REACHING BEYOND TEXTBOOKS AND LECTURES: LEARNING EXPERIENCES IN AND OUT OF THE CLASSROOM

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ABSTRACT

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by James Brian Hancock, II

In an effort to better engage students and the public in learning physics concepts, novel pedagogies, strategies for outreach, and tools to foster metacognition are explored. The main objective of the experimental pedagogy is to investigate the effectiveness of Minds-on Audio-Guided Activities (MAGA) when used in introductory college physics survey courses. These audio podcasts serve as a verbal guide through kinesthetic, all-body experimentation. Average learning gain on pre- and post-test assessment provided limited evidence because of the small sample size. Qualitative assessment suggests a propensity for MAGA to stimulate longer-term retention of topics. The outreach investigation on the development and design of a museum-quality physics merry-go-round considered factors such as safety, size, cost, and adaptability as well as applications in physics. Additionally, framework is developed to empower students to self monitor their own cognitive progress related to physics concepts as presented in introductory level algebra-based physics courses.

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INTRODUCTION

Physics Education Research (PER) is the study of educational best practices and developments in teaching physics. Today more than ever, there is an increased focus of science, technology, engineering, and mathematics (STEM) in education for secondary and post-secondary students and teachers. The expected outcome is that increasing the literacy and understanding of scientific and mathematical concepts will help drive economic development. Consequently, research in how to best teach STEM disciplines has seen a dramatic upswing due to the vast audience STEM courses now attract.

PER investigates how students best learn physics of all levels. In this context, a student is the individual that is approaching the learning, and can be any age. Research shows new methodologies used to teach physics help students achieve a better understanding of concepts. This research is in response to documented findings on the limited progress of many students towards conceptual understanding (Hestenes, Wells, & Swackhamer, 1992). In an effort to increase deeper understanding, positive perception, and long-term learning, PER is typically categorized in three main sub-areas: experimental pedagogy, outreach, and cognitive studies. This chapter will outline the motivation behind my research in these three areas of PER.

PER is not simply curriculum development or instructional design. It is an in-depth investigation into the challenges and difficulties students face as they work to resolve the concepts of physics, both in formal (classroom) and informal (public) settings. PER falls into two primary categories: basic and applied. Basic PER investigates patterns in student responses on a given topic via a pre-determined instrument of assessment. Research could be limited to studying one course at a single institution or multiple courses across numerous institutions. Applied PER is the modification of instruction based on the findings from basic PER in an effort to address issues discovered by foundational research. Additionally, there is a growing subset of research investigating socio-cultural issues like learning in collaborative groups, discourse models, etc. (R. Beichner, 2009).

Likewise, studies in cognitive research focus on understanding how people learn. This is a complex mixture of multiple fields, including studies ranging from anthropology to neurophysiology. Research shows people tend to organize experiences into patterns to form mental models. Consequently, it is relatively easy for a student to learn something that simply matches or extends their existing model. However, this is why it can be so difficult to change a student's schema on a particular concept. In addition, each student will form individualized models based on their own prior experiences and other external influences. This explains the highly diverse nature of learners; no two students are alike, nor will they create identical mental representations. This also accounts for the variation in learning style preferences, although research shows preferences do not indicate a lack of capability (Redish, 1994).

Investigations in both cognitive research and more traditional, classroom-based PER can be applied to public settings in the form of outreach. Advancing the general knowledge and appreciation of physics is a primary goal of outreach-based PER. Outreach can take many forms, from science museums to television programs to online-based interactive media. Work in outreach also helps to develop more user-friendly laboratory equipment as is typically found in high schools and undergraduate laboratories.

Physics Experimental Pedagogies

Lecturing is the primary method many post-secondary educators use to teach courses. In a typical lecture-style educational setting, instructors deliver material to students orally with the aid of written notes on a board, content on a projected document camera, or by using a digital media (e.g. Microsoft PowerPoint) slide show presentation. Economic and historical reasons dominate the justification for teaching students in large halls by single instructors. The sheer cost benefit alone by increasing the number of students able to take a particular course prompts many educational institutions to continue education by lecture instruction. Likewise, many secondary and post-secondary instructors are taught by lecture; therefore continuing to teach in that manner follows naturally from their prior experiences in the classroom.

Despite the advancement of classroom technology (e.g. document cameras, projection systems, clicker-response systems, and other novel educational inventions over the years), students are usually not primed to be active learners in the classroom. Due to the nature of lecturing, it can be very difficult for even an experienced instructor to engage the students, especially in large lecture settings. Most in-class learning is passive, that is, the student's *real-time* involvement in the classroom is typically restricted to taking notes on material and example problems. After years of similar educational experiences, most students adapt to this style of instruction and eventually assimilate their own learning preferences with that of lecturing.

