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Diagramming and Text Marking: Supporting Students in Decoding Science Texts

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Abstract

Students all over the world face similar challenges analyzing science texts as the language of science contains abstract symbols and complex terms. The challenges are particularly acute for California traditionally underserved high school students partially due to insufficient modifications and accommodations. To facilitate equitable participation in STEM (science, technology, engineering, mathematics), this intervention is designed to enhance student's confidence in decoding science text at the organizational level. The action research investigated the relative efficacy of intervention via Diagramming and Text Marking, a subset of Directed Activities Related to Texts (DARTs). Review of the literature validated DARTs as an effective strategy in supporting students for learning-to-read and reading-to-learn science texts. Cognitive, affective and attitudinal feedback data, quantitative and qualitative, were collected during the 3-week intervention implementation. Analysis of intervention's outcome indicated a relatively statistically significant positive effect for Text Marking over Diagramming. A possible implication, pending further study, would be modifications that reverse the conventional high school physics textbook approach for problem-solving in which diagramming has been typically placed ahead of text marking.

1. Context and Problem of Practice

1.1. Context

This year, 2017, marks the 14th anniversary of the founding of ABC school (name has been changed for privacy protection), an independent charter high school in California. The school's mission is to prepare students for college admission and for success in college. The school opened in the fall of 2003 and currently enrolls about 345 students, 9th grade through 12th grade. In the school year 2016-2017, 92% of the student population was Hispanic (318), 7% African American (23), and 1% others. The student population is primarily inner city and low-income. Nearly 82% of students qualify for free or reduced lunch. Many parents and guardians are newcomers to the United States, have limited English proficiency, and did not have the opportunity to complete a high school education or attend college. Many of the students are among the first in their families to go to college. About 37% are English Learners when first enrolled at the school. More than half of the student population are English Language Learners or Redesignated Fluent English Proficient. Nearly 10% of the student population receives special education services.

ABC is situated near Silicon Valley. There are numerous and remarkable opportunities for technology and science employment in the area. Students could easily take field trips to visit the headquarters of some of the biggest STEM companies in the world in terms of market capitalization --- as of 2017 February 8th: Alphabet/Google

(GOOGL, market cap $564 billion), Apple (AAPL, market cap $693 billion), Chevron (CVX, market cap $210 billion), Cisco (CSCO, market cap $157 billion), Facebook (FB, market cap $387 billion), Hewlett Packard (HPQ, market cap $27 billion), Intel (INTC, market cap $172 billion), Netflix (NFLX, market cap $62 billion), Oracle (ORCL, market cap $164 billion), Tesla (TSLA, market cap $42 billion), Uber (est. $68 billion), and Yahoo (YHOO, market cap $34 billion). While there is large population of Latinos in the area, the number of Latinos in the tech sector is relatively small, around 8% to 13% (US EEOC, 2017). Many of these tech companies seek work diversity to promote equity. Internship opportunities are available.

Never in the history of ABC school has a student graduated from college with a degree in STEM (science, technology, engineering, mathematics) nor has an ABC student been interned/employed by one of the above tech companies.

My educational background is in physics and engineering. A significant portion of my professional career is related to software production. Some portions of my job experience involve quantitative feedback via 3D motion capture, efficient frontier computation for financial portfolio risk analysis, and data transformation for aggregation. My work could thus be characterized as predominantly STEM. Since 2014, I have been a physics teacher at ABC. My goal is to support ABC students in learning physics and possibly in pursuing STEM careers.

1.2. Problem of Practice

I have become aware that in the attempts to solve physics word problems, my first-generation students tend to struggle with the specialized vocabulary and condensed meaning of scientific text. I arrived to this inference by noticing the challenges faced by my students when reading tier-2 and tier-3 words. Tier-2 words are high frequency generic academic words such as 'investigate' and 'classify' These are words that are frequently used in academic discourse but not discipline-specific. Tier-3 words are low frequency discipline-specific words such as 'photosynthesis' and 'exogenesis' (Channel, 1981). My students frequently asked me for the meanings of Tier-2 words and nearly always asked me for the meanings of Tier-3 words. My students also struggled with the structure of science texts such as figures, captions and scientific symbols. Previously, the focus of my teaching has been on the content of science and less on the literacy of science. To provide better science literacy support for my students, I hope the action research would guide me on making modifications and accommodations that assist students in learning-to-read and reading-to-learn the language of science.

There are a number of known modifications and accommodations to support students in decoding science texts. Some of them are Frayer Model, Anticipation Guide, Four Corners, Picture Walk, Reciprocal Teaching, Listening Triads, Graphics Organizers, and Directed Activities Related to Texts (DARTs). For the Problem of Practice (PoP), the focus is on DARTS, particularly on a subset of DARTs which includes Diagramming and Text Marking: How modifications and accommodations via Diagramming and Text Marking can support students in decoding science texts.

My theory of action, in brief, is that if a teacher does provide support for students to analyze physics word problems via Diagramming and Test Marking then students will improve their skills in decoding science texts, leading to the enhanced ability to solve physics word problems.

The intervention implementation covered a span of three weeks. Students utilized Text Marking and Diagram Labelling activities (a subset of Direct Activities Related to Texts or DARTs) to analyze physics word problems. We examined three related physics topics: *work*, *power* and *energy*. I collected quantitative and qualitative data relating to cognitive, attitudinal and affective feedback in order to triangulate the relative efficacy of Text Marking versus Diagramming.

The overarching research question is "When instructional strategies include modifications and accommodations relating to Text Marking and Diagram Labelling, how would these approaches improve students' performance with regards to analyzing scientific texts?"

2. Literature Review

2.1. Introduction

California high school students need to pass a minimum of two years of science courses with laboratory activities in order to meet the University of California and California State University requirements for freshman admission (CA Dept of Education, 2005). One possible unintended consequences for these requirements is that California high school physics teachers tend to focus class instruction on doing science (e.g., laboratory experiment activities) instead of reading about science (Singer, 2006; Digisi, 1995), resulting in a low priority arrangement for tasks relating to science literacy. This has been particularly true for me. I have been teaching physics at a California high school for three years. During the first two years, I focused significantly on doing science instead of reading/writing/talking science. Now in my third year, I have learned more about my students' needs for science literacy. At my school, nearly all the students are first-generation students, with over 80% of the student population qualify for free or reduced lunch and about 75% of the students come from immigrant families whose home language is not English. While the school has been in operation for over 10 years, no student has earned a college degree in science. Given that the school's mission is to prepare students for college acceptance/success and given that STEM (science, technology, engineering, mathematics) offer numerous opportunities for students to fulfill potentials, I hope to find ways to support students for possible STEM careers, starting with further development of science literacy skills.

One of the reasons for me to examine science literacy is based on the literature review which indicates that many of my students have insufficient class time for science in their middle school years, partially due the No Child Left Behind (NCLB) initiative which focused on English and Math, but often at the expense of less class time for other disciplines including science (McMurray, 2008; Dolph, 2007). The literature review also indicates that the unique nature of scientific language often poses a significant challenge for many students, especially students whose home-language is not the same as the language used in school (Greenleaf, 2004).

There are dozens of known strategies that could be implemented to support students in science literacy, ranging from Frayer Model, Anticipation Guide, Listening Triads; Graphic Organizers, Directed Activities Related to Text (DARTs), and so on. The scope of this literature review to briefly examine these strategies then focus on a subset of feasible modifications and accommodations that best meet the current science literacy needs of my students.

2.2. Underserved high school students and Science Literacy

Maxwell (2014) notes that America's public schools are experiencing a significant increase in Latino student population. In California, Latino students comprised the majority of the population of students in public school. This is particularly descriptive of my school. Following is a statistics report published by the California Department of Education for the 2015-2016 school year with regards to ethnicity distribution:

Table 1: Ethnic distribution of students in California's public school for the 2015–2016 school year (California Department of Education, 2016)

Ethnicity	Number of students	Percentage
African American not Hispanic	361,752	5.81%
American Indian or Alaska Native	34,704	0.56%
Asian	551,229	8.85%
Filipino	156,166	2.51%
Hispanic or Latino	3,360,562	53.97%
Pacific Islander	30,436	0.49%
White not Hispanic	1,500,932	24.10%
Two or More Races Not Hispanic	192,146	3.09%
None Reported	38,810	0.62%
Total	6,226,737	100.00%

Per the California Language Census of Fall 2015, about 43% of the student population speak a language other than English at home, with Spanish being the most common. Following is data published by the California Department of Education for English learner data.

Table 2: Language spoken at home by California English learners
(California Department of Education, 2016)

Language	Percent
Spanish	83.5%
Vietnamese	2.2%
Mandarin (Putonghua)	1.5%
Filipino (Pilipino or Tagalog)	1.3%
Arabic	1.3%
Cantonese	1.2%
Korean	0.8%
Hmong	0.8%
Punjabi	0.7%
Russian	0.6%

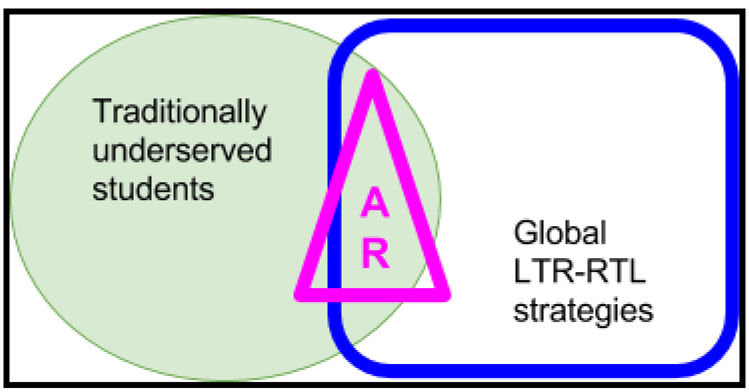
In the event of a physics classroom largely populated by English language learners (ELL) and traditionally underserved students (i.e., minority, low-income, first-generation students), it is likely that many students have not fully developed the skills of learning-to-read and reading-to-learn English scientific texts. In "The State of Higher Education in California: Latino Report", one out of two children under the age of 18 in California is Latino, yet Latinos have the lowest educational attainment rates in the state. The report states that only 39 percent of Latinos completes a California community college program, comparing to the statewide average of 48 percent (Latino Report, 2015). Gazzar (2015) reports that many Latinos students in California high schools are traditionally underserved students: students of color, low-income students, and first-generation students. Thus, in the event of a high school physics classroom populated by underserved Latino students who aspire for college, there is likely a need for the teacher to place more emphasis on the development of students' skills in learning-to-read (LTR) and reading-to-learn (RTL) English scientific texts.

While traditionally underserved Latino high school students could be fluent in the social usage of English language, Herrell and Jordan (2015) state that it is probable many of these students face challenges in the academic usage of English language. Ruiz-de-Velasco (2000) reports that the probability seems to be higher among certain Mexican and Central American students who might not be fully literate in their native language. Tong (2014) believes that many of these students have not been explicitly taught the integration between science knowledge and literacy skills.

The following sections review the global best practices for supporting science literacy, with a focus on Learning-to-Read (LTR) and Reading-to-Learn (RTL).

2.3. Operational Definition of Relevant Terms

The focus for the action research (AR) is to find and optimize an intervention approach for my students. An optimal approach here is viewed from the perspective of meeting the desired outcome as much as possible within the constraint of resource. The desired outcome is defined as an increase in students' ability to analyze physics word problem. The constraint of resource is defined mainly as the constraint of of scope and time. The scope is reading-to-learn (RTL) and learning-to-read (LTR) science texts. The following venn diagram illustrates an intersection between my students' learning environment and global RTL-LTR best practices and the focus of the action research (AR).



Learning-to-Read (LTR) is defined mainly as the ability to decode sentence's meaning by applying one's understanding of word's definition, image's connotation and grammatical structures. Reading-to-Learn (RTL) is defined mainly as the ability to interpret texts and make connections, resulting in the construction of one's knowledge (Robb, 2002; Osbourn, 2015). While there are additional definitions for LTR and RTL (e.g., compare texts for common theme, set purposes, etc.) but at this stage, the initial focus is on a small subset scope for my physics students. The scope of this particular Action Research is on the interpretation of physics text, resulting in the identification of known and unknown variables.

Osborne (2017) maintains that students struggle with science/physics texts due partially to causes such as (i) polysemy, (ii) nominalization, and (iii) lexical density.

Polysemy is the capacity for words to have multiple context-dependent meanings. For example, in everyday setting, the term 'power' is typically interpreted as the ability to accomplish or control (i.e., the utilization of violence, wealth, and/or knowledge to make others behave/perform in certain manners) (Toffler, 1990). Similarly, in Spanish, '*el poder*' (power) is usually understood as control and authority per *El poder militar del país crece sin cesar* (The country's military power is steadily growing) or *La policía no tiene autoridad para registrarte* (Police do not have the power to search you). But when the reference framework is physics (Zitzewitz, 2005), power is understood as Work_Done divided by Time or

$$P = \frac{\Delta W}{\Delta t} \text{ where } W = F d$$

Table 3: Formula for Power (Zitzewitz, 2005)
$P = \frac{\Delta W}{\Delta t} \text{ where } W = F d$
P *is power* ΔW *is work done* F *is the constant force exerted on the object in the direction of motion* *d is the object's displacement*

Δt *is the time taken to do the work*

To compound the issue, this physics interpretation of 'power' is conveyed in Spanish as *la energía* per *La energía no llega al generador* (The power is not reaching the generator), and 'energy' is also translated as *la energía* per *Hemos ideado un sistema nuevo que limita el consumo de energía* (We've devised a new system that limits energy consumption).

For the physics frame of reference, energy is related to power but energy is not power itself. See following table which shows the relationship between power, work and energy.

Table 4: Formulas for Power, Work and Energy (Zitzewitz, 2005)
$KE_i + PE_i + W_{nc} = KE_f + PE_f \text{ where } P = \frac{W}{t}$
KE_i is initial kinetic energy PE_i is initial potential energy W_{nc} is work done to a system by non − conservative forces KE_f is final kinetic energy PE_f is final potential energy P is power t is time

Another challenge faced by physics students is nominalization, a practice of packing an entire specification of complex processes into single words. Some examples of nominalization for physics are ‘photoelectric’, ‘thermonuclear’, and ‘evaporation’.

Similar to nominalization, another challenge is the practice of lexical density, the ratio of content words and the total number of words. More content words equate to higher density. Science texts tend to have high density, requiring students to read and re-read each sentence with focused concentration.

