The Effects of Deliberate Note-taking
On Conceptual Knowledge and Problem Solving
in a Physics Classroom

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Abstract:
Modeling Instruction pedagogy from Arizona State University has long been proven to be an effective delivery strategy in secondary science classrooms (Hestenes 2006; Hestenes, Wells, and Swackhammer 1995). However, the investigators have observed common feedback from listservs, peers, and workshops that a common complaint amongst practitioners of Modeling Instruction is the lack of written artifact from very rich “in-class” discourse. Our treatment incorporated a very simple and deliberate prompting of an encoding (note-taking) style to record progress through the Modeling cycle. Students were given a note-taking template to record important facets of whiteboarding discussion after labs and before assessments.

Students across a wide spectrum of ages and cognitive reasoning abilities showed moderate gains when compared to non-treatment groups. Students voluntarily contend the treatment was beneficial for themselves and worthwhile for their predecessors.

Rationale:
The Modeling Cycle has been proven to be a reliable and cognitively powerful delivery method for physics instruction (Hestenes, Wells, and Swackhamer, 1995; Halloun and Hestenes, 1987). Encoding methods also have a long documented history of having significant impacts on student learning and retention (Kiewra, 1985; Kiewra et al. 1991; Howe, 1970). In an informal assessment of students’ use of encoding practices within our own Modeling Instruction classrooms we hypothesized that a significant improvement could be accomplished by incorporating better encoding practices into the Modeling Cycle.

Literature Review:

Modeling is the name of the game. (Hestenes, 1993)
The Modeling Instruction method developed by David Hestenes and Malcolm Wells in the 1980s is well known and documented amongst secondary science instructors in the U.S. and abroad (Hestenes, Wells, and Swackhammer, 1995; Halloun, 2006). The pedagogical approach incorporates experiential learning through the application of scientific and mathematical knowledge to describe or model physical phenomenon (Wells, 1995; Hestenes, 1987). The student who enters a high school physics class already has preconceived notions about the behavior of the physical world (Wells, 1995; Hestenes, 1987). A simple didactic approach presenting new information, some of which may be contrary to the student’s own naïve understandings, is not adequate for reformulation of such thoughts (Hestenes, 1987; Wells, 1995; Swackhammer 1992). Students hold tight to their preconceptions about physical phenomena and will unconsciously defer to these preconceptions in the face of information gained in lecture and textbooks (Hestenes, 1987; Wells, 1995). Chinn and Brewer (1993) noted that students employ a wide variety of techniques to protect their pre-instructional ideas. Worse still, studies by Ganiel and Idar (1985) show a significant discrepancy between instructor assumptions about student learning and actual student development. Norman (1980) noted
that as students gave meaning to information gained from lectures and textbooks, information that seemed discrepant to the model was ignored; sentences, even paragraphs of text, seemed to be skipped. Ganiel and Idar (1985) observed that considerable discrepancies arise between the teachers’ assumptions about what students obtain from classroom experiences and what the reality was as described by objective tests.

**Modeling Instruction is rooted in cognition:**

Our motivation for utilizing Modeling Instruction is based upon its firm anchor in cognitive research. Traditional stand and deliver pedagogical approaches do not address many of the cognitive necessities to form intelligent, adaptable, and cognitively deep understandings (Hestenes, 1987). Further analysis of student processing in short term, working memory, and long term memory indicates a need to bridge sensory input with a cognitive function (Hestenes, 1987). Thinking and learning take place within working memory, where prior-knowledge schemas are activated in response to environmental input, providing context for interpreting experience and assimilating new knowledge (Derry, 1996). Within the scope of teaching and learning are three types of schema called: memory objects, mental models, and cognitive fields (Derry, 1996).

Memory objects are bits of information that come from experiences; they are simple pure representations of pictorial, declarative, procedural, auditory or emotional input (Derry, 1996). Memory objects are fundamentally incorporated in the Modeling Cycle in the form of paradigm labs. Modeling Instruction attempts to incorporate these schema from the very beginning of the teaching cycle. This allows students the opportunity to formulate and utilize their own memory objects from the unit of study they are attempting to model.

The simplest form of a memory object is known as a phenomenological primitive or p-prims. P-prims are intuitive schemas “whose origins are relatively unproblematic, as minimal abstractions of common events” (diSessa, 1993). In secondary science instruction these simple intuitive memory objects can form from demonstrations, labs, lecture, classroom discourse, and if not carefully managed can lead to stubborn and difficult anchors for students to rationalize (Halloun and Hestenes, 1985; Wells, 1987). Modeling Instruction takes deliberate steps to ensure careful demonstration and data collection steps are taken. An example of the importance of giving students the proper p-prims is illustrated in the opening of Unit IV (inertia) when dry ice is purchased and used to define motion. Students bring their own experiences into the classroom some of which is tainted and skewed because of the everyday effect of friction. Paying extra special attention to the details of a phenomenon and allowing students the opportunity to define variables is crucial to the development of a model (Wells et al. 1995).

Paying particular attention to these details ensures that the student’s p-prims are grounded firmly in scientific fact (Halloun and Hestenes, 1985). Particularly, in early stages of cognitive development, p-prims can be weakly organized forming an incomplete memory object of an event or phenomenon (Derry, 1996). The reorganization and prioritizing of these fundamental memory units is considered the development of scientific knowledge (diSessa,
1993). The task of learning should enable the activation of relevant p-prims which help to create or link other p-prims to the contexts they specify (Derry, 1996).

Practically speaking we cannot control what students have in their heads when they enter our secondary science classrooms. According to: McDermott (1984), Halloun and Hestenes (1985), Hestenes (1987), and Wells (1987) far too often students pre-instructional ideas are inconsistent with Newtonian thought. Reformulation will not occur with direct didactic instruction, but instead careful paradigm problems, demonstrations, and labs will help to build proper memory objects that will allow students to have a greater contextual understanding and approach the Newtonian thinking stage (Halloun and Hestenes, 1985).

Modeling Instruction incorporates cognitive research on mental modeling (Hestenes, 2006). Mental modeling is the second, and more complicated, of the first two schemas and can be viewed as a process of constructing, testing, and adjusting a mental representation of a complex problem or situation. The resulting interpretation is a mental model schema (Derry, 1996). Previously learned schemas (memory objects) provide the basis for the more complex mental modeling activity. Mental models represent situational understandings that are context dependent and do not exist outside the situation being modeled (Derry, 1996). The construction of mental models involves the student mapping active memory objects onto components of the real-world phenomenon, then reorganizing and connecting those objects so that together they form a model of the whole situation (Derry, 1996). The organization of cognitive schema and connection to outside information is a form of problem solving. Once constructed, a mental model may be used as a basis for further reasoning and problem solving, which may give rise to further readjustments to the mental model (Derry, 1996). Modeling Instruction as developed by Hestenes and Wells (1987) utilizes cognitive research and incorporates it into a learning cycle. Wells (1987) defines at least three main stages in this cycle: 1) “Develop qualitative physical intuition.” 2) “Develop mental models, usually mathematical, that define and describe the relationships among the system variables related to the phenomenon of interest.”, 3) “Develop the procedural knowledge necessary for effective model utilization (model deployment).” The first stage in Wells’ learning cycle “Develop qualitative physical intuition” is analogous to Derry’s formation of memory objects. Intuitive simple schema that is pure and simple in form. Performed in Hestenes’ and Wells’ Model Method this takes the form of simple clean paradigm labs and demonstrations in the physics classroom. Wells’ second step in the Modeling Cycle: “Develop mental models, usually mathematical, that define and describe the relationships among the system variables related to the phenomenon of interest” is a direct connection to the formation of mental models. These models are then tested and challenged within the Modeling materials through problem sets, lab practicums, tests, and quizzes. Wells’ third step in Modeling: “Develop the procedural knowledge necessary for effective model utilization (model deployment)” is a more reaching connection that students know when to utilize a particular set of schema. Derry (1996) has since described these as Cognitive Fields.

A cognitive field, in the work of Derry (1996), is a third type of schema. It is a governing field that controls which mental models and memory objects are utilized in any given problem.
set, demonstration, or classroom discourse. It is a response to such an event which makes certain memory objects more available for use than others and employs different schema to mediate between experience and learning. That is, experience triggers activation of the cognitive field, which in turn delineates the memory objects that are readily available for modeling the experience. The cognitive field thus determines what interpretations and understandings of experience are probable. The cognitive field activated in a learning situation also determines which previously existing memory objects and object systems can be modified or updated by an instructional experience (Derry, 1996).

In other words, Modeling Instruction helps students to restructure their intuitions about physical phenomenon by engaging them in the development, manipulation, and explanation of such phenomenon (Hestenes, 1996). The cognitive process of applying the design principles of a theory to produce a model of some physical object is called Model Development or simply “Modeling” (Hestenes, 1987).

The effectiveness of the teaching cycle experiment performed by Wells, and defined as Modeling Instruction by Hestenes indicate students perform on average up to two standard deviations better than compared to conventional didactic instructional methods (Halloun, 1984). When given identical assignments and exams consisting of tasks similar to end of unit problems typically found in traditional textbooks, students exam score increases on average up to three times better under Modeling Instruction than under conventional instruction (Halloun, 2006).

Room for improvement

One of the most important aspects of the Modeling approach is the discourse between peers, especially during the whiteboarding discussions. The teacher seeks to remove their presence as a moderator of the whiteboarding discussion as well as the ultimate authority to be consulted for the correct solution. This process has been shown to be extremely effective throughout the Modeling Cycle (Wells, Hestenes, and Swackhammer, 1995; Hestenes, 2006).

