in my ability to do well in the lesson.

9. I was pretty skilled at this lesson.

10. I enjoyed doing this lesson very much.

11. This was an activity that I couldn’t do very well.

12. My teacher encouraged me to ask questions.

13. I think I did pretty well at this lesson, compared to other students.

14. I thought this lesson was enjoyable.

15. My teacher listens to how I would like to do things.

16. I think I am pretty good at this lesson.

17. This lesson was fun to do.

APPENDIX E: TEACHER OBSERVATION CHECKLIST

1. Does the teacher establish and maintain standards for student behavior?

1	2	3	4	5
Rarely		Occasionally		Consistently

2. Does the teacher demonstrate knowledge of subject matter content?

1	2	3	4	5
Rarely		Occasionally		Consistently

3. Does the teacher provide clear directions and explanations for students?

1	2	3	4	5
Rarely		Occasionally		Consistently

4. Does the teacher make the purposes for instruction clear to the student?

1	2	3	4	5
Rarely		Occasionally		Consistently

5. Does the teacher attempt to engage students through enthusiasm?

1	2	3	4	5
Rarely		Occasionally		Consistently

APPENDIX F: IRB APPROVAL FORM

From: UCF Institutional Review Board #1
FWA00000351, IRB00001138

To: Jamie Vander Wiede and Co-PI: Michele G. Gill

Date: October 18, 2010

Dear Researcher:

On 10/18/2010, the IRB approved the following activity as human participant research that is exempt from regulation:

Type of Review: Exempt Determination
Project Title: Lecture, Hands-On or Inquiry Instruction? A comparison of instructional sequencing in maximizing academic gains and motivation in the science classroom.
Investigator: Jamie Vander Wiede
IRB Number: SBE-10-07165
Funding Agency:
Grant Title:
Research ID: N/A

This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. If changes are made and there are questions about whether these changes affect the exempt status of the human research, please contact the IRB. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

On behalf of Joseph Bielitzki, DVM, UCF IRB Chair, this letter is signed by:

Signature applied by Joanne Muratori on 10/18/2010 01:56:25 PM EDT

IRB Coordinator
University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

REFERENCES

American Association for the Advancement of Science (AAAS). (1993). Benchmarks for science literacy. New York: Oxford University Press.

Ames, C. (1992). Classrooms: Goals, structures, and student motivation. Journal of *Educational Psychology, 87*, 559-575.

Ames, C. (1990). Motivation: What teachers need to know. *Teachers College Record*, *91*(3), 409-421.

Anderman, E. & Maehr, M. (1994). Motivation and schooling in the middle grades. *Review of Educational Research, 64*, 287-309.

Anderson, R. (2002). Reforming science teaching: What research says about inquiry? *Journal of Science Teacher Education, 13*(1), 1-12.

Assor, A., Kaplan, H., Kanat-Maymon, Y., & Roth, G. (2005). Directly controlling teacher behaviors as predictors of poor motivation and engagement in boys and girls: The role of anger and anxiety. *Learning and Instruction, 15,* 397-413.

Assor, A., Kaplan, H., & Roth, G. (2002). Choice is good, but relevance is excellent: Autonomy-enhancing and suppressing teacher behaviours predicting students' engagement in schoolwork. *British Journal of Educational Psychology, 72*, 261-278.

Beck, J., Czerniak, C., & Lumpe, A. (2000). An exploratory study of teachers' beliefs regarding the implementation of constructivism in their classrooms. *Journal of Science Teacher Education*, *11*(4), 323-343.

Blanchard, M. (2006). *Assimilation or transformation? An analysis of change in ten secondary science teachers following an inquiry-based research experience for teachers* (Doctoral dissertation). Retrieved from http://etd/lib.fsu.edu.theses_1submitted/etd-07102006-

171556/unrestricted/BlanchardMDissertation.pdf

Boggiano, A., Flink, C., Shields, A., Seelbach, A., & Barrett, M. (1993). Use of technique's promoting students' self-determination: Effects on students' analytic problem-solving skills. *Motivation and Emotion, 17*, 319-336.

Chen, Z. & Klahr, D. (1999). All other things being equal: Children's acquisition of the control of variables strategy. *Child Development*, *70*(5), 1098-1120.

Chi, M., Feltovich, P., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science, 5*, 121-152.