Thus, the nature of science language itself (polysemy, nominalization, lexical density) pose challenges to the development of student’s skills in Learning-to-Read and Reading-to-Learn (LTR-RTL) science texts.

2.4. Choice of Intervention

2.4.1. Decoding science within a supporting infrastructure

The development of high school students' skills for Learning-to-Read and Reading-to-Learn (LTR-RTL) science texts is likely more sustainable when it is based on a systematic approach for a supportive learning infrastructure that involves the contribution and interaction of multiple factors, including the learning climate (Creemers, 1994). For cases in which classroom management is essential for a safe learning environment, Lemov (2010) advises that teachers can reach high standards of behavior while maintain a "warm and positive tone" through placing emphasis on the benefits that students would reap for themselves and through establishing a culture of compliance reinforced with mainly invisible discipline. Teacher is to set expectation for full compliance with least invasive form of intervention (e.g., nonverbal, positive group correction, anonymous individual correction, private individual correction, quick public correction, consequences). Note that ignoring marginal behavior is not really a minimal invasive form of intervention. Marginal misbehavior, if ignored, tends to persist and expand, leading to more invasive intervention.

Another factor for a supportive learning infrastructure is to connect the ways students learn with the lesson plan. Bransford, Brown, and Cocking (1999) suggest that learning tends to be more effective when teachers have a good grasp on students' preconceptions on how the world works. Marzano (2015) recommends that teachers can start the instruction based on this initial understanding to engage students, then monitor students' changing perception as students learn. For example, physics teachers can combine students' pre-existing knowledge on trigonometry with understanding for Newton's laws of motion. For students who are English Language Learners, teachers can explore students' pre-existing knowledge on certain words in order to explain the key terms (e.g., component, vector resolution, coefficient of kinetic friction).

Hunter (2004) suggests another factor for a supportive learning infrastructure is to combine check for understanding with modelling. Given that these concept/skills may be new to students but not to teacher, there is a likelihood that teacher might have internalized some elements of the concept and subsequently, overlook the modeling of these elements to students. Hence, teacher may need to backtrack on such internalization and reproduce the understanding for students.

These factors and others help establish a supportive learning infrastructure for students to strengthen the skills in Learning-to-Read and Reading-to-Learn (LTR-RTL) science texts. The development of high school students' skills for LTR-RTL science texts is thus being considered as a factor within a broader systematic approach.

2.4.2. Learning-to-Read (LTR) and Reading-to-Learn (RTL) English scientific texts

The difficulties of Learning-to-Read (LTR) and Reading-to-Learn (RTL) scientific texts are faced not only by students in America, but also in other countries. In France, Brigitte Marin, Jacques Crinon, Denis Legros and Patrick Avel (2007) describe these difficulties which are very similar to those encountered by students in America:

Table 5: The difficulties of Learning-to-Read (LTR) and Reading-to-Learn (RTL) scientific texts for students in France.	
La compréhension des textes scientifiques présente des difficultés particulières qui contribuent à renforcer l'échec des élèves en difficulté. Ces textes véhiculent en effet des connaissances étrangères à la culture de ces élèves. Ces élèves sont alors contraints d'élaborer la représentation du contenu de ces textes à partir d'un bagage insuffisant ou en conflit avec les principes scientifiques implicites ou énoncés dans les textes. Ces difficultés amènent ainsi les élèves à développer des conceptions naïves inappropriées et à recourir à des stratégies de traitement de l'information inadaptées.	The comprehension of scientific texts presents particular difficulties. These difficulties reinforce students' sense of failure of pupils when facing challenges. Often, scientific texts convey knowledge foreign to students' culture. Students are then forced to elaborate the representation of the content of these texts on the basis of insufficient knowledge or in conflict with the scientific principles implicit or stated in the texts. These difficulties lead students to develop inappropriate naive conceptions and to resort to inadequate information processing strategies.

Duc Minh (2013) also discusses about the challenges of learning physics faced by Vietnamese students.

Table 6: The difficulties of Learning-to-Read (LTR) and Reading-to-Learn (RTL) science texts for students in Viet Nam.	
Các em học sinh thân mến, hiện nay có không ít em lo lắng, trăn trở về việc học môn Lý, không hiểu tại sao mình học thế mà vẫn không tiến bộ, không hiểu tại sao mình không thể học thuộc và nhớ những công thức Vật Lý được. *Công thức Vật Lý rất nhiều và lại khô khan, để nhớ chúng quả thật là rất khó nhưng không phải không làm được. Việc học công thức vật lý hay bất kì một kiến thức nào cũng cần có thời gian, không chỉ một sớm một chiều là làm được. Để nhớ được công thức Vật Lý, chỉ có một cách duy nhất đó là hãy xem lại nó nhiều lần, ngày nào cũng xem, cũng vận dụng nó tự dưng các công thức đó sẽ ngấm vào đầu các em lúc nào không biết.*	To my physics students who are struggling with physics, wondering why you could not make much progress even with all your effort to read and memorize the formulas. There are many formulas and they are very dense and dry. It would take repeated attempts to digest and understand them, with multiple attempts to apply the formulas.

The issue here is the universal challenges of Learning-to-Read (LTR) and Reading-to-Learn (RTL) science texts *per se*. Global students struggle with science texts because of the condensed format, of the unfamiliar usage, of multimodal representations that are not intuitively obvious.

As the intrinsic nature of science texts makes it a challenge for students globally (Crouch and Mazur, 2001), the scope of this action research dwelled further and examined the challenges faced by my students who are mostly traditionally underserved Latino students. Duschl, Schweingruber, and Shouse (2007) state that the additional challenges faced by these students include the prioritization of standards-based instructions over specialized intervention instructions, particularly for instructions relating to abstract/symbolic thinking. Albert (2014) maintains that another challenge is that physics teachers tend to focus with hands-on activities because they presume their 11th grader students already have the foundation for science literacy. Young (1999) suggest another significant challenge is student's anxiety about making mistakes.

Greenleaf and Schoenbach (2004) state that the language of science is too specialized with its diagrams, images, models, graphs and tables. Such specialization is best taught by science teachers (Pearson et. al. 2010). Yet many science teachers expect students to acquire science literacy from English teachers. As high school physics course is usually taken by eleventh graders, many teacher operate on the premise that the students have already developed the skills of reading and learning from texts (Wade, 2000). Furthermore, Pearson (2010) notes that many science teachers still need professional development to teach their students how to read science texts effectively.

Lee and Spratley (2010) stress that while many schools provide intervention for struggling readers, these interventions focus on generic reading strategies rather than disciplinary literacy. To compound the matter, many science textbooks tend to cover large amounts of material in a superficial and uninteresting manner (Lee, 2010).

McMurray (2008) conducted a study which indicates that the promotion of ELA (English Language Arts) and math of the No Child Left Behind initiative had significantly reduced the time for science. Dolph (2007) surveyed elementary schools in San Francisco Bay Area and found the reduction of time for science had resulted in an average allocation of 60 minutes per week whereas the national average was 200 minutes per week (as of 2001).

The next section provides a review of relevant literature for strategies about Learning-to-Read (LTR) and Reading-to-Learn (RTL) scientific texts.

2.4.3. Strategies for Learning-to-Read (LTR) and Reading-to-Learn (RTL) scientific texts

For strategies relating to Learning-to-Read (LTR) and Reading-to-Learn (RTL) science texts, there are known effective strategies that could be implemented in three stages: Before, During and After (Stanford, 2017). Following is an illustration of strategies that could be utilized at each stage.

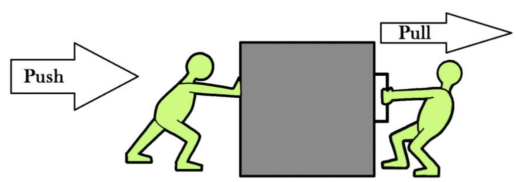
Before	During	After
Anticipation Guide, Frayer Model, DARTs, Productive Talk Moves,	Anticipation Guide, DARTs, Listening Triads, Reciprocal Teaching,	Anticipation Guide, Frayer Model, DARTs, Listening Triads, Productive Talk Moves,

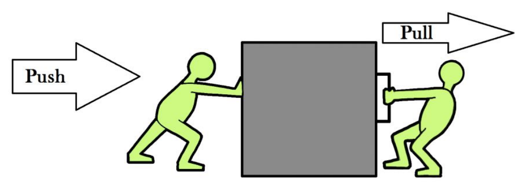
Argument Lines, Four Corner	Cornell Notes	Cornell Notes, Argument Lines, Folding Graphic Organizers, Four Corners

This section provides a review of pertinent literature. This section examines how some of those strategies have been tried and evaluates their relative applicability with respect to my students.

Anticipation Guide: Review
Pearson (2010) defines Anticipation Guide as a strategy to promote excitement. Using Anticipation Guide, teachers can produces prompts related to the purpose of the reading and designed to generate excitement. Students respond to the prompts before proceed with the reading, then later reflect on the reading and revise their responses as needed. Elham Rahmani Samani (2013) examined the effectiveness of Anticipation Guide for a group of 40 native Persian speakers EFL (English as Foreign Language) learners. The findings indicate that anticipation guide has positive but relatively insignificant effect on learners' comprehension. This is based on the null hypothesis that anticipation guide has no significant improvement in Iranian EFL learners' performances on reading comprehension quizzes. Samani utilized multivariate tests and pairwise comparisons which showed statistically insignificant improvement. Samani argued that the immediate recall assessments were insufficient in determining the success of long-term comprehension.

While Anticipation Guide could provide significant benefit for my students, I am looking for a strategy that guides my students on the structure of physics texts so my students could apply the structural understanding to solve physics word problems. I will, of course, utilize Anticipation Guide as part of the class activities but Anticipation Guide will not be the focused element of this Action Research.

Frayer Model: Example	
Definition a push or a pull upon an object	Drawing 
Example Jussell pushes one end of a table with a force of 15.0 N. Sam pushes on the other end of the table with a force of 20.0 N. What is the net force on the table?	Non-example A parked car.

Frayer Model: Review	
Frayer Model is a graphic organizer designed to support students in vocabulary development. Here is an example of Frayer Model for the physics concept of '*force in one dimension*':	
Frayer Model: Example	
Definition a push or a pull upon an object	Drawing 
Example Jussell pushes one end of a table with a force of 15.0 N. Sam pushes on the other end of the table with a force of 20.0 N. What is the net force on the table?	Non-example A parked car.

In a thesis entitled “The Effectiveness of Using Frayer Model to Improve Students’ Vocabulary Mastery on the Seventh Grade at SMP N 33 Purworejo in the Academic Year 2012/2013,” Winda Retnaningtias (2013) conducted pre-test then provided treatment and conducted post-test for Frayer Model effectiveness. The experimental group has a mean score of 75.48 compare to 67.74 of the control group, yielding a t-value of 3.22. With a 0.05 significant levels, the t-table has a value of 2.000. As 3.22 is significantly greater than 2.000, Retnaningtias concludes that Frayer Model is effective. Frayer Model is also another effective strategy for my students, but once again, I am looking for a strategy that builds my students’ confidence and support them in solving physics word problem. Naturally, I will utilize Frayer Model as part of the class activities but Frayer Model is not the key item for this research action.

Reciprocal Teaching: Review
Reciprocal Teaching (RT) is an activity in which students take turn to lead small group sessions. Cooper and Greive (2009) investigated the effectiveness of RT, utilizing control group and experimental group. The pre-test and post-test statistical results indicated no negative effect for RT. Additionally, the exit interviews suggested additional metacognitive gain among RT students.

I have tried Reciprocal Teaching earlier but I noticed that many of my students preferred to withhold participation due to fear. Thus, I need a strategy that would gradually build my students' confidence.

Think Aloud: Review
Think Aloud (TA) is the explicit verbalization of metacognitive process by the teachers as they engage in making sense of the text. Baumann, Seifert-Kessell and Jones (1992) conducted experiment comparing TA with Direct Activities Related to Texts (DARTS) and Directed Reading Activity (DRA). Results indicated DARTS students' performance to be equaled to exceeded TA students. However, exit interviews suggested that TA students had greater comprehension monitoring abilities than DARTS students or DRA students. Think Aloud has been implemented multiple times in my class but I often found many of my students struggled with vocabulary (either the meaning of the word or the pronunciation of the word). They often chose to withhold participation or to provide minimal effort.

DARTS (Direct Activities Related to Texts): Review
DARTS (Direct Activities Related to Texts) are designed to promote student's interaction with texts. Some of those activities include Prediction (predict on cause and effect), Labelling/Diagram (convert text to diagram with labels), Interrogating Texts (consider evidence and make inference), Graphic Organizers (seek patterns), Question Generator (formulate own questions), Text Marking (break string of words into manageable chunks), Relevance Game (identify relevant information), KWL Grids (organize thoughts on Know, Want to Know, and Learn) (Swansea, 2017), These activities support students to analyze the text's structure and interpret the conveyed information, to recognize patterns and evaluate evidence, to think logically and determine success. Pamelasari and Khusniati (2013) the post-test for the experimental DART's group was 78.6 compared to a pre-test score of 69. Another group was tested with Direct Instruction (DI) and yielded a post-test score of 70.2 and a pre-test score of 67.2. Pamelasari and Khusniati concluded that DARTS strategies are more effective than DI. My decision is to go with DARTs.   See following section for rationale.

2.4.4. Selection of DARTs

Overall, the various LTR-RTL strategies have proved to be effective in varying degrees. I have decided upon DARTs due to a number of reasons as follows:

1. As stated earlier, the language of science features characteristics such as polysemy, nominalization and lexical density. These characteristics could be challenging for the uninitiated. The Text Marking activity of DARTs would likely break down the complexity by separating the texts into smaller chunks.
2. Another characteristic of scientific communication is the utilization of pictures (diagram, table, animation, etc.). Many students may need support initially in the interpretation of such pictures. The Labelling/Diagram activity of DARTs would likely guide students in their ability to both interpret pictures and to express their understanding via picture generation.
3. A third key reason for DARTs selection is due to *in situ* conditions. My students are already familiar with various learning technology such as Google Sheets (cloud-based tool for visualizing data), Google Docs (cloud-based tool for generating documents with colors and shapes), and Pear Deck (cloud-based tool for interactive presentation that includes marking text and drawing diagram). These tools are well suited for Text Marking and Labelling/Diagram activities. Furthermore, these tools do provide some quantitative analytics which are good for data collection.