Student learning can be improved by the use of an external storage device and having students transfer the information presented in the whiteboarding session from working memory to that external storage device. Encoding is a powerful tool to move information from short-term memory to long-term memory, however the majority of the encoded information that appears on the whiteboards is erased at the end of the whiteboarding session, never written down by students. This creates a gap in the learning process when students attempt to remember this difficult information from internal memory (Intons-Peterson and Fournier, 1986). Incorporating external storage devices, such as personal encodings, allow students greater retention of memory objects especially when their attention is being divided, generally, amongst five other classes (Kiewra, 1985; Kiewra et al. 1991; Howe, 1970; Intons-Peterson and Fournier, 1986). Students’ external storage encodings increase the likelihood of remembering these difficult topics (Intons-Peterson and Fournier, 1986). Personal observations from our classrooms seem to indicate that students are competent at taking notes under teacher-guided discourse, but almost no attempt during student-lead discourse. When using Modeling
Instruction, the teacher generally does not lead discussions but helps students when they are struggling on a particular problem (Halloun and Hestenes, 1987; Hestenes, 1987). It is instead the students who provide the information for the other students via whiteboards that they prepare examples on and then lead a discussion for the other students. This is all based on the student’s prior knowledge from the previous work they have performed in class. The students presenting this information often have mistakes on their whiteboards which are corrected through the use of Socratic questioning done by the teacher and students in the classroom (Wells, Hestenes, and Swackhammer, 1995). Due to uncertainty of content, students could be hesitant to encode unless the teacher is providing information in the lecture format to which students are accustomed. This creates gaps in the learning process as there is not a written account of what was discussed. It has been shown by many studies: Howe (1970), Kiewra (1985) and again in a follow up study by Kiewra et al. (1991) that students who just listen to lectures and/or discussions as well as those that encode but do not review from their encodings perform near the bottom on assessments when compared to students that encode and review from those encodings prior to the assessments.

Encoding is the personal individual process that students undergo when representing information presented that they then transform into a personally meaningful encodings for later use. Examples of encoding are: note taking, journaling, concept maps, pictorial representations etc. (Kiewra, 1985; Kiewra et al., 1991; Howe, 1970). There are three main parts to effective encoding (listed in order of least to most important) which are: structure of encoding, timing of encoding, and review of encoding (Bui and Myerson, 2014). The first is the structure of the encoding. Students’ unstructured encoding, when the students are free to write anything and have to guess at what is important, generally miss the majority of the big ideas presented during discussions (Bui and Myerson, 2014). When students are provided with structure/prompt for encoding it has been shown to increase the overall quality and effectiveness of the encoding (Kiewra, 1985; Kiewra et al., 1991; Howe, 1970). Students are able to organize their ideas in appropriate places when they are given prompts on what the key ideas of the discussion should be (Kiewra et al., 1991). These organized prompts also aid in making the relationships between different ideas more clear (Kiewra et al., 1991). There are however some students that do not benefit from being told to organize encoding in a certain way. These students generally already have a method of encoding that works for them, however, being shown a way to organize encoding helps the students that do not have a “good” method of encoding (Hartley and Davies, 1978).

Timing of encoding also plays a major role in the quality and effectiveness of the encoded materials. When students were given a pretest after note taking while listening compared to just listening without note taking, their scores were not significantly different (Kiewra, 1985; Kiewra et al., 1991; Howe, 1970). The main reason for this is due to students, generally, having to attempt encoding while discussions are taking place. This is a huge cognitive demand which results in information being missed either within their notes or within the discussion (Bui and Myerson, 2014). The typical lecture and encoding process causes students to perform multiple higher level tasks at once: listening to the lecture, holding on to
information that was just presented, summarizing that information, writing down the now summarized information, while still attempting to listen to the lecture (Bui and Myerson, 2014). All of this information processing is taking place in the student’s working memory, and as Cowan (1988 and 1995) has pointed out, there is room for about 7 things for most people to focus on in their primary focus i.e. working memory. The working memory has the tasks of listening to the lecture, then transforming the information just heard, and finally summarizing that information via encoding all in less than a few seconds if they want to keep up with the lecture that is still taking place (Bui and Myerson, 2014). When a student is attempting to perform the encoding task, transcoding and composing, it becomes difficult to focus on the other higher level tasks that a lecture requires (Bui and Myerson, 2014). The ability of a student’s working memory is a big predictor in their encoding ability for organized, high quality notes. Students who possess a working memory capable of performing the tasks previously listed generally have higher quality encodings in a lecture when compared to those students that lack working memory ability whose encodings are generally of low quality (Bui and Myerson, 2014). Further compounding the difficulty of encoding during discussions is the average speaking rate far exceeds the average writing rate. It is nearly impossible to encode everything during a normal non-stop lecture, even with technological aids, and even harder when the lecture is at a rushed pace (Peters, 1972). When Peters (1972) studied lecture rate, he saw that the slower the material was delivered, the better the performance by students on following assessments. Aiken, Thomas, and Shennum (1975) took this a step further by varying the rate as well as giving breaks in between lecture for encoding. They found that student performance was the best on assessments when students took notes during breaks and immediately following the lecture (Aiken et al. 1975). When learners are allotted time during the discussions to encode, they can first listen to the discussion and then summarize the main ideas during those allotted times when the discussion is “paused.” This allows their working memory to focus on the transforming and encoding task and not worrying about keeping pace with the lecture (Ruhl and Suritsky, 1995; deZure, 2001). This has also been shown to work effectively with the learning disabled students that are increasingly in mainstream classrooms (Ruhl and Suritsky, 1995).

The third part of effective encoding, also the most important, is the review of encoded material (Kiewra 1985; Kiewra et al., 1991; Howe, 1970). Students generally have a lot going on and struggle to remember every detail of class, especially in the long term. Encoding is an external memory storage device which means that students do not necessarily have to store all of the information internally but can store it externally via encoding for later review (Kiewra 1985; Kiewra et al., 1991; Howe, 1970). It has been shown that people that write down information and can then review the information at a later time have a better chance to recall this information when needed compared to those that try to recall based solely on an internal storage method (Intons-Peterson and Fournier, 1986). Also, as stated previously, when studies compared students that sit and listen to discussions without taken notes to those students that encode during discussion but do not review their encoding prior to assessment, their performances were very similar on the follow up assessments (Kiewra, 1985 and 1991; Howe,
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1970). In contrast, students that were given high quality organized encoded material without seeing/hearing the discussion but were told to review the encoded material as well as those that were just given time to discuss amongst peers after hearing the lecture performed at a higher level than those who just listened and those that encoded but did not review on the same assessment (Kiewra, 1985; Kiewra et al., 1991; Howe, 1970). When students were given an opportunity to listen, see, encode, and review encoding prior to assessments, the overall assessment scores dramatically increased and were by far the highest out of any of the groups previously mentioned (Kiewra, 1985; Kiewra et al., 1991; Howe, 1970). By this data we can, appropriately, say that without the review part, the student’s pre-assessment scores should not be different from their post-assessment scores. We need to ensure that the students will be reviewing encoding prior to assessments (Kiewra, 1985; Kiewra et al., 1991; Howe, 1970).

In conclusion, teaching science with the Modeling Method is more effective compared to the traditional approach (Halloun and Hestenes, 1985). It has also been shown that students who encode throughout discussions for later review perform higher on post assessments (Kiewra, 1985; Kiewra et al., 1991; Howe, 1970). We are going to combine both of these approaches in an attempt to maximize student learning and understanding in science classrooms.

Locations and subjects of treatment:

Treatment Groups:
Investigator 1: Investigator 1 taught in a rural high school in southern Arizona. The student population of was composed of: 52% White, 27% Hispanic, 9% Black, 4% Asian, and 1% Native American. 20% of the student body qualifies for free lunch and 4% qualifies for reduced lunch programs. Investigator 1 was assigned 2 AP Physics 1 courses and 3 Mechanics courses.

Investigator 2: Investigator 2 taught in a suburb of the greater Denver metropolitan area. The student population was composed of: 80% Caucasian, 11% Hispanic, 4% Asian or Asian/Pacific, 1% Black, and 4% two or more races. Student population eligible for free or reduced lunch program: 6% Investigator 2 was assigned to an algebra prerequisite 9th grade physics course, an algebra prerequisite 11/12th grade physics course, and AP physics 1 including both freshmen and upperclassmen.

Investigator 3: Investigator 3 taught in a suburb of Phoenix, Arizona. The student population was composed of: 75% Caucasian, 14% Hispanic, 5% Asian or Asian/Pacific, 3% Black, 1% Native American, and 2% of Two or More Races. Student population eligible for free or reduced-price lunch program: 10%. Investigator 3 was assigned to algebra II prerequisite 11/12th AP Physics 1 Course with 115 students and an algebra II/AP Physics 1 prerequisite 11/12th grade AP Physics 2 Course with 32 students.
Investigator 4: Investigator 4 taught in a suburban high school in Phoenix Arizona. The population of was composed of: 54% Caucasian, 10% Black, 13% Asian, 21% Hispanic, and 2% Native American. Of the student population 21% are on free or discounted lunch programs. Investigator 4 was assigned 2 AP Physics C Mechanics and Electricity/Magnetism classes, 1 AP Physics C Mechanics only class, as well as 2 AP Calculus BC classes.

**Comparison Groups:**
In an effort to evaluate the effectiveness of the treatment, comparison data was generously given by other modelers to compare the current subjects receiving the treatment (2014/2015). Data was gathered for all sections of physics in which mechanics is taught through the Modeling Cycle.

Comparison group 1: A suburban High School on the west side of Phoenix, Arizona. This comparison school had an enrollment of approximately 2,100 in grades 9-12. The population was approximately 67% Caucasian, 23% Hispanic, 5% Black, 3% Asian, 1% Hawaiian or Pacific Islander and 1% Native American. Twenty-four percent of students received free or reduced price lunch.