In an effort to increase student involvement in the classroom, some developments in PER include Peer Instruction (Mazur, 1999), Just In Time Teaching (Patterson, Garvin, & Christian, 1999), Problem-Based Learning (Duch, Groh, & Allen, 2001), and Interactive Lecture Demonstrations (Sokoloff & Thornton, 1997). The overarching theme of all new physics teaching methodologies is the concept of active engagement. In education, the focus has shifted from discussions on teaching to discussions on student learning. Traditionally, instructors approached the classroom with the question of, “How will *I teach* this material?” The emphasis in this scenario is on the instructor’s ability to teach. In reality, the question posed by those in PER and other education-related fields is typically, “How will my *students best learn* the material?” Here the emphasis is on student learning, which does not necessarily coincide with ease or time-effectiveness of teaching material.

Interactive engagement methods “are those designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors” (Hake, 1998). In interactive engagement methods, the focus of in-class time is to guide students through the process of learning while providing the environment and stimuli to further their understanding of the content. The benefits of active learning methodologies such as interactive engagement techniques are evident in overall learning (Bestwick & Campbell, 2010; Hake, 1998; Keiner & Burns, 2010; Mazur, 1999; McDermott, 1991; Meltzer & Manivannan, 2002).

Full instructional redesigns, such as the SCALE-UP (Student-Centered Activities for Large Enrollment Undergraduate Programs) model developed by researchers at

North Carolina State University, incorporate interactive engagement methods into a studio-format instead of large lecture instruction. This redesign has since been reproduced in multiple institutions with continued success compared to the large lecture settings SCALE-UP replaced. Analysis of SCALE-UP methods show increased students' conceptual understanding, attitudes, attendance, and performance in subsequent physics courses, while decreasing overall failure rates relative to traditional classrooms (R. J. Beichner et al., 2007).

Another example of an interactive engagement technique in PER incorporates peer-to-peer discussion in an effort to help students better conceptualize topics in physics. Peer Instruction was developed by Eric Mazur of the Department of Physics at Harvard University. In Peer Instruction, a large component of student learning is placed on the interaction between students. Learning from peer questions and peer teaching has proven to be an effective method of increasing student achievement in the classroom, when compared with more traditional teaching methods (Crouch & Mazur, 2001). However, even in ideal settings, Peer Instruction does have limitations. A cornerstone of this instructional method is solid group dynamics and students' willingness to actively participate during class. If students do not engage in the learning environment, Peer Instruction can be a challenge. Additionally, there are limits on material coverage, both in terms of content depth and breadth, when teaching only with these methods.

Assessment of Experimental Pedagogy

Incorporating experimental teaching methodologies into the classroom helps researchers learn how different instructional strategies affect student learning. There are many metrics researchers have employed over the years to evaluate the effectiveness of physics teaching and learning. However, in 1998 Richard Hake from the department of Physics at Indiana University, Bloomington, developed a method for assessing the knowledge students *gained* due to a particular teaching methodology over the course of an instructional period (Hake, 1998).

Consider, for example, using only mid-term or final examinations as a metric for measuring the effectiveness of a particular teaching method. While some of the overall knowledge of the student will be reflected on the final score, there is no way of assessing whether or not the methodologies used over the semester affected that student's final score. The most obvious issue with post-test-only assessment is the inability to account for pre-knowledge each student brought into the class (whether correct or incorrect). For this reason, it is useful to have a comparison of pre-test and post-test scores, where individuals are categorized based on the amount of knowledge they theoretically gained over the course of the instructional period.

In Hake's method, average normalized learning gain, $\langle g \rangle$, is calculated by taking the difference between post-test and pre-test scores and dividing that quantity by the difference between a perfect pre-test score (100%) and their actual pre-test score. While calculating learning gain on the individual is useful to track a student's progress through a semester on various topics, typically as educators we are interested in the average response of a group of students to a particular pedagogical method.