2.4.5. Literature Review: Conclusion

Of the various strategies mentioned above, I have selected DARTs, particularly Text Marking activities and Modeling/Diagram activities as the starting point for my attempt at supporting students in learning-to-read and reading-to-learn physics texts. The rationale here is that Text Marking activities and Modeling/Diagram activities could be implemented for active and social learning, thus promoting collaboration and social metacognitive skills. Text Marking activities and Modeling/Diagram activities fit well with my usage to learning technology tool such as Pear Deck (an interactive and online presentation application). This allows students to share the work, thus aiding the closing of the gap of understanding students.

One step that my students could take is to be able to recognize the signposts of physics text and the patterns to solving problem, This would help my students comprehend the texts better (TFA, 2011). I believe that once students are able to see the patterns of knowledge and information in the physics word problems, they will gain confidence in their abilities of reading-to-learn science text. The desired outcome here is to facilitate further development of analytical thinking and to enhance the internalization of learning. My reasoning here is partially based on personal experience. While English is not my native language, I have done well in science because I have the ability to recognize the patterns in solving scientific problems, or rather, because I have some degree of self-confidence with regards to such an ability.

Note that the intervention plan is to start initially with Text Marking activities and Modeling/Diagram activities. My intention is to fully incorporate/integrate other activities at later stages.

3. Theory of Action

Theory of Action	
3.1. Problem of Practice *What is the context? What is the problem in that context?*	Many of my physics students are first-generation and traditionally underserved students whose home language is Spanish. Initially, my teaching focused on content because the course's initial main objective was to introduce students to the broad range of physics (classical Newtonian mechanics, thermodynamics, acoustics, optics, electricity and magnetism, etc.) and the focus was on doing science, thus preparing students for options regarding possible STEM majors in college and qualifying students for the California A-G science laboratory requirement. However, the pursue of breadth and laboratory activities left many of my students behind as they struggled with the language of science.

3.2. Literature Review 1 *What do I know about the problem?*	The literature review indicates that many California high school students could substantially benefit from further science literacy instruction, due to a number of factors such as the No Child Left Behind (NCLB) initiative and the complexity of science language. The initiative's emphasis on English and Math had likely resulted in an unintended consequence of less class time for science among middle school students. The complexity of science language makes science literacy a challenging issue for California high school students, especially for students whose home language is not English. Additionally, the literature reviews indicates that students learn science better when combining the doing of science with the reading, writing, and talking of science.

3.3. Literature Review 2 *What has been tried in the past to address the problem? What was successful and why?*	For science literacy instructions, educators have implemented strategies such as Frayer Model; Anticipation Guide; Four Corners; Picture Walk; Reciprocal Teaching; Listening Triads; Graphic Organizers, and Directed Activities Related to Text (DARTs). These strategies have been attempted with varying degrees of success as they do provide the support for student's development of science literacy skills. Note that there is no single panacea nor a one-size-fit-all solution. One key factor is a best-fit customization approach that account for *in situ* conditions.
3.4. Intervention *What am I going to try? Why do I think it will impact the problem? What is my rationale?*	For science literacy, particularly with regards to Reading-to-Learn science texts, there are three common stages: Before, During and After. Some possible strategies for the Before stage are: Anticipation Guide, Frayer Model, DARTs, Productive Talk Moves, Argument Lines, and Four Corners. Some possible strategies for the During stage are: Anticipation Guide, DARTs, Listening Triads, Reciprocal Teaching, and Cornell Notes. Some possible strategies for the After stage are: Anticipation Guide, Frayer Model, DARTs,

	Listening Triads, Productive Talk Moves, Cornell Notes, Argument Lines, Folding Graphic Organizers, and Four Corners. DARTs could be used at all three stages. Some of the DARTs' activities are Prediction, Interrogating Texts, Transformation, Graphic Organizer, Question Generation, Text Marking, Labelling/Diagram, Relevance Game and KWL (Know, Want to Know, Learned). The subset I plan to try includes Text Marking and Labelling/Diagram. I think this subset will support the development of students' skill at analyzing science texts (physics word problems) for the relevant factors (explicit and implicit known/unknown variables). My rationale here is that such subset best meets the needs of my students at this stage. My students need to develop the ability to examine physics word problems and diagnose the issues based on evidences presented by the texts.
3.5. Literature Review 3	Text Marking has been shown to be successful in guiding students toward identifying and isolating key information in texts. Labelling/Diagram has been shown to be successful in guiding students in making the connections between raw texts

What do we know about quality interventions of this kind?	and visual images. This is crucial for science literacy as science is often communicated in a combination of various formats. With Text Marking and Labelling/Diagram, teacher could provide guidance in a timely manner by examining students' performance. Data could be quantitatively collected for outcome analysis at a later time.
3.6. Expected Outcome *What do I think will change/ improve?*	I think this intervention plan will improve students' active engagement with the texts. It will facilitate a gain in self-confidence for my students, self-confidence in the ability to solve physics problems in particular and to handle challenges in general. It will facilitate a gain in discipline and concentration span for my students. It will support students' metacognitive ability in recognizing the benefit of building mental stamina.

3.7. Research Methods & Data Collection *How will I know if it changed/ improved? What data will I collect?*	Based on data collection, I will know how to make appropriate modifications that would improve students' science literacy skills. I will collect performance, attitudinal and affective feedback from students. For performance, the data are about the number of students who make attempt at solving physics word problems , who complete the required steps in solving the problems, and who arrive at the appropriate solutions to those physics word problems. For attitudinal and affective, the data are about students' responses to Likert-scale surveys. Via triangulation, the quantitative and qualitative data will let me know how Text Marking and Diagramming support students in improving performance as well students' opinion and feelings about these strategies. I will apply a statistical hypothetical *t-test* in which the null hypothesis is as follow: there is no pattern in students' performance per Text Marking and Diagramming strategies (the difference between performance on the same statistical unit has a mean value of zero). A simplified null hypothesis would be $H_0 :\ \mu_1 = \mu_2$ Where $H_0 :\ \textit{null hypothesis}$ $\mu_1 :\ \textit{mean of sample } 1$

	μ_1 : *mean of sample* 2 For **correlation**, the **null hypothesis** is that r = 0 -- that there is no relationship between the variables, no pattern in students' performance when Text Marking is deployed versus when Diagramming is deployed. The positive (+) coefficient indicates that the relationship is a positive one. For example, cold and snow are positively correlated (they tend to go together) whereas sunshine and rain are negatively correlated (Levitt & Dubner, 2009). The p value is less than .05, we can reject the **null hypothesis**.
3.8. Data *What were my results/ findings?*	The findings indicated that accommodations and modifications via Diagramming / Text Marking do support students in completing physics word problems. Overall, Text Marking has a significant edge over Diagramming per student's performance and preference.
3.9. Data Analysis *What do those findings mean? What implications*	Pending further verifications, the findings imply that accommodations and modifications via Diagramming / Text Markings do strengthen students' skills in analyzing science texts. With regards to the larger body of knowledge, the findings suggest that it may be the more appropriate to make the accommodations and modifications for some students by

do my results have for practice? How does it contribute to the larger body of knowledge (from my Literature Review)?	placing Text Marking ahead of Diagramming. Note that the traditional physics textbook problem solving approach is to place Diagramming ahead of Text Marking where Text Marking is interpreted as the identification of known and unknown variables.

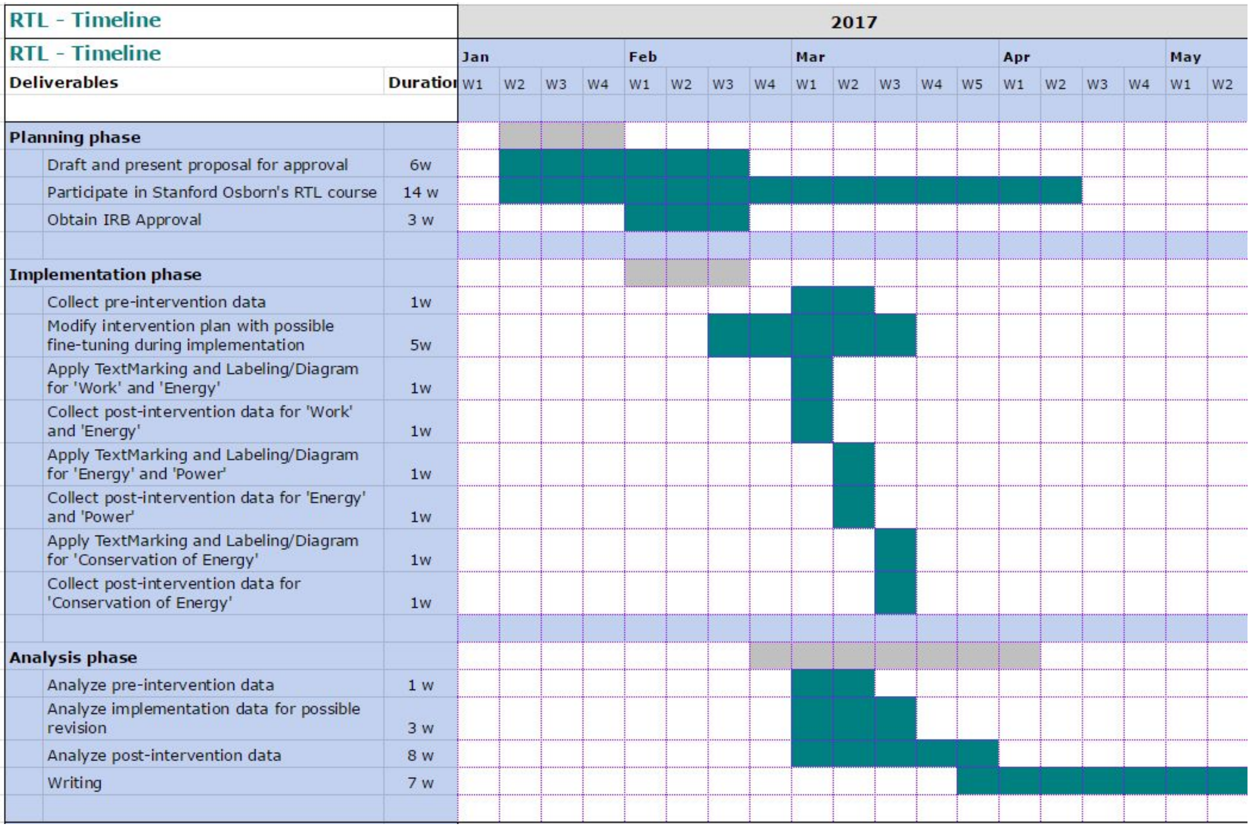
4. Intervention and Data Collection Plan

4.1. Intervention

Research indicates that Text Marking supports students in selecting the relevant information while Labelling/Diagram aids students in interpreting the information (Stanford, 2017). For the purpose of supporting students in reading to learn science texts, I design the intervention plan with instruction modification on Text Markings and Labelling/Diagram. I plan to collect quantitative performance data based on the number of students who attempt to solve the physics problem (Attempt), the number of students who complete the first stage (Modelling) in the problem solving process, the number students who complete the second stage (Analytical) in the problem solving process,, and the number of students who complete both stages with solutions that fulfill the specified rubrics

4.2. Timeline

Following is the timeline (Implementation Phase, Analysis Phase)



4.3. Data Collection Plan

The three-week intervention cycle start with the collection of students' performance for physics problems relating to work, power and energy. Students will be provided with instructions that support conceptual understanding and problem-solving procedure. This includes activities such as Think-Pair-Share (TPS) in which students read science texts and talk science texts with each other (e.g., Take 3 minutes to read about Work, Power, Energy from a physics perspective. Take 2 minutes to share your understanding with a partner. What does your partner say about Work, Power, Energy?). Students will also be asked about their confidence level with regards to solving physics problems related to work, power and energy. See Appendix A for the Likert scale sampled question.

Students will then proceed to solve a physics word problem about the physics concept of work ($W = Fd$), relying upon the problem-solving procedure and the provided examples. Utilizing Labelling/Diagram and Text Marking, students will be guided to break the text strings into manageable chunk in order to identify the known variables and unknown variables. Students will be guided to convert the word problem into a free-body diagram, completed with labels. Performance data will be collected for the formative assessment with [$\overline{x_1}$ = set1 means] and [n_1 = number of set1 participants], [$\overline{x_2}$ = set2 means] and [n_2 = number of set2 participants]. For the null hypothesis analysis, *t-test* will be computed to determine the statistical difference between set1 and set2 data.

t is computed as follow: $$t = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{\frac{(s_1)^2}{n_1} + \frac{(s_2)^2}{n_2}}}$$

where

$\overline{x_1}$ = set1 means

$\overline{x_2}$ = set2 means

s_1 = set1 variance

s_2 = set2 variance

n_1 = number of set1 participants

n_2 = number of set2 participants

It's likely that $n_1 \cong n_2$

I will triangulate the formative assessment quantitative data with observation and survey qualitative data. The observation will be collected in the form of engagement coding. I will capture data about on-task and off-task indicators, in a simplified binary approach (e.g., screen displays current assignment = on, screen display craigslist search for Camaro parts = off). The survey data is in the form of Likert scale (see Appendix A for sample).

I will also triangulate by conducting post-mortem interview with students for qualitative and metacognitive feedback, with cognitive, attitudinal and affective questions. See following questions:

- Cognitive: What do you understand about the use of Text Marking and Labelling/Diagram?
- Attitudinal: What is your opinion about using Text Marking and Labelling/Diagram to learn physics?
- Affective: How do you feel about solving physics problem relating to the physics

concept of work?

It is likely that I will modify these questions as I proceed in order to elicit meaningful responses from students. For example, I might start by revealing about how I learn via DARTs, then gradually probe with open-ended questions.

Following the sessions on work ($W = Fd\,cos\theta$), I plan to apply similar Modelling and Text Marking approaches on the physics concept of power ($P = \Delta W/\Delta t$) and the physics concept of energy ($GPE_i + KE_i + W = GPE_f + KE_f$).

Altogether, there would be data for Labeling/Diagram formative assessment result, Text Marking formative assessment result, observation engagement data, survey data and post-mortem cognitive-attitudinal-affective interview.