Comparison group 2: This comparison group is comprised of two teachers at the same school as Investigator 4 and, thus, have the same demographics as above, a suburban high school in Phoenix Arizona. The population of was composed of: 54% Caucasian, 10% Black, 13% Asian, 21% Hispanic, and 2% Native American. Of the student population 21% are on free or discounted lunch programs. Comparison Group 2 was assigned AP Physics 1 classes and the accompanying math classes.

**Method and Procedure for Treatment:**
We wanted to implement the treatment in a manner that efficiently captured the value of in class discourse and activities. It was apparent to the investigators that the two common places for this summation of events was after the paradigm lab and preceding unit assessments. Much of the unit is formulated in the paradigm lab and following worksheets, so the time immediately after is a convenient time to record some of the model aspects. Within the modeling cycle the model is further deployed and refined with additional labs, practicums, and worksheets so this too would be an appropriate time to record advancements. Most often the investigators implemented the encoding prompts at two locations in the unit, before the first quiz and before unit test.

1. **Permissions:** A permission form was sent to parents or guardians to gain consent for video and document submissions. If no consent was given, the student’s data was not included in the study.
2. **Pre-Assessment:** All students were administered the Force Concept Inventory (pre-FCI) (Hestenes, Wells, and Swackhammer, 1992; Hestenes and Halloun, 1995) and the Lawson's
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Classroom Test Scientific Reasoning Test (pre-CTSR) in the beginning of the year (Lawson, 1978).

3. **Treatment**: The investigators acknowledge encoding is a personal effort and task. We therefore made concessions to different encoding modes, but due to the variation in student encoding methods, investigators accepted students use of encoding in the method they felt most comfortable. Investigators and collaborators feel as long as students include the requisite three sections: model development and important concepts, mathematical model and corrections, and summary and connections. Varying methods can be used without compromising the data across groups. As some students will have subpar or no models for encoding, the investigators will model the first unit as an example.

   During the first encoding session, students were given a template (Appendix B) with space to record their discussions, corrections, and summations of the unit’s conceptual developments. To allow for student creativity and novel processes, investigators prompted students to choose a method, presentation, or arrangement for which they are most comfortable, provided it still contains at least the three encoding topics required by the format and is in a form which is coherent to the investigator. Most students in the first-year courses continued to follow the template, while most of the students in the second-year course chose a more personalized encoding format other than the template. At the end of a unit, students recorded a final encoding to complete a unit summary from their previous encoding and discussions.

Class methods:

1. **Introduction**

   Students were given some background (Ornek, 2008) on difficulties in physics learning to introduce the meta-cognitive strategy of intentional reflection immediately after our discussions and problem solving strategies developed during whiteboarding sessions. Since physics is a collection of models and interlocking mathematical, graphical, and diagrammatic interpretations of natural phenomena, we wanted them to be cognizant of their personal progress as we developed concepts in our mechanics units.

   Students were asked to encode the first unit, constant velocity, in any method they chose, with no instruction or observable rubric during lab discussions and whiteboard presentations. Upon reaching the second unit, constant acceleration, investigators described the research project, the method being developed, and displayed a poster with an outline of our encoding format which set a minimum scheme for their encodings. To model the behavior we wanted to elicit, investigators demonstrated how to perform the encoding technique on the constant velocity unit material.

2. **Encoding session description**

   Encoding sessions were focused on two main facets: deployment and review. Encoding at deployment occurred after much of the a unit’s model has been initially exposed and just before the first quiz. After group discussion to show broad trends in data, students were given time to summarize with their peers to produce three objectives: Model Description, Mathematical Models, Summary and Connections. Model Description: students needed to state
the name of the model being developed and how the data in the lab gave rise to it. Mathematical Models: students described the mathematical models which their data suggests to include new terminology and definitions of slopes, y-intercepts, derivatives and integrals (areas). During deployment of the model and after students have whiteboarded the first few worksheets the students will be given a quiz. With peer discussion, students stated the current evolution of the physics model as elaborated from the previous days’ deployment from the whiteboarding session. This included the standard multiple representations including diagrams, graphical relationships, and formulae. Additionally in this section, the students noted any particularly challenging aspects or problems they encountered to include corrections to mistakes during whiteboarding. Summary and Connections: the students summarized the model with connections to real world events, preferably applications from their daily lives.

Review Encoding: As review is the most important part of encoding (Fisher and Harris 1973), the students had a final review assignment prior to the unit assessment. During this session the students review all previous encoding materials and generate a final product which states the final form of the model.

3. Encoding template

The investigators posted the encoding template (Appendix B) in their classrooms for students to refer to, although, as stated, clever and novel deviations were welcome, provided the minimum requirements were adhered to. Students were given copies of the template.

4. Review Template:

A separate template was used, (Appendix D), as treatment before the unit exam and ensured students another opportunity to review their previous encodings. Encoding templates were scored on a nominal participation points scale. The review template was scored against the 12-point rubric (Appendix E) and included in the student’s grade report.

During the deployment of the models, investigators set aside time for students to converse with their lab groups and/or the teacher in order to construct useful “so what’s,” or questions to expand on the meaning of the previous material, about the material presented in class to allow students to assimilate and process information (McKeachie et al., 1986). The frequency of this time is nicely aligned with quizzes in the Modeling Instruction; generally a quiz happens every 2-3 whiteboarding sessions. This allows students to take a step back and survey the previous days’ work and discussion in order to condense and crystallize their development of the burgeoning model. This has the additional motivation of offering better quiz performance for the students. The final reflection was performed at the end of the unit. Students combined their reflections with their lab groups and the class at large to completely lay bare the model developed over the preceding weeks.

Assessment during treatment: During units, students’ encoded materials were periodically collected by the investigator for inspection of participation in their reflective efforts. Encoding was collected from the students to verify nominal participation credit, copies were made and then handed back to students for their collection. While there is no “right” answer to a reflection on their developing understanding, investigators were broadly looking for diligent participation and communication of errors the student has made in the unit. Students were
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offered a nominal participation grade, minimal homework points for completing the encoding sheet, for their efforts. The attached rubric (see Appendices C and E) were shared with students to offer them guidance and establish a baseline for completion of the encoding material. For the constant velocity unit an investigator led discussion was given with the rubric

Post-treatment Assessment:

1. Students were assessed by comparison of their Force Concept Inventory at the end of the mechanics units (post-FCI) scores and their pre-FCI scores. Students were compared to aggregate Force Concept Inventory (FCI) data from comparison students when the groups were deemed to be sufficiently similar through independent sample t-tests on the pre-FCI and Lawson's Classroom Test of Scientific Reasoning (pre-CTSR).

2. Students were video-interviewed by investigators for anecdotal evidence on the efficacy of the encoding.

Data Analysis:

Quantitative Data Analysis:

Prior to any treatments taking place and within the first week of the school year starting, all students in the treatment groups and comparison groups were given the pre-CTSR and the pre-FCI. When the data was analyzed the treatment groups and the comparison groups showed differences in their reasoning and physics knowledge as evidenced by these pre-tests. The investigators determined through independent sample t-tests which groups could be combined and which groups could be compared. Investigator 1 and Investigator 3 had similar pre-test scores on both the FCI and the CTSR and as such were combined. Investigators 2 and 4 both had scores that were not comparable to the other investigators and as such were analyzed as their own groups. Table 1 lists the aggregate data for the different treatment groups and comparison groups.

Table 1: Table of all aggregate data for the different treatment groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Pre-CTSR (Score)</th>
<th>Pre-FCI (Score)</th>
<th>Post-FCI (Score)</th>
<th>FCI Gain (G)</th>
</tr>
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Table 1: Summary of pretest and posttest FCI and CTSR scores for treatment and comparison groups. The mean score on each test is displayed with the standard deviation below each score in parentheses. All scores are reported on raw scores on each test.

*Comparison Group 2 was comprised of two teachers from the same school teaching the same level physics class that students were randomly assigned. Only one of the teachers had data for the Pre-CTSR scores. Being that the students were from the same school and randomly distributed to each teacher we assumed the Pre-CTSR scores would be similar based on the Pre-FCI scores and Post-FCI scores being similar.

**Treatment Group 1:** These students were first year physics students comprised of 20 regular physics students from Investigator 1’s school and 20 Advanced Placement Physics 1 students from Investigator 3’s students. The distributions for the pre-FCI and post-FCI are graphed in Figure 1 below.

*Figure 1:* Treatment Group 1’s pre-FCI and post-FCI scores.

<table>
<thead>
<tr>
<th>Treatment Group 1</th>
<th>40</th>
<th>15.40 (4.07)</th>
<th>8.55 (4.11)</th>
<th>21.03 (5.07)</th>
<th>0.51 (0.22)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment Group 2</td>
<td>56</td>
<td>16.39 (3.26)</td>
<td>8.66 (4.32)</td>
<td>18.64 (6.22)</td>
<td>0.47 (0.25)</td>
</tr>
<tr>
<td>Treatment Group 3</td>
<td>54</td>
<td>19.11 (3.25)</td>
<td>19.30 (6.42)</td>
<td>21.67 (6.02)</td>
<td>0.20 (0.34)</td>
</tr>
<tr>
<td>Comparison Group 1</td>
<td>46</td>
<td>17.59 (3.05)</td>
<td>9.62 (4.79)</td>
<td>14.04 (5.67)</td>
<td>0.24 (0.21)</td>
</tr>
<tr>
<td>Comparison Group 2</td>
<td>97</td>
<td>13.95* (3.38)</td>
<td>8.99 (3.81)</td>
<td>23.19 (5.46)</td>
<td>0.69 (0.24)</td>
</tr>
</tbody>
</table>
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Based on a dependent sample t-test, Treatment Group 1’s pre-FCI scores (Mean (M)=8.55, Standard Deviation (SD)=4.11) were significantly lower when compared to Treatment Group 1’s post-FCI scores (M=21.02, SD=5.07), t(39)=−11.43 p<0.001. These scores show that Treatment Group 1 came into their first year physics class with a minimal understanding of Newtonian mechanics concepts earning scores barely better than guessing on the FCI with an average of 8.55 questions correct (Hestenes, Wells, and Swackhammer, 1995). After a year with the investigators, students showed improvement via post- FCI test scores with a mean of 21.02. These results show that the physics students in treatment group 1 showed great improvement.