Cobern, W., Schuster, D., Adams, B., Applegate, B. Skjold, B., Undreiu, A.,…Gobert, J. (2010). Experimental comparison of inquiry and direct instruction in science. *Research in Science & Technology Education, 28*(1), 81-96.

Dewey, J. (1913). *Interest and Effort in Education.* Cambridge, MA: Riverside Press.

Eccles, J., Midgley, C., Wigfield, A., Buchanan, C. M., Rueman, D., Flanagan, C., & Mac Iver, D. (1993). Development during adolescence: The impact of stage-environment fit on young adolescents' experience in schools and families. *American Psychologist*, *48*, 90-101.

Egleston. (1973). Inductive vs. traditional methods of teaching high school laboratory experiments. *Science Education, 57*(4), 467-477.

Ertepinar, H. & Geban, O. (1996). Effects of instruction supplied with the investigative-oriented laboratory approach on achievement in a science course. *Educational Research, 38*(3), 333-341.

Eslinger, E., White, B., & Frederiksen, J. (2008). Supporting inquiry processes with an interactive learning environment: Inquiry island. *Journal of Science Educational Technology, 17*, 610-617.

Grolnick, W. & Ryan, R. (1987). Autonomy in children's learning: An experimental and individual difference investigation. *Journal of Personality and Social Psychology, 52*, 890-898.

Hall, D. & McCurdy, D. (1990). A comparison of a biological science curriculum study (BSCS) laboratory and a traditional laboratory on student achievement at two private liberal arts colleges. *Journal of Research in Science Teaching,* 27, 625-636.

Hardy, I., Jonen, A., Möller, K., & Stern, E. (2006). Effects of instructional support within constructivist learning environments for elementary school students' understanding of "floating and sinking". *Journal of Educational Psychology,* 98(2), 307-326.

Hidi, S. & Renninger, K. A. (2006). The four-phase model of interest development. *Educational Psychologist, 41*, 111-127.

Hiebert, J., Carpenter, T., Fennema, E., Fuson, K., Human, P., & Murray, H. (1996). Problem solving as a basis for reform in curriculum and instruction: The case of mathematics. *Educational Researcher, 25*(4), 12-21.

Hmelo-Silver, C., Duncan, R., & Chinn, C. (2007). Scaffolding and achievement in problem-based and inquiry-learning: a response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist, 42*(2), 99-107.

Hofstein, A., Nahum, T., & Shore, R. (2001). Assessment of the learning environment of inquiry-type laboratories in high school chemistry. *Learning Environments Research, 4*, 193-207.

Hofstein, A. & Walberg, H. (1995). Instructional strategies. In B. J. Fraser & H. J. Walberg

(Eds.), *Improving science education* (pp. 1-20). Chicago: National Society for the Study of Education.

Hudson, S., McMahon, K., & Overstreet, C. (2002). *The 2000 national survey of science and mathematics education: Compendium of tables.* Chapel Hill, NC: Horizon Research.

Kalyuga, S. (2007). Expertise reversal effect and its implications for learner-tailored instruction. *Educational Psychology Review, 12*, 509-539.

Kalyuga, S., Chandler, P., Tuovin, J., & Sweller, J. (2001). Learner experience and efficiency of instructional guidance. *Educational Psychology, 21*, 5-23.

Kirschner, P., Sweller, J., & Clark, R. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential and inquiry-based teaching. *Educational Psychologist, 41*, 75-86.

Klahr, D. & Nigam, M. (2004). The equivalence of learning paths in early science instruction. *Psychological Science, 15*, 661-667.

Komarraju, M. & Karau, S. (2008). Relationships between the perceived value of instructional techniques and academic motivation. *Journal of Instructional Psychology, 35*(1), 10-82.

Kuhn, D. (2007). Is direct instruction an answer to the right question? *Educational Psychologist, 42*, 109-113.

Kyle, W., Bonnstetter, R., & Gadsden, T. (1988). An implementation study: An analysis of elementary students' and teachers' attitudes toward science in process-approach versus traditional science classes, *Journal of Research in Science Teaching, 25,* 103-120.

Lawson, A., Benford, R., Bloom, I., Carlson, M., Falconer, K., Hestenes, D.,… Wyckoff, S. (2002). Evaluating college science and mathematics instruction, *Journal of College Science Teaching 31*(6), 388-393.