5. Data, Analysis and Findings

5.1. Introduction

At first, I started the data collection process with the intent to collect pre-intervention and post-intervention data. The original plan was to determine the effectiveness of intervention via DARTs (Directed Activities Related to Texts), with Diagramming and Text Marking being two of the selected approaches within the DARTs repertoire. However, as I conducted preliminary analysis while implementing the intervention, I noticed a significant difference in actual outcome. Students consistently preferred Text Marking over Diagramming. Cognitively, students consistently performed better when modifications involved Text Marking when compared with modifications involved Diagramming. While both Diagramming and Text Marking did support students in decoding science texts, I began to realize that a more meaningful action research would be to examine the relative efficacy of Diagramming versus Text Marking. ‘Meaningful’ here is construed as how modifications and accommodations could be implemented to optimally support my students. ‘Relative efficacy’ here is construed as how intervention A likely does more good than harm comparing to intervention B, with the understanding that it’s not always possible to predict all unintended consequences.

Midway through the data collecting and *in situ* analyzing process, it seemed that an action research about relative efficacy would be more beneficial for the accommodations and modifications instructional strategy. I thus revised the proposal, at the risk of changing the scope and complicating the timetable.

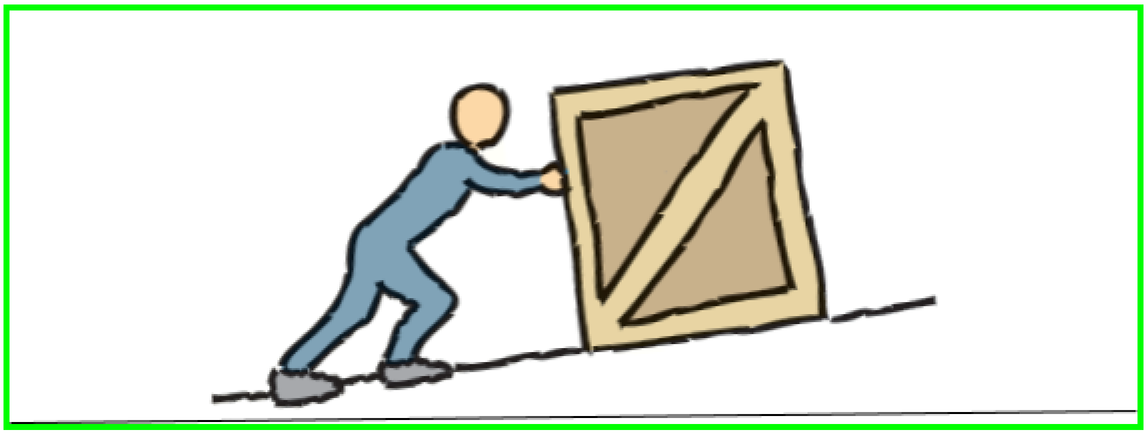
5.2. Research Methods

For cognitive performance quantitative data, I implemented 11 activities over a span of 3 weeks, including warm-up exercises, formative assessments and summative assessments. Following is a list of those activities.

#	*activity*	*note*
1	warmup_h28_work	Exercise I-Do We-Do
2	10.1 work 3/6	Pear Deck session on work You-Do We-Do
3	h28_work	Homework You-Do
4	warmup_h29_power	Exercise I-Do We-Do
5	h29_power	Homework You-Do
6	warmup_h32_energy	Exercise I-Do We-Do
7	h32_energy	Homework You-Do
8	e3_work	exam questions on work You-Do
9	e3_power	exam questions on power You-Do
10	11.2c	Pear Deck session on energy You-Do We-Do
11	h36_eCompute	homework on energy You-Do

Here is an example for one of those activities.

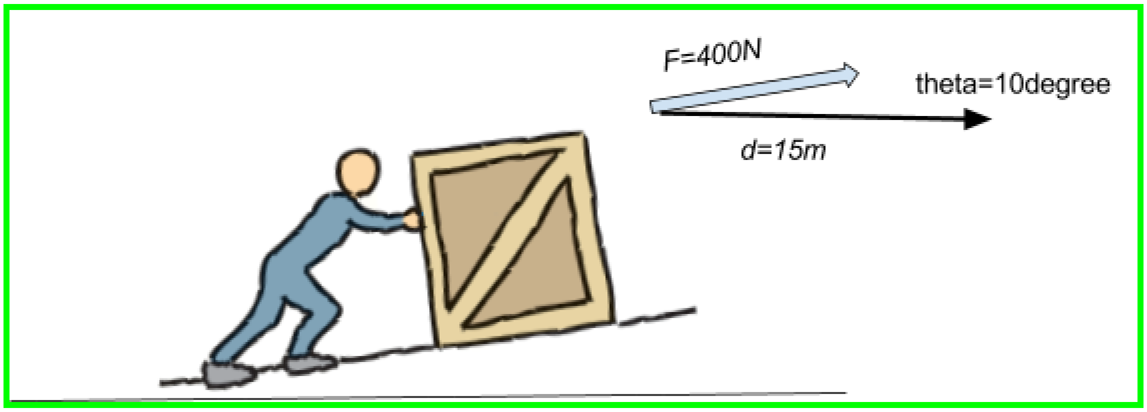
1. Students were given a physics word problem: *How much work is done in pushing a tall box 15 m with a force, the magnitude of which is 400 N, that is applied slightly upward at an angle of 10.0° from horizontal?*
2. Students were given a prompter image.



3. Students were asked to draw free-body diagram (FBD) per the Modelling Rubric

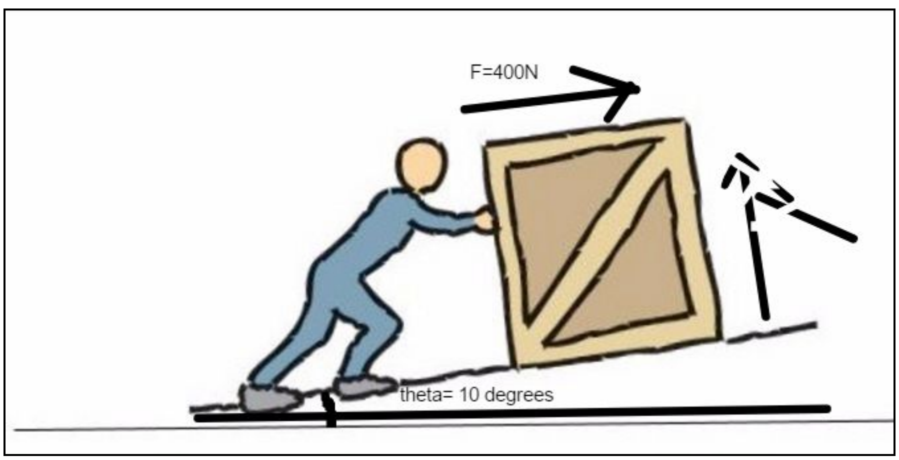
Rubric for Modeling (mO)		code
1	Does your vector have arrow?	mO1
2	Is the arrow pointing away from the object?	mO2
3	Is the vector labeled with the corresponding letter/symbol?	mO3
4	Is the arrow pointing to the same direction as the force/motion?	mO4
5	Does the vector's length correspond to its magnitude?	mO5

4. The desired result should look something like this:



5. Student's effort was evaluated based on rubric. Raw data was recorded.

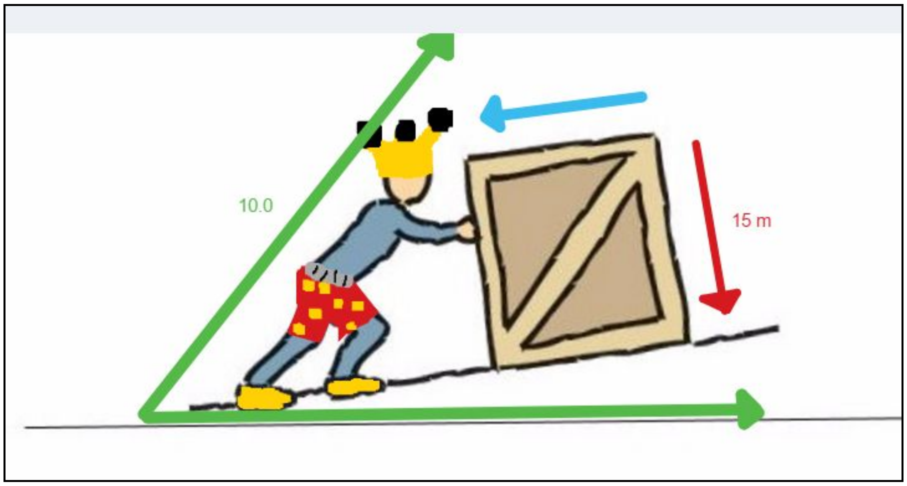
5.1. So something like the following vector diagram nearly met the criteria (for applied force and angle).



Per the Modelling Rubric, here is how I tabulated the data for the above vector diagram

blank	partial	complete	mO1	mO2	mO3	mO4	mO5
0	0	1	1	1	1	1	0

5.2. Whereas something like the following Mickey Mouse drawing would rate well in the artistic criteria but did not fully meet the Modelling Rubric criteria.



Per the Modelling Rubric, here is how I tabulated the data for the above vector diagram

blank	partial	complete	mO1	mO2	mO3	mO4	mO5
0	0	1	1	0	0	0	0

6. Next, for Analytical, students were asked to underline the known variable/s in blue and the unknown variable/s in red. Here is an effort from one of the students.

How much work is done in pushing a tall box 15 m with a force, the magnitude of which is 400 N, that is applied slightly upward at an angle of 10.0° from horizontal?

7. Students were asked to list the known variable/s and unknown variable/s per the Analytical Rubric.

Rubric for Analytical (aN)		code
1	Is each of the known variable listed, with corresponding symbol, value and unit?	aN1
2	Is each of the unknown variable listed, with corresponding symbol and unit?	aN2

8. The desired result should look something like this:

Known			Unknown
$F = 4.0x10^2\ N$	$d = 15\ m$	$\theta = 10^0$	$W = ?J$

8.1. Here is an effort from one the students that nearly met the Analytical criteria.

How much work is done in pushing a tall box 15 m with a force, the magnitude of which is 250 N..

1.2.a. Analytical: List the 7 knowns and 2 unknowns (9 points, one per each variable listed)

Known			Unknown
d=15m			Work done
F= 400N			
10 degrees			

Per the Analytical Rubric, here is how I tabulated the data for the above table

blank	partial	complete	aN1	aN2	size
0	0	1	1	0	1

Following is the raw data for cognitive performance which shows the number of students that met each criterion per activity.

Raw Data: Student Feedback cognitive Modeling vs. Analytical								
	mOdelling criteria					aNalytical criteria		
activity	mO1	mO2	mO3	mO4	mO5	aN1	aN2	size
warmup_h28	12	7	3	7	9	11	6	13
10.1 work 3/6	12	11	8	9	9	11	8	15
h28_work	17	18	16	17	11	17	18	18
warmup_h29	16	15	3	2	1	15	8	17
h29_power	15	16	15	13	12	15	15	18
warmup_h32	16	12	7	9	8	14	12	17
h32_energy	17	17	16	16	13	16	16	18
e3_work	18	18	16	13	12	18	9	18
e3_power	18	18	16	14	13	18	7	18
11.2.c	15	15	12	12	15	16	15	16
h36_eCompute	16	16	8	7	3	14	14	16

For qualitative attitudinal and affective data, students' feedbacks were collected via Likert-scale survey as illustrated by the following screenshots.

Modelling Reflection. On a scale from 1 (minimum) to 10 (maximum), how satisfied are you with **Modeling** as a tool for diagnosing physics problems? *(1 point)*

unsatisfied								very satisfied	
1	2	3	4	5	6	7	8	9	10

Analytical Reflection:On a scale from 1 (minimum) to 10 (maximum), how satisfied are you with **Analytical** as a tool for identifying variables in physics problems? *(1 point)*

unsatisfied								very satisfied	
1	2	3	4	5	6	7	8	9	10

How do you feel about using Modeling to understand physics problem?

Feeling the pain	*Yeah, whatever*	*A bit puzzled*	*Kinda neat*	*Totally into it*

How do you feel about using Analytical to identify variables in physics problem?

Feeling the pain	*Yeah, whatever*	*A bit puzzled*	*Kinda neat*	*Totally into it*

Following is the Likert-scale data, normalized to percentage, for attitudinal and affective feedbacks from students (code: mO=mOdelling, aN = aNalytical).

Student Feedback attitudinal *at*											
	1	2	3	4	5	6	7	8	9	10	Total
mO	0.00%	0.00%	6.25%	6.25%	25.00%	6.25%	25.00%	12.50%	18.75%	0.00%	100.00%
aN	0.00%	0.00%	6.25%	0.00%	6.25%	25.00%	6.25%	31.25%	25.00%	0.00%	100.00%

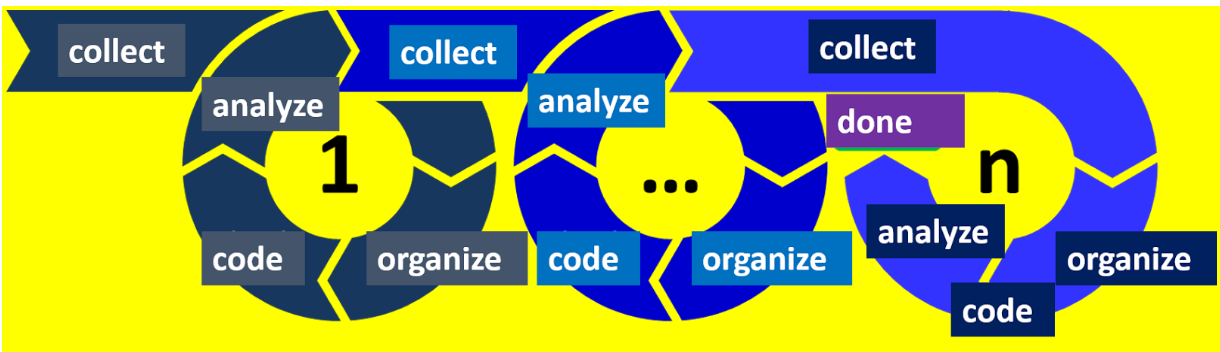
Student Feedback affective *af*						
	1	2	3	4	5	total
mO	0.00%	12.50%	37.50%	43.75%	6.25%	100.00%
aN	0.00%	12.50%	18.75%	56.25%	12.50%	100.00%

Students also provided feedback via questionnaire. The verbiage expressions were used to triangulate Likert-scale feedbacks. Here is a sample of the questions and answers.