To further test the results of the encoding treatment, Treatment Group 1 was compared to Comparison Group 1. Treatment Group 1 (M=8.55, SD=4.11) was statistically similar to Comparison Group 1 (M=9.61, SD=4.91) on pre-FCI scores based on an independent sample t-tests (t(84)=−1.074, p=.286). Treatment Group 1 (M=15.40, SD=4.07) was not statistically similar to Comparison Group 1 (M=17.59, SD=3.17) CTSR scores from an independent sample t-test (t(84)=2.749, p=.008. This meant that Treatment Group 1’s students were similar, but slightly lower, on pre-FCI and significantly lower on their scientific reasoning skills when compared to Comparison Group 1. We therefore concluded that we could compare Treatment Group 1’s post-FCI scores to Comparison Group 1’s post-FCI scores and expected to see higher scores by Comparison Group 1 based on students with higher scientific reasoning skills generally have higher gains, or growth for each student between the pre-FCI and the post-FCI, on the FCI, see Figure 2 (Coletta and Phillips, 2005; Coletta, Phillips, and Steinert, 2007).

Figure 2: Treatment Group 1’s post-FCI scores and Comparison Group 1’s post-FCI Scores.

Based on a directional independent sample t-test, Treatment Group 1 (M=21.02, SD=5.07) had higher post-test results compared to Comparison Group 1 (M=14.04, SD=5.67), t(84)=−5.98, p<.001. This was opposite of what was predicted based on the pre-test results and again adds validity to using the encoding treatment although other factors may have influenced these results as well.

Treatment Group 1 was also compared to Comparison Group 2. Treatment Group 1 (M=8.55, SD=4.11) was statistically similar to Comparison Group 2 (M=8.99, SD=3.81) on pre-FCI scores based on an independent sample t-tests (t(136)=−.601, p=.549). Treatment Group 1 (M=15.40, SD=4.07) was also statistically similar to Comparison Group 2 (M=13.95, SD=3.38) on
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pre-CTSR scores based on an independent sample t-test (t(59)=1.394, p=.169. Comparison Group 2 was a better comparison group for Treatment Group 1 as all pre-test scores were similar. We therefore concluded that we could compare Treatment Group 1’s post-FCI scores to Comparison Group 2’s post-FCI scores and expected similar results on the post-FCI test, see Figure 3 (Coletta and Phillips, 2005; Coletta, Phillips, and Steinert, 2007).

**Figure 3: Post FCI for Treatment Group 1 and Post FCI for Comparison Group 2**

Based on a directional independent sample t-test, Treatment Group 1 (M=21.02, SD=5.07) had lower post test results compared to Comparison Group 2 (M=23.19, SD=5.46), t(135)=-2.148, p=.017. These results show that Comparison Group 2 outperformed Treatment Group 1 by a statistically significant margin. Of particular interest in this result is the exceptional number of max scores and the distribution of scores from Comparison Group 2. Without knowing more details of the comparison groups methodology and implementation of the FCI, the researchers reserve judgement about fully interpreting the meaning of this comparison.

**Treatment Group 2:** Treatment group 2 consisted of students from Investigator 2’s school. This group consisted of 20 upper class students mixed between regular level physics and AP Physics 1 classes. The remaining 36 freshman were mixed between regular physics and AP Physics 1. It should be noted that all of the freshman attempting the course are considered advanced for their age being enrolled in Honors Geometry or Honors Algebra II. Despite the age differences between the upperclassmen and freshman classes they are considered comparable populations via independent sample t-test’s on both the pre-FCI and the pre-CTSR tests. These students showed significant gains in their physics knowledge over the course of the year as shown by their pre-FCI scores versus their post-FCI scores as shown in Figure 4.
Figure 4: FCI Scores for Treatment Group 2 before and after the treatment.

Based on a dependent sample t-test, Treatment Group 2’s pre-FCI scores (M=8.66, SD=4.32) were significantly lower when compared to Treatment Group 2’s post-FCI scores (M=18.64, SD=6.22), t(55)=-16.32, p<0.001. The pre-FCI scores show that Treatment Group 2’s students had minimal understanding of Newtonian mechanics concepts upon entering their first year in a physics course earning scores barely better than guessing on the FCI with an average of 8.66 questions correct (Hestenes, Wells, and Swackhammer, 1995). After a year of Modeling Instruction, students showed improvement via the post-FCI with an average score of 18.64. These results again show that the students who received the encoding treatment showed great improvement on the FCI, although other factors again could have contributed to this growth.
To further validate the encoding treatment for Treatment Group 2 we compared Treatment Group 2 to Comparison Group 1. Treatment Group 2 (M=8.66, SD=4.32) was statistically similar to Comparison Group 1 (M=9.61, SD=4.91) on pre-FCI scores based on an independent sample t-tests (t(100)=-1.04, p=.397). Treatment Group 2 (M=16.39, SD=3.26) was also statistically similar to Comparison Group 1 (M=17.59, SD=3.17) on pre-CTSR scores based on an independent sample t-test (t(100)=-1.86, p=.065. This meant that Treatment Group 2’s students were similar, but slightly lower, on pre-FCI and similar, but again slightly lower, on their scientific reasoning skills when compared to Comparison Group 1. We therefore concluded that we could compare Treatment Group 2’s post-FCI scores to Comparison Group 1’s post-FCI scores, see Figure 5, and expected to see similar scores by Treatment Group 2 and Comparison Group 1 based on their pre-test results (Coletta and Phillips, 2005; Coletta, Phillips, and Steinert, 2007).

Figure 5: Post FCI for Treatment Group 2 and Post FCI for Comparison Group 1

Based on a directional independent sample t-test, Treatment Group 2 (M=18.64, SD=6.22) had higher post test results compared to Comparison Group 1 (M=14.04, SD=5.67), t(84)=-5.98, p<.001. This again validates the use of the encoding treatment as we expected the two groups to have comparable post-test results but Treatment Group 2 significantly outperformed Comparison Group 1.
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Treatment Group 2 was also compared to Comparison Group 2. Treatment Group 2 (M=8.66, SD=4.32) was statistically similar to Comparison Group 2 (M=8.99, SD=3.81) on pre-FCI scores based on an independent sample t-tests (t(152)=-.491, p=.624). Treatment Group 2 (M=16.39, SD=3.26) was not statistically similar to Comparison Group 2 (M=13.95, SD=3.38) on pre-CTSR scores based on an independent sample t-test (t(59)=1.394, p=.169. We therefore concluded that we could compare Treatment Group 2’s post-FCI scores to Comparison Group 2’s post-FCI scores, see Figure 6, and expected to see higher scores by Treatment Group 2 again based on students with higher scientific reasoning skills generally have higher gains on the FCI (Coletta and Phillips, 2005; Coletta, Phillips, and Steinert, 2007). 

Figure 6: Post FCI for Treatment Group 2 and Post FCI for Comparison Group 2

Based on a directional independent sample t-test, Treatment Group 2 (M=18.64, SD=6.22) had significantly lower post test results compared to Comparison Group 2 (M=23.19, SD=5.46), t(135)=-2.148, p=.017. These results again say that Comparison Group 2 outperformed our treatment group. For reasons stated previously, the researchers have concerns with the distribution of scores for Comparison Group 2.
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**Treatment Group 3:** Second Year Advanced Placement (AP) physics students. This treatment group was comprised of students from Investigator 4’s school that were concurrently, and with the same teacher, taking AP Physics C Mechanics and AP Physics C Electricity and Magnetism as well as AP Calculus BC. These students were in their second year of physics courses and the majority of these students came from Comparison Group 2’s students from the previous year, see Figure 7.

*Figure 7: FCI Scores for Treatment Group 3 before and after the treatment.*

Based on a dependent sample t-test, Treatment Group 3’s pre-FCI scores (M=19.30, SD=6.42) were significantly lower when compared to Treatment Group 3’s post-FCI scores (M=21.67, SD=6.02), t(53)=-5.03, p<0.001. These results offer validity to using the encoding treatment in a second year physics course.

To test this validity of the encoding treatment in a second year physics course we compared Treatment Group 3 to Comparison Group 1 and Comparison Group 2. The investigators attempted to find another Comparison Group comprised of second year physics students but were unable to do so. Neither Comparison Group 1 or Comparison Group 2 was statistically similar to Treatment Group 3 and both comparison groups were for first year physics students.

Treatment Group 3 (M=19.30, SD=6.42) was not statistically similar to Comparison Group 1 (M=9.61, SD=4.91) on pre-FCI scores based on an independent sample t-tests (t(96.97)=8.54, p<.001). Treatment Group 3 (M=19.11, SD=3.25) was also not statistically similar to Comparison Group 1 (M=17.59, SD=3.17) on pre-CTSR scores based on an independent sample t-test (t(98)=2.37, p=.020. This meant that Treatment Group 3’s students were not similar on pre-FCI and not similar on their scientific reasoning skills when compared to Comparison Group 1. We therefore concluded that we could compare Treatment Group 3’s post-FCI scores to Comparison Group 1’s post-FCI scores, see Figure 8, however the results
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should be interpreted based on the previous information that the group’s are not similar populations and we would expect Treatment Group 3’s post test results to be higher than

![Graph of Treatment Group 3 Post-FCI Scores](image1)

![Graph of Comparison Group 1 Post-FCI Scores](image2)

Comparison Group 1’s (Coletta and Phillips, 2005; Coletta, Phillips, and Steinert, 2007).