Leonard, W. (1983). An experimental study of a BSCS-style laboratory approach for university general biology, *Journal of Research in Science Teaching, 20,* 807-813.

Lord, T. (1997). A comparison between traditional and constructivist teaching in college biology. *Innovative Higher Education*, *21*(3), 197-216.

Martin-Hansen, L. (2010). Reexamining inquiry pedagogy in the science classroom. *Electronic Journal of Science Education, 14*(2), 1-4.

Mayer, R. (2003). *Learning and Instruction*, Upper Saddle River, NJ: Pearson.

Mayer, R. (1998). Cognitive, metacognitive, and motivational aspects of problem solving. *Instructional Science*, *26*, 49-63.

Mayer, R. (2004). Should there be a three-strikes rule against pure discovery learning? The case for guided methods of instruction. *American Psychologist, (59),* 1, 14-19.

Merriam, S. & Caffarella, S. (1991). *Learning in Adulthood. A comprehensive guide*, San Francisco, CA: Jossey-Bass.

Minner, D., Jurist Levy, A. & Century, J. (2009). Inquiry-based science instruction- What is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching, 47*(4), 474-496.

National Research Council (NRC). (1996). National science education standards. Washington, DC: National Academy Press.

Paas, F. & Van Merrienboer, J. (1994). Variability of worked examples and transfer of geometrical problem-solving skills: A cognitive-load approach. *Journal of Educational Psychology*, *86*, 122-133.

Pintrich, P. (2003). A motivational science perspective on the role of student motivation in learning and teaching contexts. *Journal of Educational Psychology, 95*(4), 667-686.

Pintrich, P. & Schunk, D. (2002). *Motivation in education: Theory, research, and applications*. Upper Saddle River, NJ: Pearson.

Reeve, J. (2002). Self-determination theory applied to educational settings. In E. L. Deci & R. M. Ryan (Eds.), *Handbook of self-determination research* (pp.183-203). New York: University of Rochester Press.

Reeve, J. & Jang, H. (2006). What teachers say and do to support students' autonomy during a learning activity. *Journal of Educational Psychology*, *98*, 209-218.

Reeve, J., Jang, H., Carrell, D., Jeon, S., & Barch, J. (2004). Enhancing students' engagement by increasing teachers' autonomy support. *Motivation and Emotion*, *28*(2), 147-169).

Renninger, K. A., Hidi, S., & Krapp, A., eds. (1992). *The Role of Interest in Learning and Development*. Hillsdale, NJ: Erlbaum.

Ryan, R. & Deci, E. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development and well-being. *American Psychologist, 55*, 68-78.

Ryan, R. & Grolnick, W. S. (1986). Origins and pawns in the classroom: self-report and projective assessments of individual differences in children's perceptions. *Journal of Personality and Social Psychology, 50*, 550-558.

Schmidt, H. G., Loyens, S. M. M., van Gog, T., & Pass, F. (2007). Problem-based learning is compatible with human cognitive architecture: Commentary on Kirschner, Sweller, and Clark (2006). *Educational Psychologist*, *42*(2), 91-97.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, *12*, 257-285.

Sweller, J. & Cooper, G. A. (1985). The use of worked examples as a substitute for problem solving in learning algebra. *Cognition and Instructions*, *2,* 59-89.

Tsai, Y., Kunter, M., Ludtke, O., Trautwein, U., & Ryan, R. (2008). What makes lessons interesting? The role of motivation and individual factors in three school subjects. *Journal of Educational Psychology, 100(*2), 460-472.

Von Secker, C. & Lissitz, R. (1999). Estimating the impact of instructional practices on student achievement in science. Journal of Research in Science Teaching, 36(10), 1110-1126.

Vygotsky, L. (1978). *Mind in society*. Cambridge, MA: Harvard University Press.

Weiss, I., Pasley, J., Smith, P., Banilower, E., & Heck, D. (2003). *Looking inside the classroom: A study of K-12 mathematics and science education in the U.S.* Chapel Hill, NC: Horizon Research.

Welch, W., Klopper, L., Aitkenhead, G., & Robinson, J. (1981). The role of inquiry in science education: analysis and recommendations. *Science Education, 65*, 33-50.