"Does modeling help you to understand this problem? Why or why not?"
"Does text marking help you to solve this problem? Why or why not?"
Modeling doesn't really help me because I feel like it's just a graph with numbers.
Text marking does help me identify the variables because it helps me understand and makes it easier on what to focus on.
No it [modeling] doesn't help me understand this problem because I don't understand how it explains it.
Yes it [Text Marking] really helps me identify the variables since it highlights what I already know and what I need to know.
For me, modeling is the most difficult part and if I understand it, it is helpful.
Yes it [Text Marking] does because it makes it easier to see what variable I am solving for.

5.3. Data Analysis

Data analysis was conducted during and after data collection. From a process perspective, in teaching students to decode science texts I have learnt to improve my listening ability. This was achieved partially by optimizing the feedback loop, as illustrated in the following diagram.



The above diagram illustrates the iterative nature of the feedback process. For instance, the feedback I received from students during the initial data collection phase was organized, coded and analyzed. This helped me to fine-tune the accommodations and modifications which were subsequently implemented at the next phase, resulting in more feedback and more fine-tuning, and so on.

At first, I collected pre-intervention and post-intervention data. I ran sanity test, a brief testing instead of an exhaustive testing. Nearly all students made very limited attempt to proceed on the problem-solving process at pre-intervention stage. After the first session of intervention, nearly all students tried to solve the physics problem. So p*rimum non nocere* (do no harm) could be safely presumed with regards to intervention, at least on a short-term basis. I decided to go further and changed the impact question which became "*Based on evidences presented by the texts, how would modeling and text marking support students in developing the ability to examine physics word problems and diagnose the issues?*" Hence, data collection was modified to a finer, more granular level: a comparative analysis between Modeling Intervention and Text Marking Intervention.

With three rounds of data, I had sufficient points to run *t-test* and examine pattern (i.e., testing the null hypothesis in which the points present random choices). Here is a table showing data from three rounds:

mO 1	mO 2	mO 3	mO 4	mO 5	aN 1	aN 2	mO 1	mO 2	mO 3	mO 4	mO 5	aN 1	aN 2	mO 1	mO 2	mO 3	mO 4	mO 5	aN 1	aN 2
12	11	8	9	9	11	8	17	18	16	17	11	17	18	16	15	3	2	1	15	8
17	17	16	16	13	16	16	18	18	16	13	12	18	9	18	18	16	14	13	18	7

For the sanity/exploratory sample, I ran *t-test* with the parameters [=TTEST(U6:AO6,U16:AO16,2,3)] where the first two parameters {U6:AO6,U16:AO16} refer to ranges, the third {2} refers to a two-tailed test and the fourth {3} refers to a two-sample unequal variance. Result is 0.009. At [0.009] or [0.9% probability], it could be said that the ratio of signal to noise is high. Setting the risk level (alpha level) at 0.05, it could be said that the pattern is not likely a chance finding. In other words, there is a consistent pattern in students' cognitive feedback.

The next step I took was transposing the raw data table, flipping columns and rows. This allowed me to run *t-test* for Modelling (mO) and Analytical (aN) cognitive feedbacks. After the table had been transposed, I focused on mO3 and aN1 as these two criteria reflected compatible comprehension of the texts.

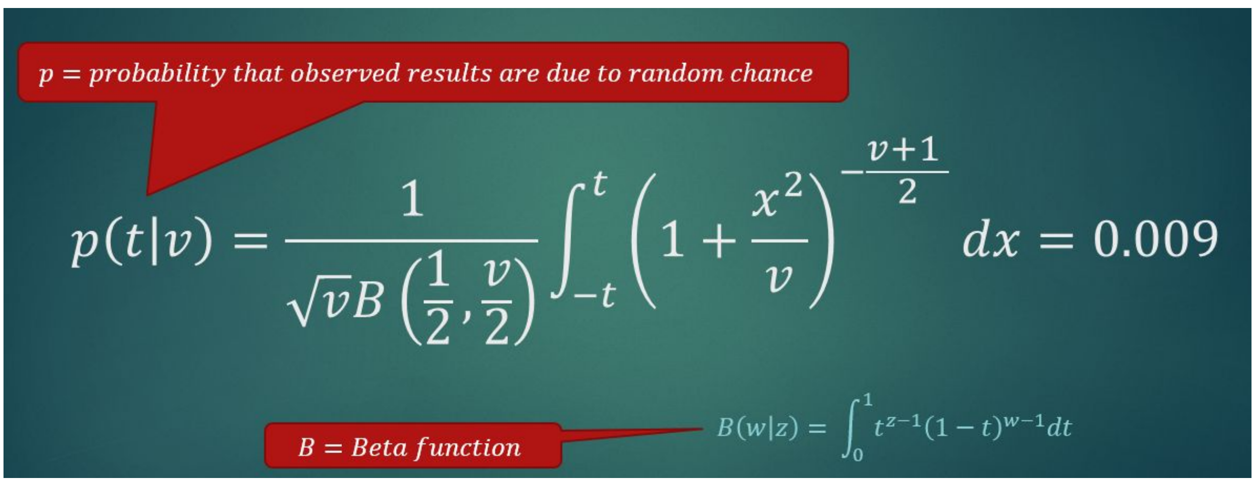
code	Description of criteria
mO3	Is the vector labeled with the corresponding letter/symbol?
aN1	Known variable is listed, with corresponding symbol, value and unit.

Following is the transposed table where the rows represent Analytical (aN) and Modelling (mO) rubric criteria; the columns represent activities.

Transposed Table of Cognitive Feedback Data											
	activities										
criteria	1	2	3	4	5	6	7	8	9	10	11
mO1	12	12	17	15	16	17	18	18	18	15	16
mO2	7	11	18	16	12	17	18	18	18	15	16
mO3	3	8	16	15	7	16	16	16	16	12	8
mO4	7	9	17	13	9	16	13	13	14	12	7
mO5	9	9	11	12	8	13	12	12	13	15	3
aN1	11	11	17	15	14	16	18	18	18	16	14
aN2	6	8	18	15	12	16	9	9	7	15	14
size	13	15	18	18	17	18	18	18	18	16	16

5.4. Findings

For qualitative cognitive feedback data, the iterative collection process allowed me to run sanity test during the early stage of data collection. For this action research, I utilized a derivation of sanity/exploratory testing to do a brief run-through and check for the probability of random feedback. With randomity being the null hypothesis, the finding of exploratory/sanity *t-test* at 0.9%, and risk level at 5%, the null hypothesis (randomity) could safely be rejected. The following image shows the *t-test* formulas and result.

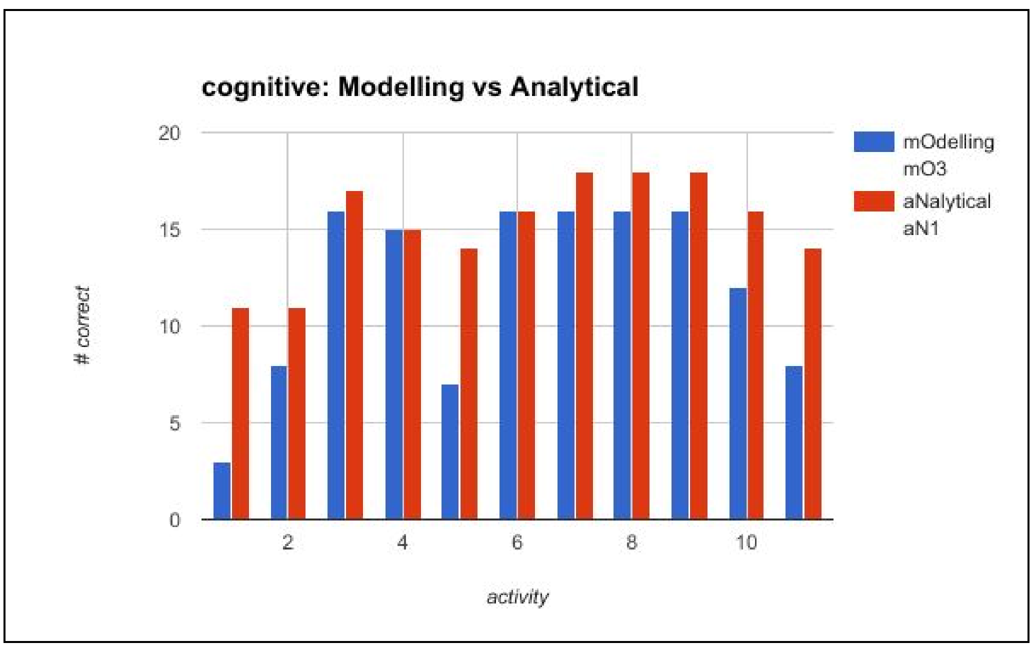


Having established via sanity/exploratory testing that there was indeed a pattern to students' cognitive feedback, I proceeded to continue running iterative cycles and perform triangulation and exhaustive testing, with the focus on mO3 and aN1.

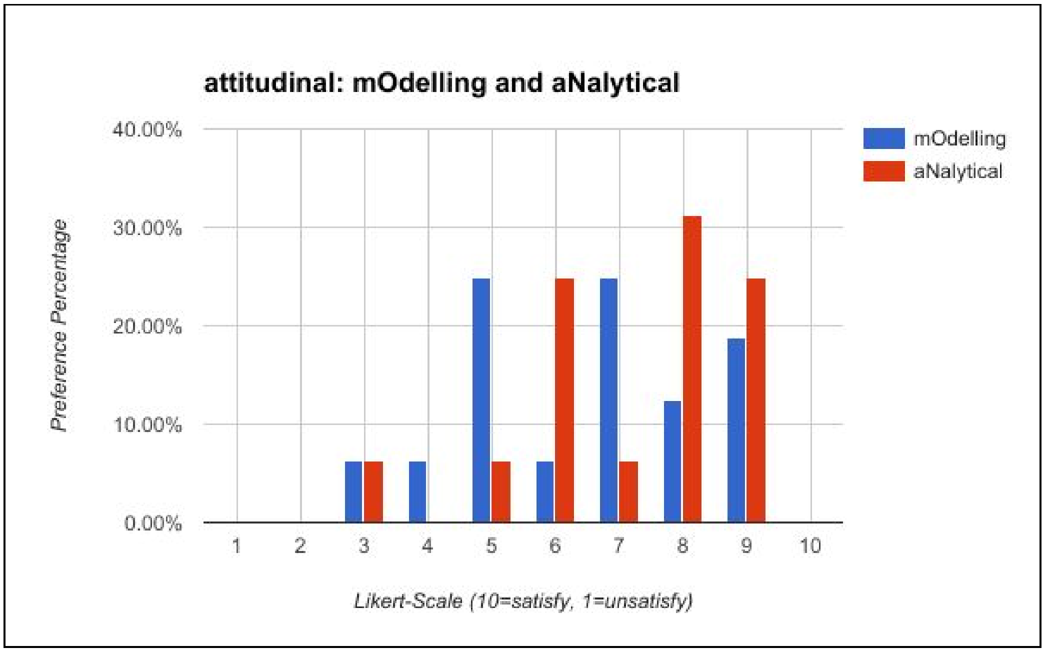
activity	1	2	3	4	5	6	7	8	9	10	11
mOdelling mO3	3	8	16	15	7	16	16	16	16	12	8
aNalytical aN1	11	11	17	15	14	16	18	18	18	16	14

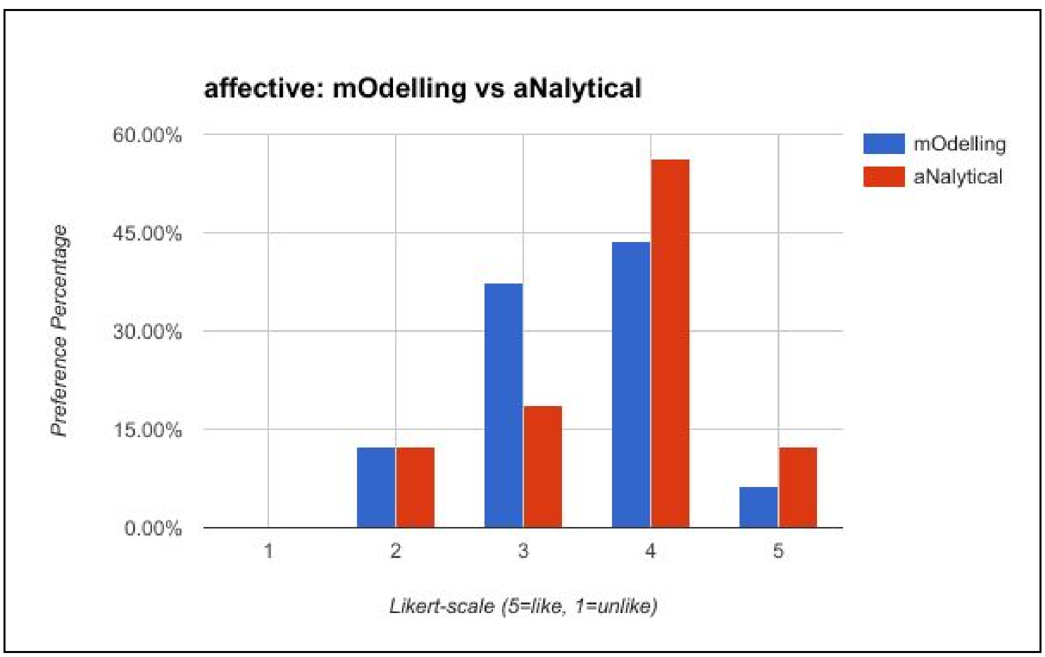
For the 11-activity sample, I ran *t-test* with the parameters =TTEST(N20:X20,N23:X23,2,3) where the first two parameters {N20:X20,N23:X23} refer to ranges for mO3 and aN1, the third {2} refers to a two-tailed test and the fourth {3} refers to a two-sample unequal variance. Result is 0.069. At [0.069] or [7% probability], this slightly exceeds the risk alpha level of 5%, leading to a claim of [failing to reject null hypothesis]. In other words, it is slightly possible that the pattern is due to chance. However, at 7%, the probability of chance finding is relatively small. On the relative confidence of non-random finding, I proceeded to plot Modelling criterion 3 (mO3) versus Analytical criterion 1 (aN1).

Plotting bar-chart of Modelling criterion 3 (mO3) versus Analytical criterion 1 (aN1) yields the following chart which shows a consistent higher cognitive feedback for aN over mO.



For students' attitudinal feedback (code *at*) and students' affective feedback (code *af*), the normalized percentage data correlated with the questionnaire responses. Students somewhat prefered accommodations and modifications via Analytical activities more than Modelling activities. See following diagrams which show a slight edge of preference for Analytical over Modelling.