*Figure 8: Post-FCI for Treatment Group 3 and post-FCI for Comparison Group 1*

Based on a directional independent sample t-test, Treatment Group 3 (M=21.67, SD=6.02) had higher post test results compared to Comparison Group 1 (M=14.04, SD=5.67), t(98)=6.481, p<.001. As predicted, Treatment Group 3 had significantly higher post-FCI test results. This does offer some validity to the encoding treatment being used in a second year physics course although other factors may have contributed to these results.

Treatment group 3 was also compared to Comparison Group 2. Treatment Group 3 (M=19.30, SD=6.42) was not statistically similar to Comparison Group 2 (M=8.99, SD=3.81) on pre-FCI scores based on an independent sample t-test (t(74.07)=10.80, p<.001). Treatment Group 3 (M=19.11, SD=3.25) was also not statistically similar to Comparison Group 2 (M=13.95, SD=3.38) on pre-CTSR scores based on an independent sample t-test (t(73)=6.104, p<.001. We therefore concluded that we could compare Treatment Group 3’s post-FCI scores to Comparison Group 2’s post-FCI scores however the results should be interpreted based on the previous information that the group’s are not similar populations and we again expected Treatment Group 3 to outperform Comparison Group 2, see Figure 9 (Coletta and Phillips, 2005; Coletta, Phillips, and Steinert, 2007).
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Figure 9: Post FCI for Treatment Group 3 and Post FCI for Comparison Group 2

Based on a directional independent sample t-test, Treatment Group 3 (M=21.67, SD=6.02) had significantly similar post test results compared to Comparison Group 2 (M=23.19, SD=5.46), t(149)=-1.578, p=.117. Comparison Group 2 and Treatment Group 3 actually had similar post test results. The investigators again can’t really put a lot of meaning behind this comparison as it is a second year course compared to a first year course.

Figure 10: Correlation is weak at r(77)=.079
Correlation is again weak at r(77)=.141

Uniformly we observed that there isn’t a strong indicator of student performance from the quality of an encoding task. This suggests that students are acquiring their performance increases from other classroom attributes. By viewing samples of student responses (See Figure
11 with more in Appendix F), there is a huge amount of subjectivity in possible grading outcomes from such a personal task as student’s put importance on what they deem necessary to understand the material.

*Figure 11:* Samples of student encoding sheets.

This tool was extremely valuable to the instructors though for much the same reason. As the task was designed to be a fast, accurate, and concise representation of work that sometimes took weeks to fully expose. Investigators were able to quickly see whether students were acquiring knowledge that was intended or missing the objective of the activity. Because the responses were student generated we were able to verify the effectiveness of the delivery method. Although the information was important, there was not a strong correlation to student grade:

<table>
<thead>
<tr>
<th>Student</th>
<th>2-D Motion</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>deployment</td>
<td>review</td>
</tr>
<tr>
<td>Student S</td>
<td>2 2 2 2 2 1</td>
<td>83</td>
</tr>
<tr>
<td>Student T</td>
<td>2 2 2 2 3 1 1</td>
<td>87</td>
</tr>
<tr>
<td>Student U</td>
<td>3 2 2 2 2 2 2</td>
<td>83</td>
</tr>
<tr>
<td>Student V</td>
<td>2 2 2 2 2 3 2</td>
<td>100</td>
</tr>
<tr>
<td>Student W</td>
<td>3 2 2 2 2 2 2</td>
<td>100</td>
</tr>
<tr>
<td>Student X</td>
<td>2 2 2 2 2 3</td>
<td>83</td>
</tr>
<tr>
<td>Student Y</td>
<td>3 2 2 2 3 2</td>
<td>87</td>
</tr>
<tr>
<td>Student Z</td>
<td>3 3 3 2 3 3 2</td>
<td>96</td>
</tr>
</tbody>
</table>
Table 2: A table comparing the different scores on encoding and exams. Note Student V scored lower on the encoding, but did better on the exam compared to Student Y.

As an example Student Y had very high scores on both the deployment and review encoding activity receiving a total of 20 out of 21 points however scored an 76% on the unit test, whereas Student V scored 15 out of 21 yet got 100% on the test (See table 2). This indicates the complexity of student learning and shows that our treatment does not fully encompass everything students are processing. Our treatment was not a comprehensive evaluation of student cognition, rather a brief, concise attempt at improving student recall and conceptualization.

Overall, these results show that the implementation of the encoding treatment could be beneficial to students in both first year and second year physics courses. All treatment groups showed an increase of physics knowledge based on the FCI pre and post-test scores with an average normalized score gain of 0.3933. Unfortunately, these results cannot entirely be attributed to the encoding treatment. Further research in more classrooms over the course of a few years would need to be carried out before the investigators could exclusively contribute the encoding treatment to being effective in a physics classroom.

**Qualitative Data analysis:**

While the results above show moderate improvement many of the most significant indicators of the treatment came from sitting down with students and asking them about it. The investigators strongly support the implementation of the treatment according to voluntary information provided by students below. Student identities were replaced with pseudonyms.

**Investigator 1 qualitative data analysis:**

The number of students in the study group was small with only 20 of a possible 110 students agreeing to participate. Though initially interested in the study, as many had enjoyed the first unit and the Modeling methods in class, interest seemed to wane and students opting into the study comprised a small percentage of my classes.

With the limited student buy-in, large numbers of students in each class would take the time set aside for encoding to be distracting or otherwise “tune out,” which could disturb the students participating in the study. Despite these challenges, students in general found the encoding helpful and had positive reviews of the technique. Here are some quotes from the Post-Treatment Survey (Appendix A).

Responses to the question: *In what way did the encoding help you ‘put the pieces together’ in our physics units?*

David: “It allowed me to connect everything we learned in the unit”
Erwin: “Encoding allowed me to incorporate the same autodidactic process that I used to learn the information, to recall the information, which to me is more valuable”
Stephen: “It [encoding] was a nice refresher and allowed me to think more about it myself”
Voltaire: “It got all the ideas written down so I could see the connection between things.”
Camille: “It provided an organized format to arrange thoughts into”

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Richard: “It just help makes sense (sic)”

Students were overall positive with respect to the utility of encoding and spending time to construct their models.

Responses to the question: Did you notice a change in your performance in class you could attribute to encoding?

Emmy: “I noticed that I learn things more fully when I encode”

Chandra: “Yes, I can’t do nothing [sic] and expect to pass. It helped”

David: “Yes, I could understand the material better.”

Vera: “No.”

Kiersten: “The encoding didn’t make a huge change in performance”

Albert: “Yes, in this class only, though when we started doing them I grasped the general concepts better”

Stephen: “Not really, it helped bring back memories quicker, and allowed me to spend less time thinking”

This question had a much larger spread in their thoughts. Some students gave a decidedly no answer, and the last respondent seems to undervalue the encoding technique with its aid of bringing back memories and not fully understand the significance the encoding had on his learning.

Excerpts from video interviews:

Subject 1: Emmy was a senior and a high functioning student, scoring 20 out of 24 on the CTSR and 11 out of 30 on pre-FCI compared to averages of 15.9 and 7.9 respectively. Emmy earned an A throughout the course though earned a below-average post-FCI score of 18 out of 30.

Describe the similarities or differences you used.

“Taking notes is taking notes, but this was more how you arrived at a concept instead of just here’s information, copy it down and learn it. This was more of us recording our thinking process and how we arrived at different things.”

Did you notice a change in your performance in class you could attribute to encoding?

“Yes, things made a lot more sense if I wrote them down, in the way I was thinking. At first I tried to take notes like it was a different class, just to copy things and I didn’t learn anything that way, so yeah, this worked well.”

In what way did the encoding help you “put the pieces together” in our physics units?

“Everything kinda tied together a lot of times. Being able to refer back to the notes I had taken previously helped to develop the new concepts. And again, the notes are just more of how I was thinking so it’s easier to understand myself.”

What was the highlight and low point of encoding for you?
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“Highlight, not only did I learn what I needed to learn, but it was easier to remember it and use it with other ideas and concepts not immediately after I learned it. I didn’t have any low points at all.”

What major problem have you encountered and how did you deal with it?
“I think for me, it was keeping my notes straight, because I guess I wrote them the way my mind works which is a little sporadic and everywhere. But that wasn’t too hard, I just had to go through my notes after writing them and sometimes rewrite them and get rid of things I didn’t need at all.”

Subject 2: Enrico started the course with a CTSR score of 15 out of 24 and below average FCI of 7 out of 30. Enrico earned an A throughout the course and earned a 27 out of 30 on the post-FCI.

Did you use the encoding for other classes?
“Absolutely not. This was the first approach I’ve seen of anything like this in a class.”

Describe the similarities or differences you used.
“In here, I found the entire class was autodidactic, rather than just having a lot of information spewed out and recording it, I had to work towards it myself. With a few key points I figured things out and wrote down what I needed to, whereas getting all the information and not being able to apply it and get a deeper understanding of it (in other classes).”

Did you notice a change in your performance in class you could attribute to encoding?
“Yes, like I said with the whole autodidactic sense of the class it was nice to recall from my own memory rather than going through some premade note sheet and that kept all the information fresh and helped me from making stupid mistakes. Made sure I checked everything before turning things in.”