Therefore, calculating the average normalized learning gain over the entire student body (an entire class, for example) is a useful metric to evaluate how well students responded to a particular instructional method:

$$\langle g\rangle = \tfrac{1}{N}\sum_{1}^{N}\left\{\frac{\text{Posttest \% - Pretest \%}}{\text{100\% - Pretest \%}}\right\}$$

In practice, one example where learning gain has been employed extensively is with the Force Concept Inventory (FCI) test (Hestenes et al., 1992). This test focuses on basic concepts in mechanics typically covered in the first semester of an introductory physics course sequence. Over the past twenty years the FCI has been used to document learning gains in thousands of introductory physics courses and is considered a benchmark in PER. For example, in a study by Richard Hake at Indiana University in 1998, FCI scores were analyzed from fourteen courses taught with little or no use of interactive engagement methods and 48 courses taught with interactive engagement methods. Average learning gain for the traditional courses was 0.23 +/- 0.04, while average gain for the interactive engagement courses was 0.48 +/- 0.14 (Hake, 1998).

However, since the FCI is a multiple-choice test the depth of questioning in the assessment is limited. While multiple-choice tests do provide a measurement that can be easily quantified, there exist pitfalls due to the limited answer nature of tests written in that style. Additionally, the primary focus of the FCI is on forces, therefore leaving out a significant portion of content traditionally covered in the first semester of the introductory physics course sequence.

One important measure of the effectiveness of instruction is students' ability to retain concepts over the long-term. Although traditional tests, such as the FCI, do provide a metric on which to quantify data, qualitative tools may be appropriate to measure concepts retained over periods longer than a semester or an academic year. By the nature of qualitative assessment, an instructor is able to probe deeper into the level of understanding than can be done by a traditional test. While drawing conclusions from student responses in this scenario can be difficult, qualitative assessment does serve as a very informative form of measurement. Therefore, while the FCI and other traditional tests are highly regarded as benchmarks of learning assessment in introductory physics courses, there do exist limitations on their comprehensive ability to capture a student's actual progress.

Statistical Methods

In addition to understanding the gain associated with a particular teaching method and class, understanding the significance of that methodology relies on the comparison in performance of an experimental group with that of a control group. Bias between these groups is by far the largest source of error in educational statistics. However, the best way researchers can reduce the biased nature of sampling is by randomizing the control and experimental group selection process.

Sometimes, when considering multiple sections of an introductory physics course, the instructor may choose to deliver experimental pedagogy to one section and incorporate traditional methods (the control) in another section. Likewise, if the control and experimental groups originate from the same section of a course (but instructed separately), it is equally important to understand whether or not the two groups can be considered identical. Any differences in either group before and/or after instruction can be understood with statistical tests performed on pre- and post-test assessments.

The Student t-test is commonly used in educational statistics to classify whether or not an experimental pedagogy is likely to be the origination of any difference in learning gain over the instructional period. The t-test is used when the sample size is smaller than 30, since one cannot count on a normal distribution. The t-distribution has heavier tails than a normal distribution and will result in larger confidence intervals for a given, smaller, sample size. As the number of students increases over 30, the t-distribution converges to the normal distribution (Myatt, 2006). When comparing two samples, the assumption is that the two will provide the same statistical mean (null hypothesis). The alternative, or research, hypothesis results when the null hypothesis is rejected because the required confidence level is reached.

The t-test is a 'signal-to-noise' ratio between the mean of each group (signal) to the variability between the groups (noise). Since the sample sizes are considered to be in the small-size range of the student t-test, the pooled standard deviation, s_p, is calculated from the pooled variance, s_p^2:

$$s_p^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{(n_1 - 1) + (n_2 - 1)}$$

Where n_1, n_2, s_1^2, s_2^2 represent the experimental sample size, the control sample size, the experimental variance, and the control variance, respectively. The t-score is therefore defined as:

$$t = \frac{(\bar{x}_1 - \bar{x}_2) - (\bar{\mu}_1 - \bar{\mu}_2)}{s_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

Where $\bar{x}_1, \bar{x}_2, \bar{\mu}_1, \bar{\mu}_2$ represent the experimental sample mean, the control sample mean, the experimental population mean, and control population mean, respectively.

The t-score, in combination with the number of degrees of freedom for a given sample (n – 1 or n – 2, depending on the scenario), can be used to determine the probability the differences in means between two groups are due to random chance (called the p-value). To do so, one must first establish a confidence level, called the alpha level, which sets the probability that any difference between the two groups is due to random chance. In education and most social research, the commonly accepted alpha value is 0.05. This indicates there is only a 5% chance that differences in the two groups is due only to random chance and in reality, there is no significant difference in the groups. Therefore, the alpha value is only a chosen parameter, and it does not expressly eliminate the possibility that true differences exist for p-values greater than the confidence level or that they do not exist for p-values less than the alpha level.