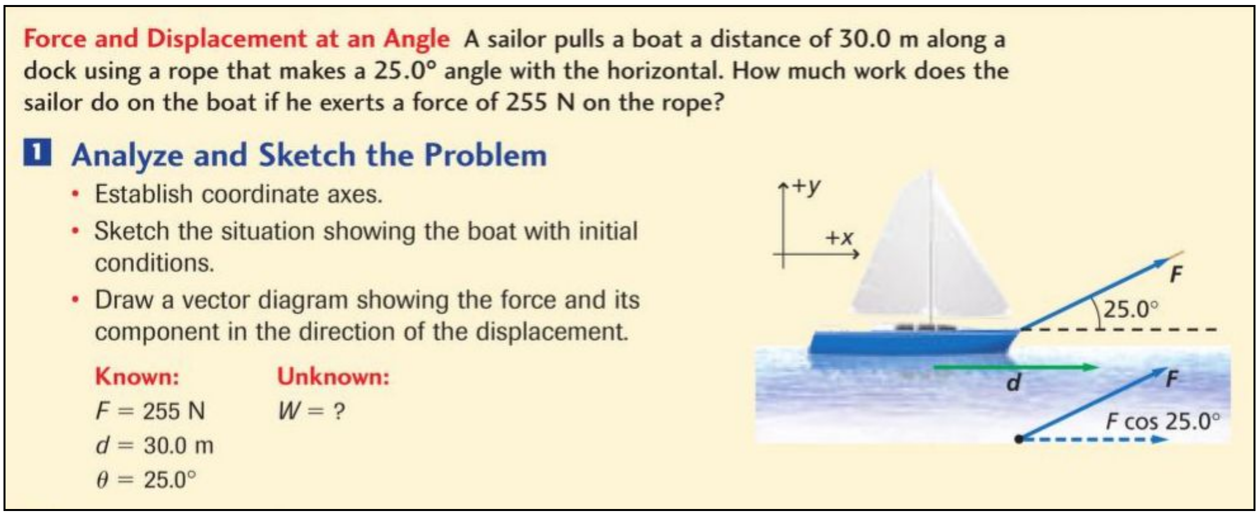




For qualitative attitudinal and affective feedback, the Likert-scale findings correlate with the cognitive data. However, the verbiage questionnaire responses indicate several negative cases in which students ranked Modelling above Text Marking. One student stated "*Modeling does help me understand because images makes me understand more than numbers. Text marking doesn't help me that much because the numbers confuse me sometimes especially when it comes to physics.*" Overall, the findings address the problem of practice in which students who struggle with science texts could be supported through modifications that involve Diagramming and Text Marking activities.

5.5. Implications

A common problem-solving approach described in high school physics textbooks is to start with drawing diagram then identifying the variables, as shown in the following image (Zitzewitz, 2005, p. 262).



Force and Displacement at an Angle A sailor pulls a boat a distance of 30.0 m along a dock using a rope that makes a 25.0° angle with the horizontal. How much work does the sailor do on the boat if he exerts a force of 255 N on the rope?

1 Analyze and Sketch the Problem

- Establish coordinate axes.
- Sketch the situation showing the boat with initial conditions.
- Draw a vector diagram showing the force and its component in the direction of the displacement.

Known:	Unknown:
$F = 255$ N	$W = ?$
$d = 30.0$ m	
$\theta = 25.0°$	

While the diagram-first, variable-second approach is appropriate for some students, that may not be necessarily so for all students. In the case of traditionally underserved first-generation students such as my students, some possible accommodations and modifications could be to start with variables first by way of Text Marking, then proceed to diagram by way of Modelling. Aligning to Herrel's work (Herrel, 2015), the data indicates that while my students were fluent in the social usage of English language, they struggled in the academic usage of English language. This led to a lack of confidence in solving physics word problems which tend to feature tier-2 and tier-3 vocabulary (Channel, 1981), along with nominalization and lexical density (Osborne, 2017).

My findings of higher cognitive feedback and stronger preference for Analytical activities over Modelling activities suggest that the popular textbook approach of diagram-first, variable-second ought to be reverted as modifications for some students. The rationale here is that the variable-first approach via Text Marking (e.g., highlight known variables in blue and unknown variables in red, then list the variables in blue-red table) scaffolds certain students with the appropriate confidence-building structure.

There are limitations for this study. Firstly, the study examined only one population so any generalization should come with a caveat. Secondly, the research setting was not a controlled environment where contributing factors could be held constant (e.g., factors such as student's emotional mood. Be that as it may, management of contributing factors would likely result in an artificial environment thus invalidate the research's result). Thirdly, while the research did include perspectives from students, the research would likely gain depth if it were to include viewpoints from third-party observers (e.g., another teacher's observation).

With respect to further study, one suggestion is to examine and manage the risk of scaffold dependency. This is the risk that students may become too reliant on support, leading to a risk-avoidance mindset (Sherrington, 2015). A continuation of this action research could be on how to architect the scaffold to support students in understanding the underlying concepts, in recognizing their metacognitive process, and in minimizing the consequences of failure. For example, students could practice learning techniques such as modelling and text marking, and also practice learning strategy such as selecting the appropriate technique, monitoring the efficacy of that technique, and making adjustment as needed (Wade, 1990).

Note that the iterative data collection process involved qualitatively and quantitatively data . By combining ethnographic research (e.g., participant observation, face-to-face interviewing) and data analytics (e.g, metric, rubric, statistical analysis), I have gained further insight about how my students learn. Subsequently, one possible implication is with regards to modifications and accommodations. While the usual approach (of diagramming first, then table of variables second) is helpful for many students, such an approach may not be applicable to all students.

A caveat here: it is highly unlikely to have an approach that works for all students in all environment. I had 20+ students in one physics class and there were significant variation within just that class. While many students prefered Text Marking over Modelling, a few students highlighted the benefits of Modelling. One student commented “Personally, I found diagramming to be helpful in identifying the problem.” Another student commented “Modeling does help me understand because images makes me understand more than numbers.”

Given the current crisis of scientific literacy among first-generation students, perhaps we should consider alternative approaches to support our students in decoding science texts, perhaps we should consider ways to build our students’ confidence in solving physics word problems. While Diagramming, Text Marking, and other strategies have shown some success, perhaps the optimal approaches are those combinations that have been customized for *in-situ* local environment.

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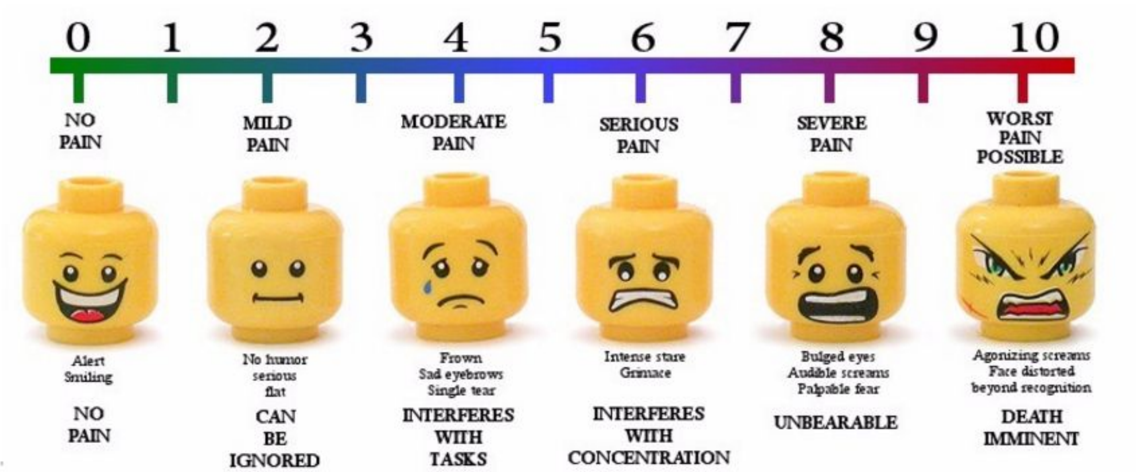
7. Appendices

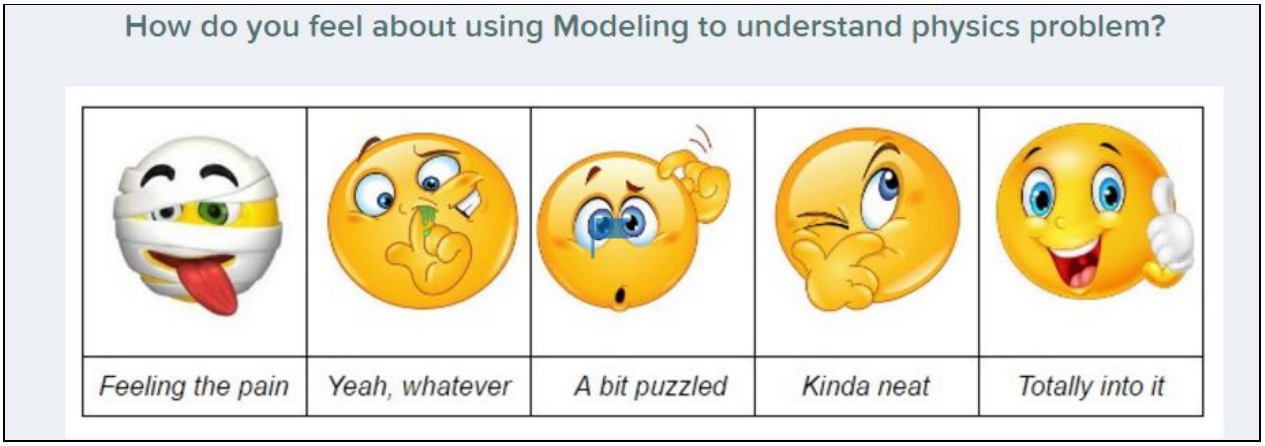
7.1. Sample Likert-scale Survey

How do you feel about solving physics problem related to Work, Power, Energy?



On a scale between 1 (not useful) and 10 (very useful), what is your opinion about using Modeling as a tool to understand physics problem?

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Not useful at all								*Very useful*	



7.2. Sample Questionnaire Responses

1. **Modelling Reflection**: "Does modeling help you to understand this problem? Why or why not?" Write at least one sentence to explain your answer.

No it doesn't help me understand this problem because I don't understand how it explains it.

Support students in making connection between modeling/diagram and solving problem

2. Analytical Reflection: "Does text marking help you to identify the variables? Why or why not?" Write at least one sentence to explain your answer.

Yes it really helps me identify the variables since it highlights what I already know and what I need to know.

---

1. **Modelling Reflection**: "Does modeling help you to understand this problem? Why or why not?" Write at least one sentence to explain your answer.

The modeling helped me to understand this problem bc it makes it obvious to see the action taking place.

2. Analytical Reflection: "Does text marking help you to identify the variables? Why or why not?" Write at least one sentence to explain your answer.

The text marking helps me to identify the variables because it makes it stand out from the rest of the text.

1. **Modelling Reflection**: "Does modeling help you to understand this problem? Why or why not?" Write at least one sentence to explain your answer.

For me, modeling is the most difficult part and if I understand it, it is helpful.

2. Analytical Reflection: "Does text marking help you to identify the variables? Why or why not?" Write at least one sentence to explain your answer.

Yes it does because it makes it easier to see what variable I am solving for.

---

1. **Modelling Reflection**: "Does modeling help you to understand this problem? Why or why not?" Write at least one sentence to explain your answer.

Modeling does help me understand because images makes me understand more than numbers

2. Analytical Reflection: "Does text marking help you to identify the variables? Why or why not?" Write at least one sentence to explain your answer.

Text marking doesn't help me that much because the numbers confuse me sometimes especially when it comes to physics

---

1. **Modelling Reflection**: "Does modeling help you to understand this problem? Why or why not?" Write at least one sentence to explain your answer.

It helps me get a better image of the problem.

2. Analytical Reflection: "Does text marking help you to identify the variables? Why or why not?" Write at least one sentence to explain your answer.

Yes because you don't have to read the whole thing you can just see what is marked.

---

1. **Modelling Reflection**: "Does modeling help you to understand this problem? Why or why not?" Write at least one sentence to explain your answer.

It helps me get a better image of the problem.

2. Analytical Reflection: "Does text marking help you to identify the variables? Why or why not?" Write at least one sentence to explain your answer.

Yes because it puts them next to their correct unit and variable.

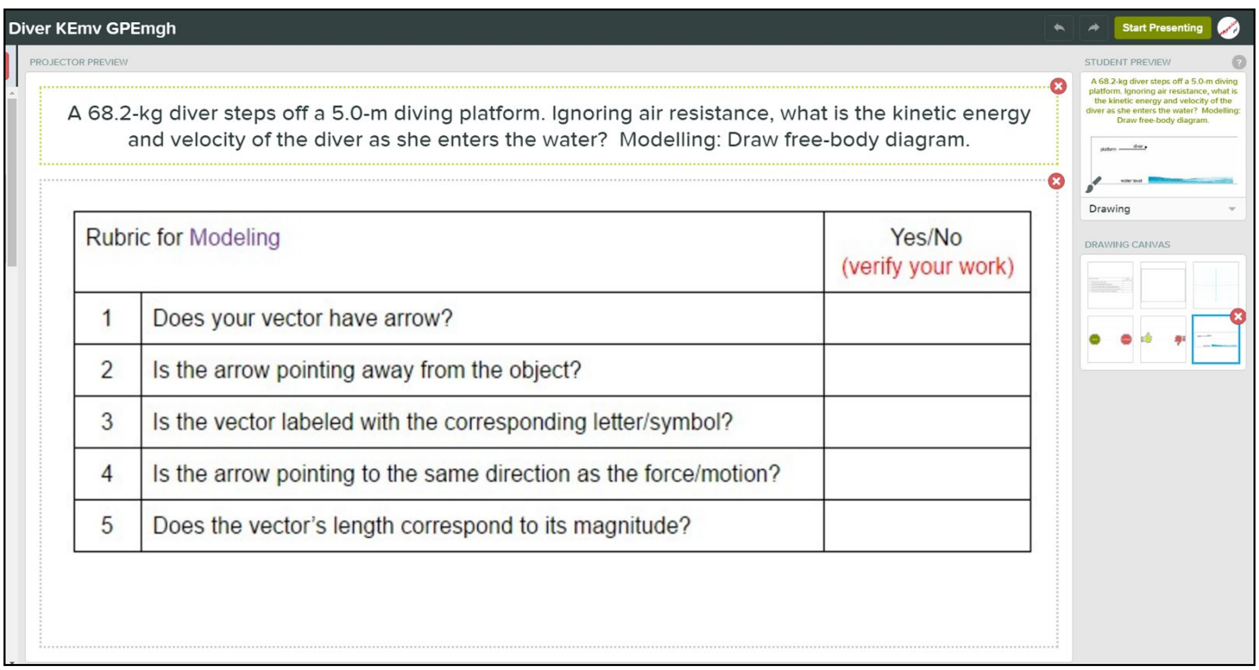
1. **Modelling Reflection**: "Does modeling help you to understand this problem? Why or why not?" Write at least one sentence to explain your answer.