In what way did you find the whiteboard review before quizzes and exams helpful?
“Whiteboard review was nice because it gave several perspectives on how to do things right and a couple ways that people did it wrong. Whether I was right or wrong population varied, but working through with the class and Mr. Scott, the right answer always presented itself towards the end of the discussion and the wrong answers were weeded out quickly. But multiple ways to get the answer were present and it was nice to see those.”

In what way did the encoding help you ‘put the pieces together’ in our physics units?
“Being able to recall the information from memory and having already used and applying it umm, and kind of breaking it down into a simple distillation from all the different applications of a quiz, worksheet, practicum, it helped to get the information fresh in my mind and it made everything easier.”

What was the highlight and low point of encoding for you?
“Highlight was being able to review the information myself and mentally knowing I knew the information. And realizing I knew the information before the quiz. Some of the low points it felt like I didn’t have enough information, that I wasn’t recalling enough of the information, but that’s purely an opinion.”

What major problem have you encountered and how did you deal with it?
“My major problem was working too fast, skipping details, not necessarily making assumptions but not breaking things down the way it should have been. Dealing with it, everything we did in class, worksheets, encoding, whiteboarding, it all helps to make sure I’m going through the processes getting every little piece I need to and once I’m proficient with everything, I can say, ‘I don’t need to use this equation, I don’t need to do all the work I can start generalizing here and there.’ But being able to see where I’m going wrong and where I need to spend more time was my biggest challenge and biggest victory because that helped me where I needed to improve and then I did.”

Final thoughts:
“The way the class was taught with the encoding, with the autodidactic sense to it, it was my most challenging, most fun, most enjoyable class this year. It was nice to know I could figure this stuff out myself and then after figuring out for myself, it was an even better sense of accomplishment to see it work. In physics you can tell if something works, that’s convenient.”

Students felt our encoding was a great idea, but my implementation needed support and more forceful intervention on my part to corral stragglers. Personally, I feel students taking summative notes with a guideline at crucial moments in a unit is clearly a powerful tool for everyone. Mistakes were made with my implementation and my usual ‘hands-off and let them figure it out’ strategy was too aloof and above their heads for the treatment to really sink in and make the kind of gains I am sure it could with proper scaffolding and rigor. When I implement this in the future, I will be sure to be more directly supportive and involved with their usage and participation with the encoding.

Investigator 2 qualitative data analysis:
In an effort to capture as many samples as possible I made the treatment a regular classroom task. This meant everyone had to do the treatment whether voluntarily participating in the study or not. Classes routinely had over 90% completion rates for the encoding assignments. Initially I would give examples of possible items to be included on the encoding sheets, with an intention to wean them off of the help and allow them to complete the encoding sheet all on their own. However students often complained or showed a complete empty look when given the task and left to work. Around the middle of the year I gave an attempt to give some guidance while still allowing them the chance to generate their own encodings. The method I employed involved writing up a sample set of models on a template that was projected onto a smart-board. Then I would clear the screen leaving it blank and hand out the encoding sheets. This seemed to give an adequate amount of recall for students and
they were able to complete the encoding tasks with good results. Rarely did students require more than a quick sketch of the lab setup or an empty skeleton of a graph with labeled axis to jog their memory. However, it was surprising that with no prompting whatsoever students would briefly fiddle around completely blank not even be able to generate a sketch of the lab setup or one graph that resulted. They were simply blank, with no anchor or model in their head. To be fair, this never lasted more than a few minutes, for a quick look around at nearby equipment or left over whiteboards usually was enough to initiate recall of the model. Near the end of the mechanics units I was feeling really disheartened by the entire notion of encoding having an effect on student conceptual understanding. The largest revelation for me came during the student interviews. At the conclusion of the interviews I asked if they could make a recommendation to me personally for the following years students to either: continue the practice of encoding unchanged, increase the frequency, decrease the frequency, or not do the activity at all? Unanimously the result was to continue the encoding with the same frequency. Even the students who complained the most about the task, thought it was a worthwhile experience enough to recommend it for their peers.

Students responding to the prompt: If you could make a recommendation to me for next year, should students do this encoding activity: more, less, the same, or not at all?
Student (1): I think you should do it the same amount, I don’t think it needs to be more frequent or less frequent cause it’s kinda like a review sheet in a way without having multiple pages of a review you just can go over what you need to know on the test and so I thought the amount we did it was good.

Student (2): I think you should do it again just not change anything.

Student (3): I think they (next year's students) should do this and about the same amount.

Student (4): I would say definitely do these worksheets, ah, I think they are very helpful and they don’t take a long time at all maybe five minutes so yeah, I’d say definitely do it.

It was this testament alone that convinced me that this needs to be a regular part of my classroom activities. In general I feel like the encoding exercise had a positive benefit to students ability to recall material.

Investigator 3 qualitative data analysis:
To increase the participation rate of this project, the encoding sheets were assigned to students as a homework grade. This meant every student, whether participating in the study or not, had to fill out an encoding sheet or create their own before each quiz and each unit test. The classes routinely turned in over 85% of the encoding sheets with a handful of students going away from the box template sheet and creating their own encodings in a way in which they found the most benefit to them.

During the first unit and halfway into the second unit (about 5 encoding sessions) the encoding sessions were done group style with each student having their own encoding sheet in
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front of them as the class discussed what was important in the unit and what they should write down. I led the students to what I deemed important during these times and made sure they understood the rubric. Each student had a copy of in their folder for class as well as numerous copies were displayed around the room. After the students gained knowledge of what was expected to be produced on their encoding sheets, the encoding time turned into a homework assignment that was to be done the day before each quiz or test and turned in to me before the students took the quiz/test the next day.

This homework method was used the majority of the year up until the last few encodings when students started doing them as class work (about ten minutes at the end of the class before a quiz/test) but only allowed to talk to their nearest neighbors. If the student did not finish the encoding they had to finish it as homework. Students were still required to turn these sheets in the following day before the quiz/test. This method, as students claimed during classes, helped them to remember more information from the unit due to them talking with their peers which resulted in each student recalling different aspects of the unit and then sharing with the others in the small groups.

Select students were then interviewed at the end of the year and asked about their personal feelings as related to the encoding treatment. (See Appendix A for a full list of the interview questions). Here is a brief description of select interviewees and their responses on some of the interview questions:

Marie Curie is an all A student with a 5.0 G.P.A. out of 5.0 and was the number one student in her class this past year. Marie had a 65% for her encoding grade, however she would often only turn in the very final encoding sheet which she worked on the entire unit so her percentage is skewed lower than what her effort actually was on the encoding sheets.

Maria Mitchell is mostly an A and B student with a few Cs. Maria had a 69% on her encoding sheets and this is a fair grade for her. Maria turned in the majority of her encoding sheets, she had three missing encoding sheets throughout the treatment.

Erwin Schrödinger is mostly a C student with the occasional B and D grade. Erwin had a 10% for his encoding sheet and only turned in a total of three encoding sheets.

Here are the responses from the interview questions:
“Did you notice a change in your performance in class you could attribute to encoding?”
Marie: I think that the first, ummm, unit, the kinematics unit or whatever, was a little bit of a struggle..because I didn’t really know like oh, like I actually had to sit down and work through this or I am not going to understand it. Um, and I think I did relatively well on the first test but I noticed a lot of improvement on the next test because of the encoding.

Maria: No, not really. I mean we did them from the beginning didn’t we? Interviewer: I believe we started them on the third unit. Ummmm......Yea I think I got a little bit better overall.

Erwin: Well ya, it definitely helps if you take the notes. but ah...overall I still didn’t do well with it but....Interviewer: And why do you think that is? I..I guess that just isn’t how my mind works with summarizing at the end. I guess I need to kind of take it as we go. Interviewer: Did you ever think
Erwin:
We would...I mean go pretty in depth on the note taking..like... Putting

Maria:
Umm, Jus

Marie:
Umm, the first time I got a 100 on a qui

Response to the question “What was one highlight of encoding for you?”
Marie: Umm, the first time I got a 100 on a quiz was probably, and knowing that I spent the night before and the week before kind of going over, umm, those concepts and teaching, like teaching, umm, not only like, not teaching, but like reinforcing those ideas that we learned in class.

Maria: Umm, Just being able to really...separate....like information in my mind more so than just having it all at once kind of thing....I guess....was probably the best just because I liked being able to summarize all of it... like all together at the end and just be like ok....this is the general stuff that I need to remember and then having the umm.... mathematical models in comparison to the umm... because like I think up here (points to top box on 3 box template) I usually did like graphs and stuff and then down here I would do umm...equations (points to middle box on 3 box template) so I mean I just prefered to be able to see it separated that way instead of having it all like all over the place.

Erwin: We would...I mean go pretty in depth on the note taking..like... Putting down all of the mathematical examples and everything really helped me....like just having the equations there and seeing examples of how to use it.

“In what way did the encoding help you ‘put the pieces together’ in our physics units?”
Marie: So I kind of, I kind of tried to start with like the graphs because that is always where we, um, began the lessons and so I would, umm, even if I didn’t like turn them in on my encoding sheets I would just kinda work through those and say like ok, what is the relationship between x and y, what’s the PMS, the physical meaning of the slope. Umm and then after that I kind of attached it to conceptual ideas you know via physicsclassroom (www.physicsclassroom.com), umm, and then...tied....in the vocabulary. So I guess it really like it kinda brought everything together in the sense that it kinda forced you to work through everything you know, because you had to include the graphs, you had to include, you know, force diagrams, and you needed your terminology and everything so...

Maria: Umm, well like this note taking, how did that help? Interview: Yea. Umm, I really liked the third one just because umm....or this whatever Interviewer: The three box? Yea, umm cause a...just because I didn’t like having to...do...the motion maps/force diagrams but I think that is just cause that is four boxes and this is three and I like three better I guess...I don’t know.