Modeling kind of helps me but sometimes it confusing me because of the way the line is suppose to go.

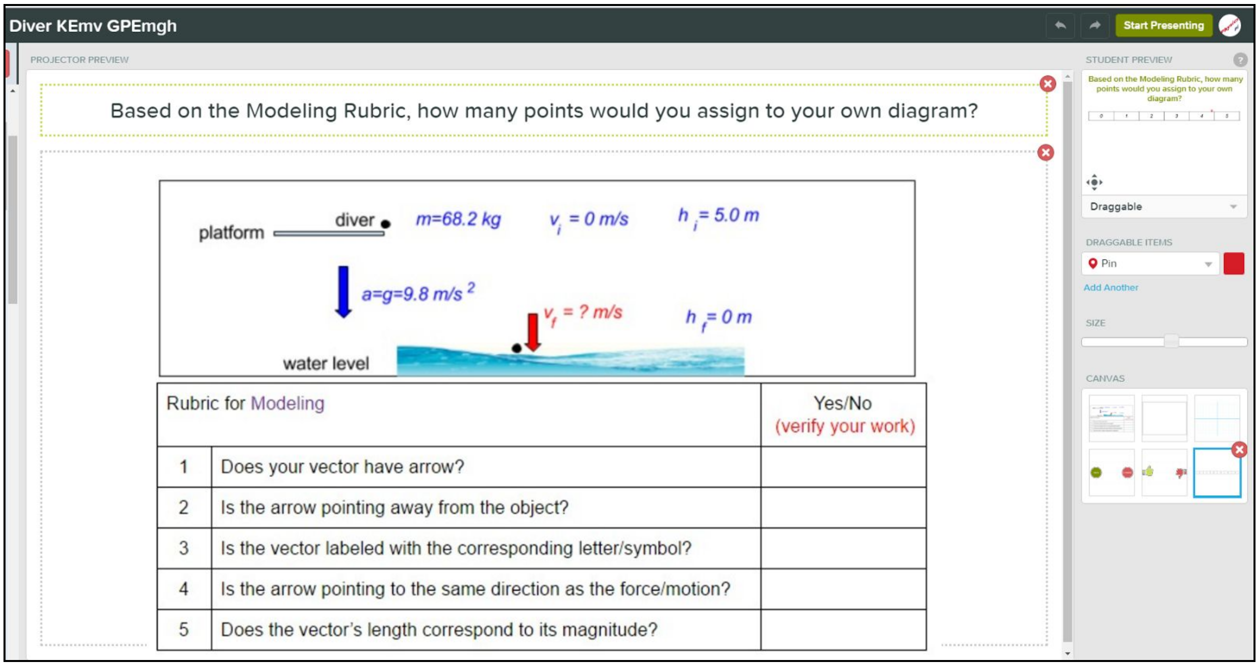
2. Analytical Reflection: "Does text marking help you to identify the variables? Why or why not?" Write at least one sentence to explain your answer.

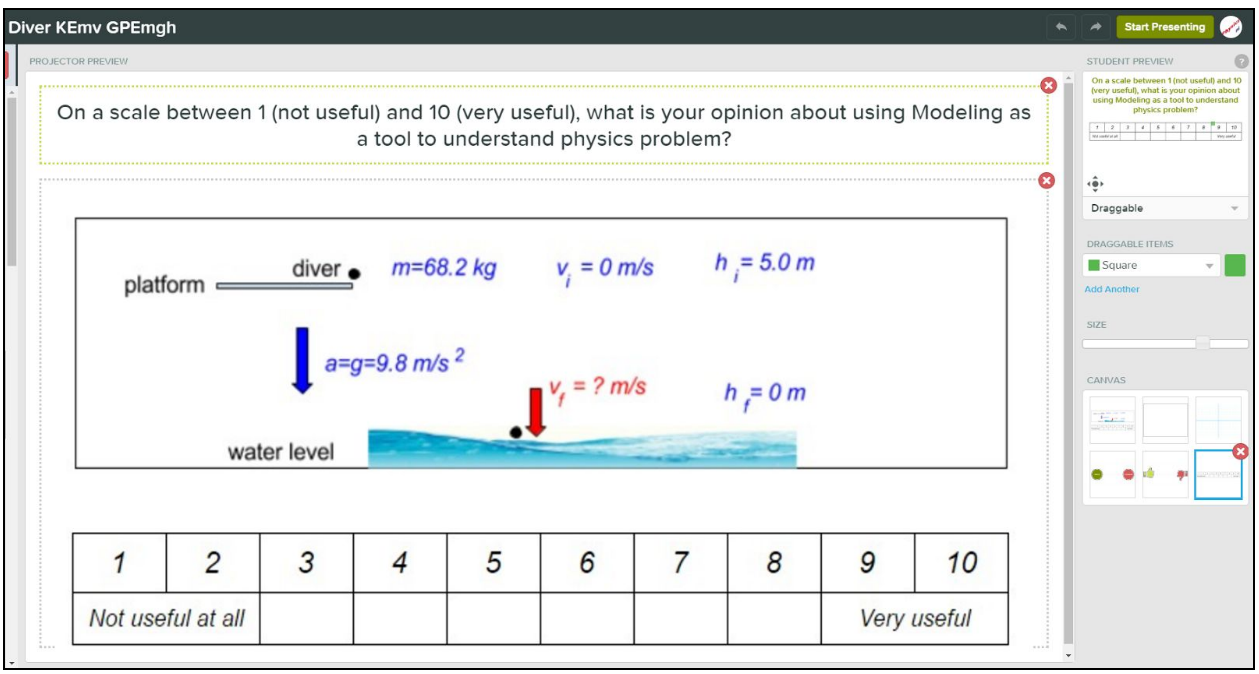
Yes text marking helps me identify the variable because it helps me what I am looking for so I won't get confused.

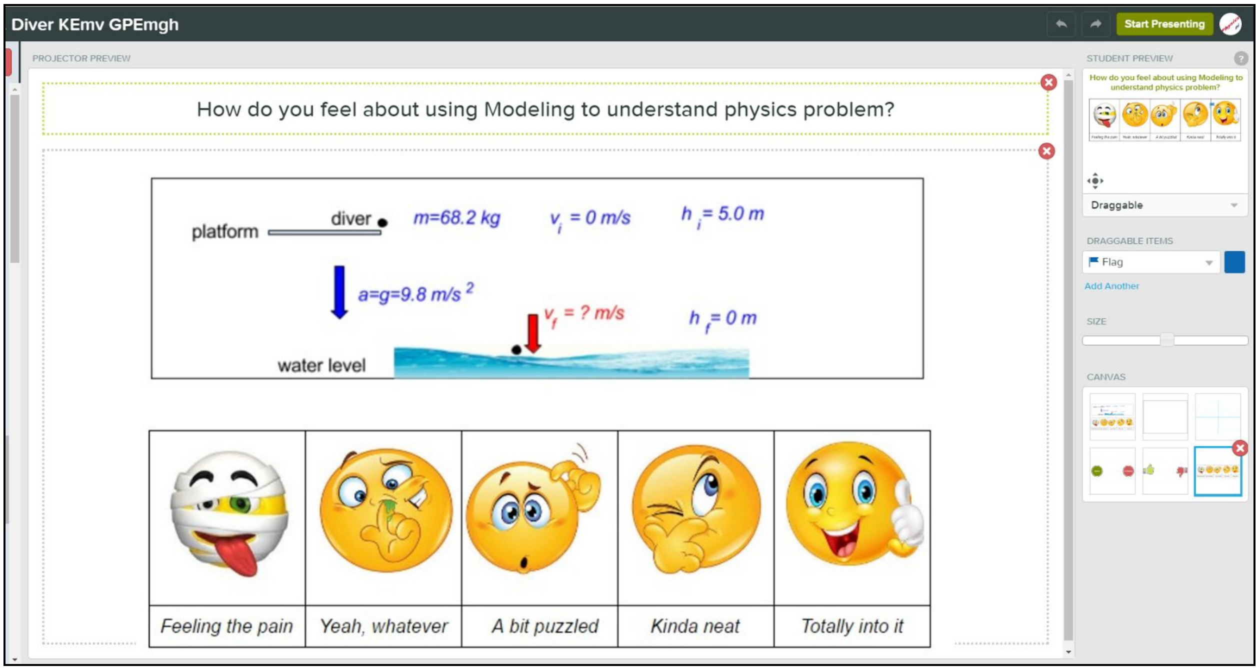
7.3. Sample Pear Deck Formative Assessment

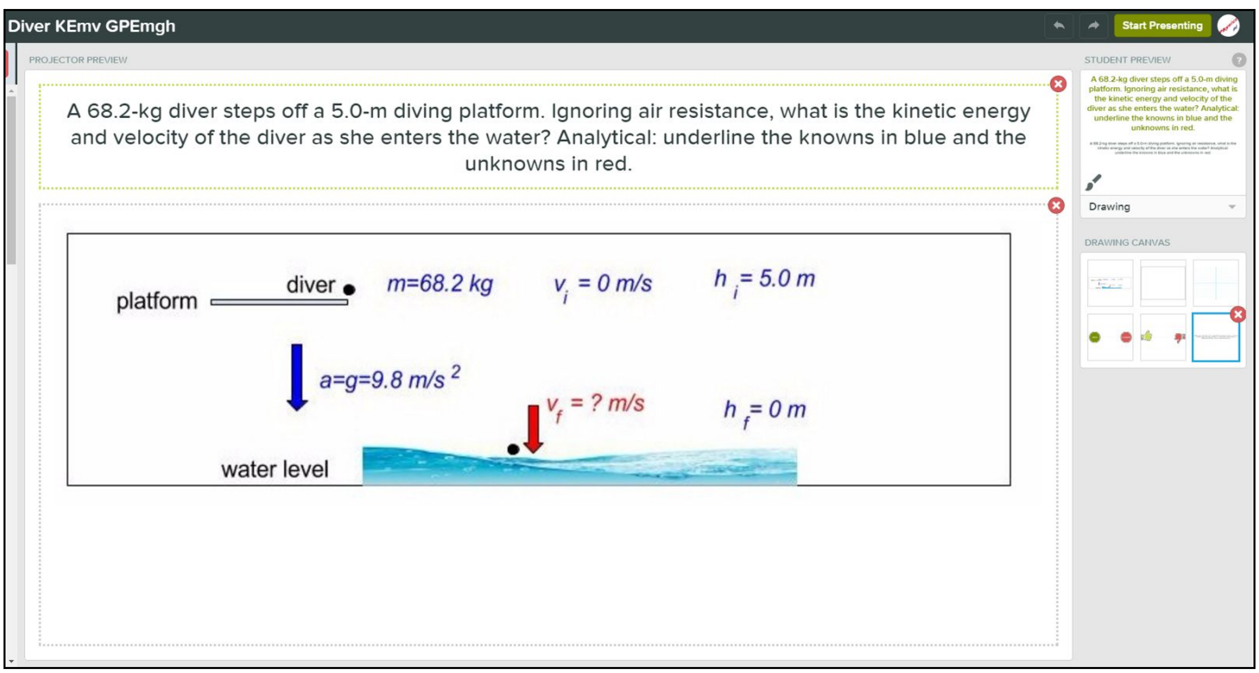


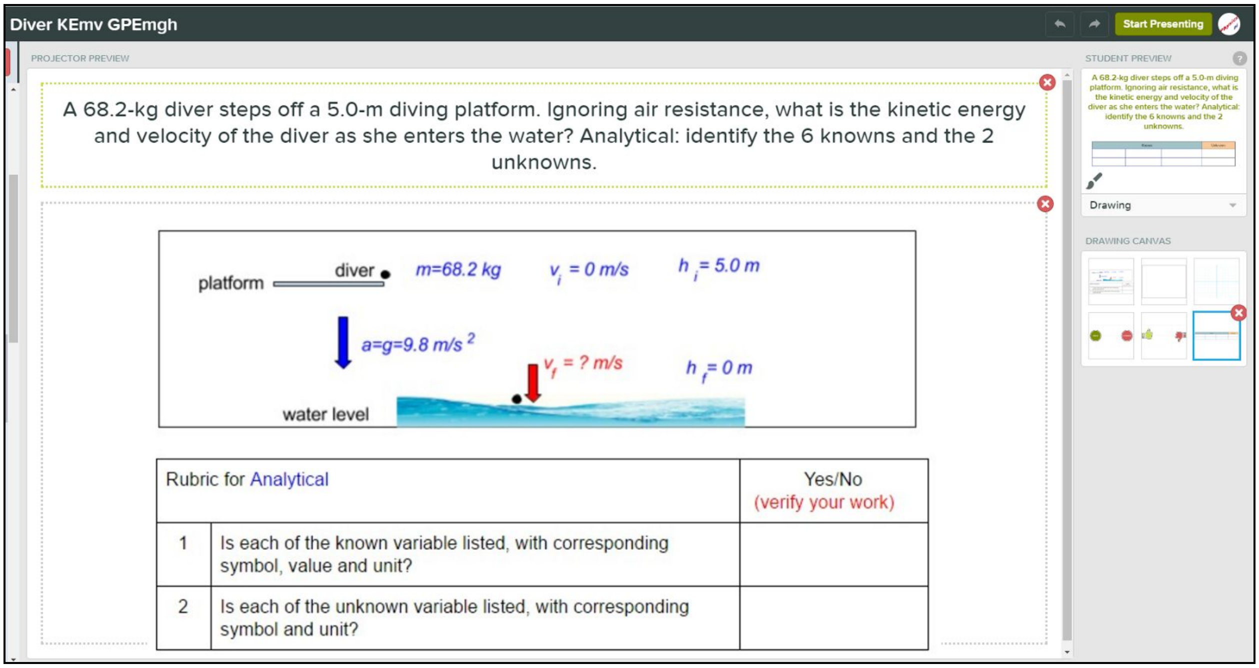
Rubric for Modeling		Yes/No (verify your work)
1	Does your vector have arrow?	
2	Is the arrow pointing away from the object?	
3	Is the vector labeled with the corresponding letter/symbol?	
4	Is the arrow pointing to the same direction as the force/motion?	
5	Does the vector's length correspond to its magnitude?	