Erwin: Well in this class just a lot of it...pretty much everything fits together that you have to..like towards the end there are a lot of big problems that use multiple parts of each lesson so it did help with that. Interviewer: How did it help with that? Just reviewing everything so you remembered how to do it for the next unit to me.
Response to the question “What was a low point of encoding for you?”
Marie: Umm, it took time, you know, it wasn’t... you know, just sit down and like ok, like lets get this done in ten minutes. Like for me to fully understand the concepts it took me about an hour...two hours and it was difficult when I had you know other assignments to do so sometimes it got put on the back burner.
Maria: Umm, because it is so open like I never knew what to write down. Sometimes I ended up just writing down a bunch of stuff that wasn’t actually important for the.... whatever it was quiz or test whatever was coming up so I mean.... It... that’s just me probably more than anything so I mean.... yea.
Erwin: Low point... was ah... that we didn’t, I don’t know, take more notes.

There were more student responses that echoed these three student’s responses. The overall feeling from the students though was that they saw the benefit in the encoding sheets and they all suggested that this process be continued with future classes. There was a lot of students that also felt like Maria with the openness of the notes and not knowing exactly what was to be written down. This did result in a lot of the encoding sheets having random information that the students thought was important to the unit but in reality wasn’t that important to the conceptual and mathematical understanding of the unit’s concept. I feel this could have been corrected with more direction by the investigator and if this correction was instituted, the quality and the benefit of the encoding would increase with the students.

There was also the issue of only teaching AP Physics 1 classes and the time allotted for in-class encoding was limited by the amount of material the classes had to cover in the year. I think if we could have spent more time as a class going through the encoding sheets and summarizing them on whiteboards, the students would have had more invested in the encoding exercise. Also, the review process is crucial for the encoding to set in completely.

I plan on continuing the encoding process with next year’s classes with the changes stated above. If the encoding turns out to be a bigger benefit with the proposed changes, then it will be continued indefinitely. If the encoding doesn’t benefit the students as much, then alternative methods/focuses of encoding will need to be looked at and explored.

**Investigator 4 qualitative data analysis:**

As this is a second year course and the handouts and rubric was somewhat directed towards a first year course I had to modify some of the material to fit my students needs. In the first year courses a paradigm lab is the initial experience in the Modeling Method yet all of my students had the paradigm lab in the previous year.

Students encodings were associated with a grade within the class so participation was high. Throughout the year there were 3 major comments/requests during the treatment. The first comment was: We already take notes so why are you making us do it a different way. In general my reply was that the study was timing of encoding and these specific notes are summative reflections of their own notes. The second comment was a request that their regular notes be counted towards the study as the students felt they were taking summative
notes already in preparation for tests. To this, the usual reply was that the student was “amazing and I am glad you are so thorough in your note taking skills.” The third response was from students who never took notes and expressed their derision of mundane tasks. This put the students in three categories: First category is the avid notetaker where everything is journaled and even side conversations were subject to being on record. Second, the student who will not take notes even if there are point deductions, and finally the last group who will encode following the rubric to satisfactory levels. When the final copies were collected from students some of the artifacts that were 50 pages in length.

The encodings were not graded until the year, but during the year while walking around the room scoring homework the students were asked to show their notes so participation could be gauged for the study to that point. Around 75% of the class participated regularly in the encoding process, but around the end of the year it was noticed that more participation was evident and students asked that their past unit encodings be looked at because they had just completed them. They thought the encodings were being graded the whole time and they desired to gain points even though they were late. The students were asked why they were working on notes from past units and the students indicated they were using the encoding process as a method for studying for the AP Test. It seemed that the students thought particular method of encoding was effective enough to revisit old materials to prepare for a summative exam like the AP Tests. When the encodings were collected at the end of the year there was an 85% completion rate. The 15% generally were students who also had an extremely poor homework grade.

To a large extent I believe that that the encoding process was beneficial to my students. In upcoming years I will be using this format or a modified form of this encoding process with students during the Modeling Instruction process.

Conclusion:

Encoding information in the form of notes is an important process in the recall of material. Socially and constructively building a model-centered understanding of our physical world is an important and difficult task. It is important that physics instruction incorporates these two practices together because this treatment attempts to combine two well-known and proven methods, Modeling Instruction and encoding. Modeling Instruction by itself provides gains in student understanding of Newtonian mechanics. Our study suggests that encoding your own notes increases student recall. There is a weak statistical improvement for students who use encoding exercises over students who do not. The results of our study indicate a quantitatively mixed relationship to improving student performance with our prescribed treatment. This treatment did yield gains higher than one of our comparison group and lower than the other comparison group. However, are the gains entirely attributable to the treatment and would our student’s gains be as high as they are without the treatment? There are too many uncontrollable variables to quantitatively evaluate this data and claim that it worked or
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didn’t work. However, qualitatively our student’s expressed that the treatment helped them better understand and focus on the important Newtonian concepts and suggested that we continue the treatment in future years. We as investigators felt that this qualitative evidence was the biggest reasons to continue using this treatment and for suggesting to other teachers that they adopt this treatment into their own teaching method.

**Implications for Future Instruction:**

From qualitative analysis of students’ opinions, the researchers found the encoding treatment to be worth continuing and expanding. We now have a deeper insight into the treatment and suggest the following retainable aspects of the method:

1. The frequency of performing written encoding tasks before quizzes and tests was spaced well. This timing limits the amount of time the instructor spends on formative assessments and provides the students a good chance to reinforce and set an order to their learnings. Some advantage was observed by allowing a day’s worth of discussion and digestion between the encoding task and assessment instead of turning the encoding sheet in moments before the assessment.

2. Four Box (review) template: The researches agree that a single template used twice per unit would be more beneficial than changing the template from the deployment template (Three Box) to the review (Four Box) templates. The Four Box (review) template would be more beneficial at both deployment and review because it includes more detail and greater diversity of the models being developed.

3. Investigators found the simplicity of the encoding task very non-invasive for students. It does not require a large portion of time, nor does it require any lengthy write-ups or solutions. It is meant to be a concise, powerful, and efficient summary of the learnings that happen in class.

However there are some observations that the researchers would like to share which may improve the effectiveness of the encoding task.

1. Students will benefit from more time to review the notes in class. While the frequency of the task was adequate, investigators noted that collecting encodings immediately before assessments did not leave time to evaluate the encodings. Critical observations of student comprehension need to be evaluated with time for intervention before the summative assessment. The investigators think a days time would be adequate for evaluation of student encodings and to provide intervention before summative assessments.

2. Teachers should establish high expectations for the completion of the encoding tasks at the beginning of the year. Teachers should clearly define the expectations of the caliber of content that is expected within the first two units and with continued critique and a nominal completion score, to increase student participation.

3. Due to time constraints, researchers would occasionally have students complete the encoding outside of class. As with most facets of Modeling, we feel the class
environment is the best environment for student formation of ideas with their group and the teacher present. Therefore enough time to at least discuss or share the content of the encoding task should be incorporated into class time.

4. Researchers found the nomenclature of the encoding sheet was a little challenging for some students. We recommend a more student friendly language that is immediately clear to students what is expected in the sections of the encoding template and is not specific to any unit; for example, our four box template had the box motion map/force diagram which didn’t fit with a lot of the later units and students were then confused with what to write in this box.

5. Researchers feel a grade for the encoding task is unnecessary except as a motivational tool to keep completion rates high. Encoding is a personal process and students will find different sections of the model more or less difficult which will require varying degrees of thought on their part for them to grasp the ideas. Instructor discretion of what is complete and not complete can also be used in the determination of a score. Mainly this would be used to keep students’ efforts on the assignment consistent with classroom expectations.

6. Giving this assignment to students with less teacher guided content on each session would allow for more original student generated encodings. The researchers gave in to the notion that this assignment was too open ended and would often help students “remember” parts of the unit. The purpose of encoding is for students to engage with the material and create a summary of their understanding thus pushing the activity to higher echelons of Bloom’s taxonomy. To keep the activity cognitively original the instructor may prompt the students with examples and setups but should avoid writing things down for students to look at and then copy down like a scribe.

Implications for Further Research:

Encoding and Modeling are a rich terrain to continue research. We are proud to be part of the Physics Education Research community in the small part we have played. With the treatment completed, we would like to offer some guidance for future researchers regarding investigations which might align with our work.

A proper instrument for assessing second year students growth. There seems to be sort of a ceiling that students will naturally hit and any gains beyond that level require a significant amount of additional physics knowledge to achieve. Incorporating a better assessment instrument for second year physics students is greatly needed.

Another possible contributing factor to be investigated further is frequency. Does the frequency of encoding have a significant impact on conceptual understanding? To what extent is frequency related to FCI gains? There is plenty of research that encoding improves student recall, but at what capacity does the task start to become laborious and mundane versus rich and rewarding? In an environment that is ever increasing in competition for minutes with students, instructors are always searching for things that have the greatest gain for the smallest
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use of time. From our limited understanding of this effect we feel like twice per unit has enough of an impact to make it worthwhile and is easy enough to implement without disrupting the efficient flow of a unit.

While collaborating on grading the notes with the rubric we noticed there was a possible connection between word count and substance. We noticed students who wrote copious amounts often had less substantial inclusions in their notes. We think it could be of value to study the relationship between simple statements and paragraph length notes. As Einstein said, “The supreme goal of all theory is to make the irreducible basic elements as simple and as few as possible without having to surrender the adequate representation of a single datum of experience.”