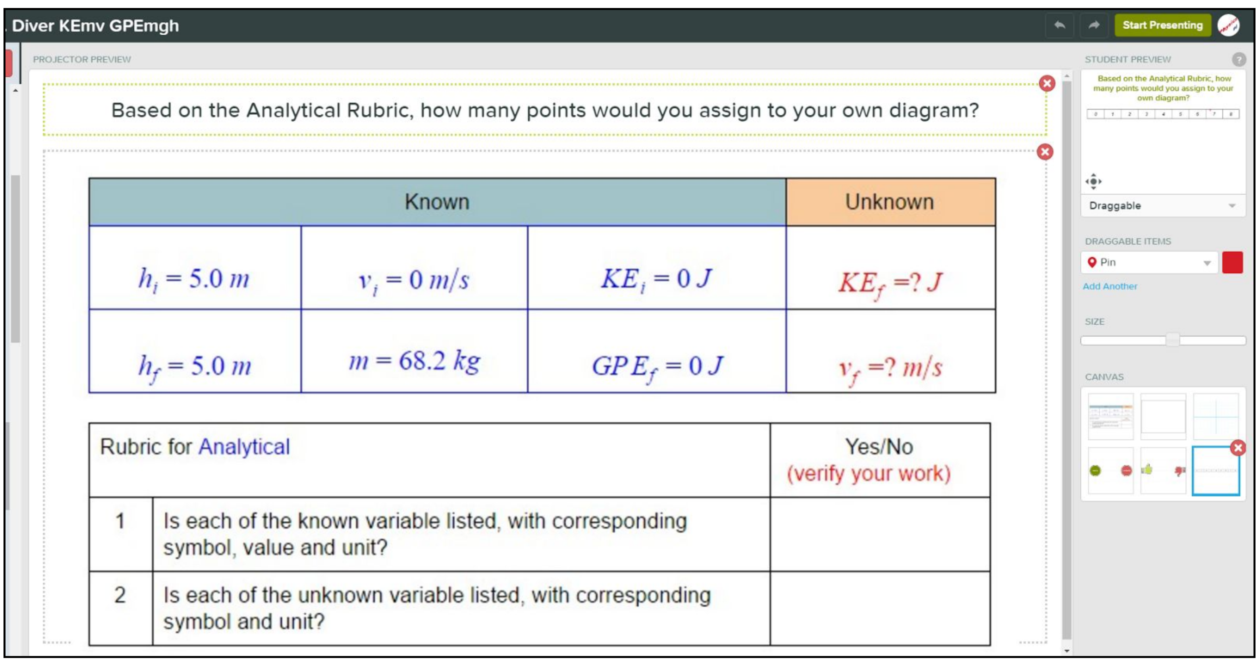

Diver KEmv GPEmgh
Start Presenting
PROJECTOR PREVIEW
Based on the Modeling Rubric, how many points would you assign to your own diagram?
platform
diver
m=68.2 kg
v_i = 0 m/s
h_i = 5.0 m
a=g=9.8 m/s 2
v_f = ? m/s
h_f = 0 m
water level
Rubric for Modeling
Yes/No (verify your work)
1 Does your vector have arrow?
2 Is the arrow pointing away from the object?
3 Is the vector labeled with the corresponding letter/symbol?
4 Is the arrow pointing to the same direction as the force/motion?
5 Does the vector's length correspond to its magnitude?
STUDENT PREVIEW
Draggable
DRAGGABLE ITEMS
Pin
Add Another
SIZE
CANVAS

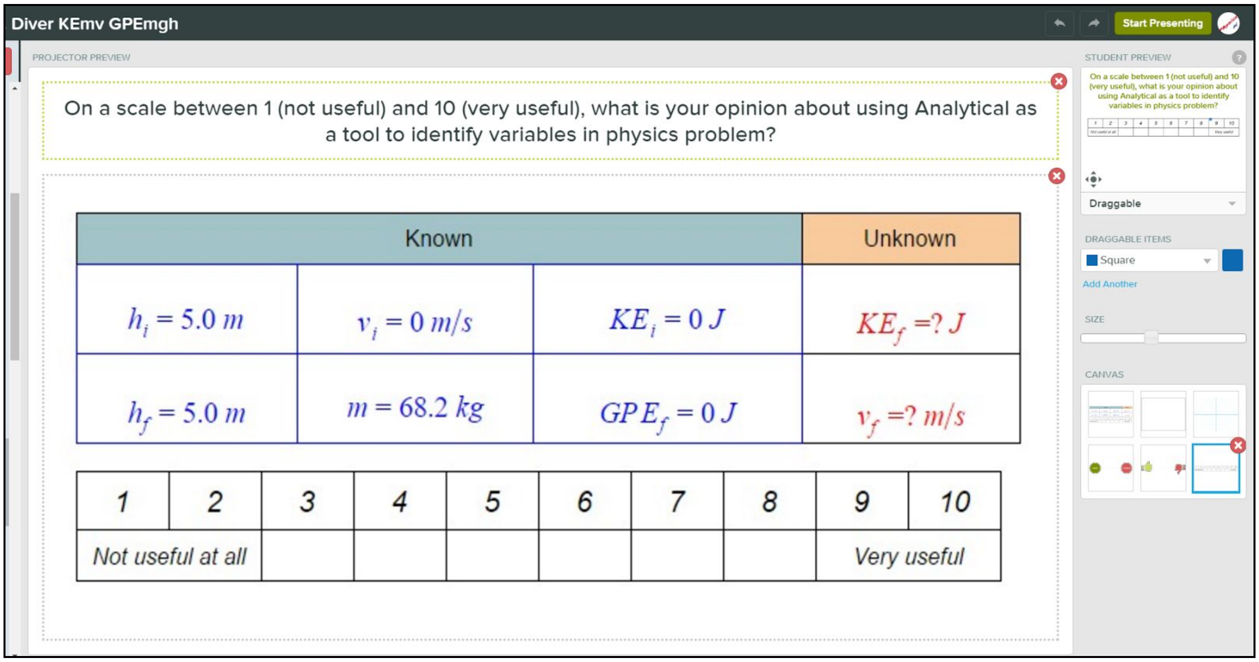

Diver KEmv GPEmgh
Start Presenting
PROJECTOR PREVIEW
On a scale between 1 (not useful) and 10 (very useful), what is your opinion about using Modeling as a tool to understand physics problem?
platform
diver
m=68.2 kg
v_i = 0 m/s
h_i = 5.0 m
a=g=9.8 m/s 2
v_f = ? m/s
h_f = 0 m
water level
1 2 3 4 5 6 7 8 9 10
Not useful at all
Very useful
STUDENT PREVIEW
Draggable
DRAGGABLE ITEMS
Square
Add Another
SIZE
CANVAS

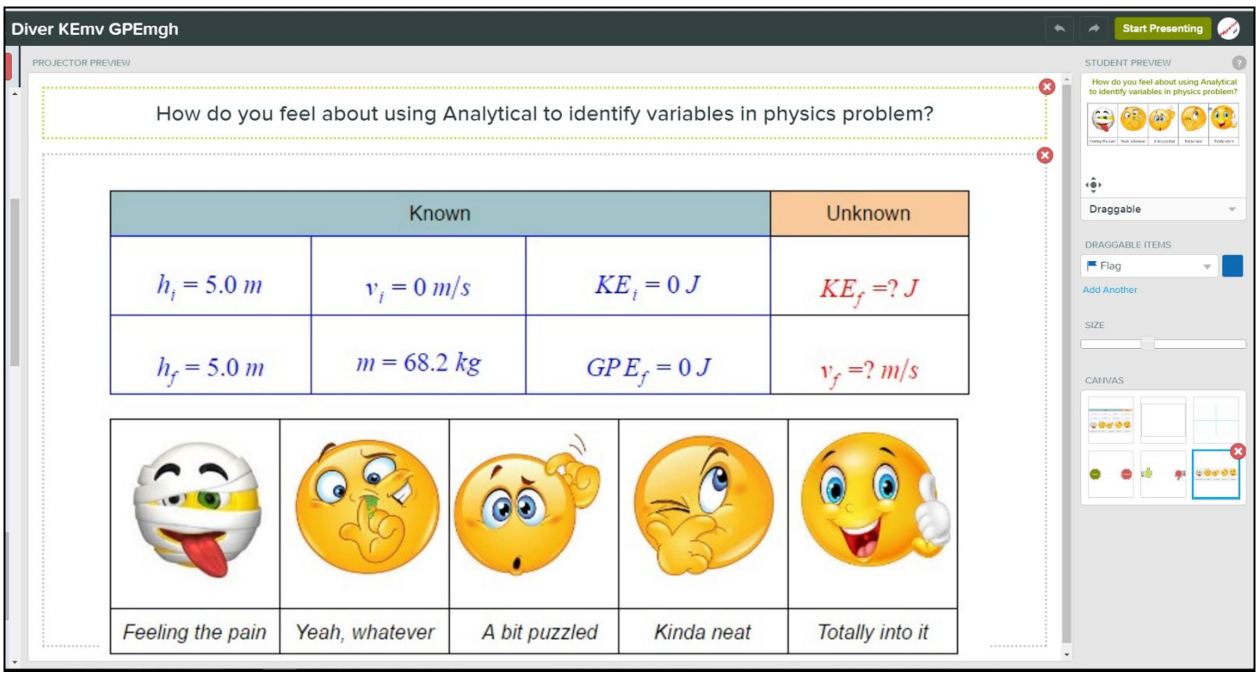

Diver KEmv GPEmgh
Start Presenting
PROJECTOR PREVIEW
How do you feel about using Modeling to understand physics problem?
platform
diver
m=68.2 kg
v_i = 0 m/s
h_i = 5.0 m
a=g=9.8 m/s 2
v_f = ? m/s
h_f = 0 m
water level
Feeling the pain
Yeah, whatever
A bit puzzled
Kinda neat
Totally into it
STUDENT PREVIEW
How do you feel about using Modeling to understand physics problem?
Draggable
DRAGGABLE ITEMS
Flag
Add Another
SIZE
CANVAS


Diver KEmv GPEmgh
Start Presenting
PROJECTOR PREVIEW
A 68.2-kg diver steps off a 5.0-m diving platform. Ignoring air resistance, what is the kinetic energy and velocity of the diver as she enters the water? Analytical: underline the knowns in blue and the unknowns in red.
platform
diver
m=68.2 kg
v_i = 0 m/s
h_i = 5.0 m
a=g=9.8 m/s 2
v_f = ? m/s
h_f = 0 m
water level
STUDENT PREVIEW
A 68.2-kg diver steps off a 5.0-m diving platform. Ignoring air resistance, what is the kinetic energy and velocity of the diver as she enters the water? Analytical: underline the knowns in blue and the unknowns in red.
Drawing
DRAWING CANVAS


Diver KEmv GPEmgh
Start Presenting
PROJECTOR PREVIEW
A 68.2-kg diver steps off a 5.0-m diving platform. Ignoring air resistance, what is the kinetic energy and velocity of the diver as she enters the water? Analytical: identify the 6 knowns and the 2 unknowns.
platform
diver
m=68.2 kg
v_i = 0 m/s
h_i = 5.0 m
a=g=9.8 m/s²
v_f = ? m/s
h_f = 0 m
water level
Rubric for Analytical
Yes/No (verify your work)
1 Is each of the known variable listed, with corresponding symbol, value and unit?
2 Is each of the unknown variable listed, with corresponding symbol and unit?
STUDENT PREVIEW
Drawing
DRAWING CANVAS


Diver KEmv GPEmgh
Start Presenting
PROJECTOR PREVIEW
Based on the Analytical Rubric, how many points would you assign to your own diagram?
Known
Unknown
h_i = 5.0 m
v_i = 0 m/s
KE_i = 0 J
KE_f =? J
h_f = 5.0 m
m = 68.2 kg
GPE_f = 0 J
v_f =? m/s
Rubric for Analytical
Yes/No (verify your work)
1 Is each of the known variable listed, with corresponding symbol, value and unit?
2 Is each of the unknown variable listed, with corresponding symbol and unit?
STUDENT PREVIEW
Draggable
DRAGGABLE ITEMS
Pin
Add Another
SIZE
CANVAS


Diver KEmv GPEmgh
Start Presenting
PROJECTOR PREVIEW
On a scale between 1 (not useful) and 10 (very useful), what is your opinion about using Analytical as a tool to identify variables in physics problem?
Known
Unknown
$h_i = 5.0\ m$
$v_i = 0\ m/s$
$KE_i = 0\ J$
$KE_f = ?\ J$
$h_f = 5.0\ m$
$m = 68.2\ kg$
$GPE_f = 0\ J$
$v_f = ?\ m/s$
1 2 3 4 5 6 7 8 9 10
Not useful at all
Very useful
STUDENT PREVIEW
Draggable
DRAGGABLE ITEMS
Square
Add Another
SIZE
CANVAS


Diver KEmv GPEmgh
Start Presenting
PROJECTOR PREVIEW
How do you feel about using Analytical to identify variables in physics problem?
Known
Unknown
$h_i = 5.0\ m$
$v_i = 0\ m/s$
$KE_i = 0\ J$
$KE_f = ?\ J$
$h_f = 5.0\ m$
$m = 68.2\ kg$
$GPE_f = 0\ J$
$v_f = ?\ m/s$
Feeling the pain
Yeah, whatever
A bit puzzled
Kinda neat
Totally into it
STUDENT PREVIEW
Draggable
DRAGGABLE ITEMS
Flag
Add Another
SIZE
CANVAS

Rubric for Modeling		Yes/No (verify your work)
1	Does your vector have arrow?	
2	Is the arrow pointing away from the object?	
3	Is the vector labeled with the corresponding letter/symbol?	
4	Is the arrow pointing to the same direction as the force/motion?	
5	Does the vector's length correspond to its magnitude?	

Rubric for Analytical		Yes/No (verify your work)
1	Is each of the known variable listed, with corresponding symbol, value and unit?	
2	Is each of the unknown variable listed, with corresponding symbol and unit?	