Acknowledgements:

We would like to extend our warmest gratitudes to Colleen Megowan for her insight, expertise and consistently high expectations. Her help and indefatigable guidance were integral to the completion of this work. Melissa Girmscheid, Brian Roach, and Kevin Welch for their gracious sharing of comparison data. Jane Jackson for her tireless contributions and arrangements to get us all together and keep this program running. Alicia Hawley and Morgan Texeria for their logistical support and being advocates of students to the Graduate College. Our Committee members: Dr. Carl Covatto and Dr. Stephen Krause and our committee chairman, Dr. Robert Culbertson for their continued dedication to the MNS program and their compassion to teachers and students everywhere.

Bibliography

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Appendix A: Post Treatment Interview questions.

What was your overall grade in the course? Is this typical with other classes?
__________________________________________________________________________

How often did you participate in the encoding? Did the frequency change over the course?
__________________________________________________________________________

Did you use the encoding for other classes?
__________________________________________________________________________

Describe the similarities or differences you used.
__________________________________________________________________________

Did you notice a change in your performance in class you could attribute to encoding?
__________________________________________________________________________

In what way did you find the whiteboard review before quizzes and exams helpful?
__________________________________________________________________________

In what way did the encoding help you ‘put the pieces together’ in our physics units?
__________________________________________________________________________

What was the highlight and low point of encoding for you?
__________________________________________________________________________

What major problem have you encountered and how did you deal with it?
__________________________________________________________________________

What have you learned from your mistakes?
__________________________________________________________________________
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Appendix B: First encoding template.

<table>
<thead>
<tr>
<th>Model Development (Lab) / Important Concepts:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Mathematical Models(Lab) / Corrections (Whiteboarding):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
Summary / Connections: (from whiteboarding discourse)

Appendix C: Scoring Rubric for first encoding.

<table>
<thead>
<tr>
<th>Points</th>
<th>Conceptual (Lab and WB)</th>
<th>Mathematical models (Lab)</th>
<th>Summary (Lab and WB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Exceptional Examples and records which include detailed diagrams and descriptions of all aspects of model</td>
<td>Exceptional understanding of lab workings / phenomenon. Math models clearly developed and unify lab data to general model</td>
<td>Exceptional description of main concepts and 1 connection to real life</td>
</tr>
<tr>
<td>2</td>
<td>Adequate Examples and records missing key details or incomplete description of model</td>
<td>Adequate Display of lab phenomenon and explanation of lab data. Missing key details, diagrams, or model features</td>
<td>Adequate Missing some main concepts or missing necessary details</td>
</tr>
<tr>
<td>1</td>
<td>Unsatisfactory Notes disorganized, fail to elaborate concepts or provide sufficient model development</td>
<td>Unsatisfactory Little to no evidence of development of mathematical model</td>
<td>Unsatisfactory No connection made to real life experiences and model incomplete</td>
</tr>
</tbody>
</table>
Appendix D: Review encoding template.

| Graphical Models: | Mathematical Model: |
### Appendix E: Rubric for the review encoding sheet.

<table>
<thead>
<tr>
<th>Points</th>
<th>Graphical models / corrections</th>
<th>Mathematical Models</th>
<th>Pictorial Models</th>
<th>Verbal Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Exceptional No corrections necessary or exceptional corrections including color differences, notations, drawings, with possible elaboration of incorrect prior model usage</td>
<td>Exceptional understanding of lab workings / phenomenon. Math models clearly developed and unify lab data to general model</td>
<td>Exceptional Examples and records which include detailed diagrams and descriptions of all aspects of model</td>
<td>Exceptional description of main concepts and 1 connection to real life</td>
</tr>
</tbody>
</table>
### THE EFFECT OF PERSONAL DELIBERATE NOTE-TAKING (ENCODING)

<table>
<thead>
<tr>
<th></th>
<th>Adequate Corrections made without adequate notations, differences, or changes. Model usage is unclear or ill-detailed</th>
<th>Adequate Display of lab phenomenon and explanation of lab data. Missing key details, diagrams, or model features</th>
<th>Adequate Examples and records missing key details or incomplete description of model</th>
<th>Adequate Missing some main concepts or missing necessary details</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Unsatisfactory Missing, trivial, or no corrections. Few to no insight into the model or extending questions.</td>
<td>Unsatisfactory Little to no evidence of development of mathematical model</td>
<td>Unsatisfactory Notes disorganized, fail to elaborate concepts or provide sufficient model development</td>
<td>Unsatisfactory No connection made to real life experiences and model incomplete</td>
</tr>
</tbody>
</table>

**Appendix F:** Example Student Encodings.
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Model Development (Lab) / Important Concepts:

Mathematical Models(Lab) / Corrections (Whiteboarding):

\[ \text{Force} = \text{mass} \cdot \text{acceleration} \]

\[ a = \frac{\Delta v}{\Delta t} \]

\[ F = m \cdot a \]

\[ N = K_g \cdot m \cdot a \]

\[ K_g = N / m \cdot a \]

Example:

\[ a = 2.0 \text{ m/s}^2 \]

\[ m = 4 \text{ kg} \]

\[ F = (4)(2) \]

\[ F = 8 \text{ N} \]

Find normal force if

\[ \text{m} = 80 \text{kg} \text{ and } a = 1 \]

\[ F = m \cdot a \]

\[ F = 80 \]

\[ F_n + F_g = 80 \]

\[ F_n + (-800) = 80 \]

\[ F_n = 880 \text{ N} \]
Summary / Connections: (from whiteboarding discourse)

Force \times acceleration by a factor of mass. If I push a calculator, it does not weigh a lot so I could push with little force. If it was an elephant, the force would have to be a lot bigger to make them accelerate 1 m/s².

Summary / Connections: (from whiteboarding discourse)

accelerating positive ×

mass + Normal Force

Higher reading on scale (++)

accelerating negative ×

mass + Normal Force

Lower reading on scale (--)++
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Model Development (Lab) / Important Concepts:

Mathematical Models (Lab) / Corrections (Whiteboarding):

\[ F = M \cdot a \]
\[ \sum F = M \cdot a \]
\[ \sum F = F_n + F_g \]
\[ N = kg \cdot \text{m/s}^2 \]

Summary / Connections: (from whiteboarding discourse)

If you push a box of tissues, it takes almost less force to make it accelerate than it would take to push a fridge.
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Model Development (Lab) / Important Concepts:

Mathematical Models (Lab) / Corrections (Whiteboarding):

\[ \Sigma F = m \cdot a \]
\[ F_g = m \cdot a \]
\[ \text{Unit IV} \]

Summary / Connections: (from whiteboarding discourse)

Slope is equivalent to slope of force. Acceleration.
Model Development (Lab) / Important Concepts:

![Diagram of force diagrams and equation showing mass in Newtons (N) and acceleration in meters per second squared (m/s²).]

Mathematical Models (Lab) / Corrections (Whiteboarding):

![Diagram of equation ΣF = ma and additional annotations showing slope and mass relationship.]

Summary / Connections: (from whiteboarding discourse)

- Grocery Bag Problem:
  - max force: 250 N
  - mass: 20 kg
  - acceleration: 5 m/s²

- Will bag rip?
  - ΣF = 20.5 \times 100 N
  - 100 = 200 \times \text{FN}
  - 100 + 200 = \text{FN}
  - \text{FN} = 300 N \rightarrow Bag will rip

- Objects are not accelerating forces are no longer equal

- Net Force: = \text{mass} \times \text{acceleration}

- Acceleration is normally not constant or equal to zero in (most) real-life situations
Model Development (Lab) / Important Concepts:
\[ f(N_1, N_2, k) \]

Mathematical Models (Lab) / Corrections (Whiteboarding):
\[ \sum F = ma \]
\[ F = \text{net force} \]
\[ v_f^2 = 2a \Delta x + v_i^2 \]

Summary / Connections: (from whiteboarding discourse)
If there is a net force, the object is accelerating.
\[ mg = 65 \text{ kg} \]
\[ \Delta x = 10 \text{ m} \]
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Model Development (Lab) / Important Concepts:

When released, the object will go whichever direction it was going before.

Mathematical Models (Lab) / Corrections (Whiteboarding):

The kid in Figure 1 is going way faster than the kid in Figure 2 because the kid in Figure 1 has his knees pulled in and the other kid has his legs extended. This makes a difference because in the equation $F = \frac{mv^2}{r}$, when the radius is smaller (knees in/knees out), $mv^2$ is being divided by less, so the kid ends up going fast like in Figure 2, whereas in Figure 1 there is a larger radius so $mv^2$ is divided by more.

Score: 9/9
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Model Development (Lab) / Important Concepts:

Mathematical Models (Lab) / Corrections (Whiteboarding):

\[ \frac{\Delta N}{\Delta x} = \frac{y}{r} \]

\[ \frac{\Delta F}{\Delta x} = \frac{m}{t} \]

\[ \Delta N = \frac{y}{r} \]

\[ \Delta X = \frac{y}{t} \]

\[ y = \frac{\Delta N}{\Delta t} \]

\[ r = \frac{2\pi r}{2} \]

Summary / Connections: (from whiteboarding discourse)

When spinning on a swing, the farther your legs (r) are, the slower you go. The tighter your legs are, the faster you go. Your legs act as your radius. When you divide by a larger #, your force is lower, meanwhile when your radius is shorter, the larger your total force is.

Score: 9/9
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Model Development (Lab) / Important Concepts:

Motion is tangent

Tangent due to inertia

Mathematical Models (Lab) / Corrections (Whiteboarding):

\[ a = \frac{v^2}{r} \]
\[ \sum F = m \cdot a \]
\[ \sum F = \frac{mv^2}{r} \]

Summary / Connections: (from whiteboarding discourse)

If you are spacing something (like a tree) then if you stop the object will go tangent due to inertia.