Using the t-score and the number of degrees of freedom, researchers can calculate the p-value associated with their data and compare this with the alpha value. For example, in Microsoft Excel the TDIST function calculates the p-value that corresponds to the integral of the probability distribution curve (Student (William Sealy Gosset), 1908):

$$y = \frac{1}{2}\frac{n-2}{n-3}\cdot\frac{n-4}{n-5}\cdots\frac{5}{4}\cdot\frac{3}{2}\left(1+t^2\right)^{-\frac{1}{2}n}, \text{ if } n \text{ is odd}$$

$$y = \frac{1}{2}\frac{n-2}{n-3}\cdot\frac{n-4}{n-5}\cdots\frac{4}{3}\cdot\frac{2}{21}\left(1+t^2\right)^{-\frac{1}{2}n}, \text{ if } n \text{ is even}$$

Researchers use information provided by the t-test to determine the likelihood any difference in the two groups is due to random chance. The null hypothesis states that the two groups are identical, and any difference between the groups is indeed due to chance. Conversely, the alternative hypothesis states that the experimental and control groups are different. From the information provided by the t-test, researchers either reject or fail to reject the null hypothesis of the experiment.

For example, to determine the effect of experimental teaching on normalized learning gain one must first use pre-test data to determine whether the control and experimental groups are statistically identical at the beginning of an experiment. Consider the two groups in Table (1). From this hypothetical data, one can easily calculate the mean of each group's pre-test and the variance of each group. The mean pre-test score for the control group is 12.065; the variance is 32.662. The mean pre-test score for the experimental group is 12.069; the variance is 30.352. The pooled variance can then be calculated as indicated previously:

$$s_p^2 = \frac{(29-1)*(30.352)+(31-1)*(32.662)}{(29-1)+(31-1)} = 31.547$$

and the t-score calculation follows:

$$t = \frac{(12.069-12.065)}{\sqrt{31.547}*\sqrt{\frac{1}{29}+\frac{1}{31}}} = 0.003$$

The p-value can be determined using this t-score, the number of degrees of freedom (29 + 31 – 2 = 58), and the number of tails from the distribution pattern. In this example, the p-value describes the probability that the groups are statistically similar and that any difference is due to random chance. A two-tailed distribution is required since it is unclear if the experimental or control group will perform better. Using the TDIST function in Microsoft Excel (or simply looking up the values in a table of calculated p-values), the t-score can be used to determine the p-value. In this example, the p-value is 0.9976, indicating there is effectively a 99.76% chance the two groups are, in fact, identical prior to instruction.

After the probability has been determined that the control and experimental groups are identical, the calculation of normalized learning gain can help researchers

Table (1). Sample Groups

Control Group

Pre-test	Post-test	Normalized Gain
7	11	0.17
9		
7		
12		
13	15	0.12
14		
7		
6		
17	16	-0.08
7		
6	10	0.17
8	14	0.27
11	14	0.16
15		
20	27	0.70
17		
9		
22	30	1.00
14	14	0.00
24	25	0.17
10		
7	16	0.39
16		
12	9	-0.17
25		
13	15	0.12
6	7	0.04
11	10	-0.05
2		
18	21	0.25
9		

Experimental Group

Pre-test	Post-test	Normalized Gain
7		
13		
17	17	0.00
14		
7	9	0.09
15		
5	17	0.48
7	14	0.30
17		
8	10	0.09
7		
6	7	0.04
14		
9		
21	23	0.22
10		
11		
12	13	0.06
10	10	0.00
13	13	0.00
9		
25	24	-0.20
12	9	-0.17
3		
16	20	0.29
18	18	0.00
7	7	0.00
24	27	0.50
13		

quantitatively determine the effectiveness of a given pedagogical method. This data can then be used in a t-test to determine whether there exist any statistical differences between the two pedagogical methods. Continuing analysis from the previous example, calculations can be found in Table (2). In this example, the p-value for the post-test is 0.6648, indicating a 66% chance that the two groups were in effect identical. Likewise, the p-value for normalized gain is 0.2826, indicating only a 28% chance the groups were effectively identical after instruction. In this example, all three p-values fail to meet the previously set reference confidence level of 0.05 necessary to reject the null hypothesis. Therefore, there is no statistical evidence the experimental methods produced differences in normalized learning gain that are significant.

Table (2). Sample Calculations

	Pre-test	**Post-test**	**Normalized Gain**
Pooled Std. Deviation:	5.62	6.46	0.25
t-score:	0.003	0.438	1.094
Degrees of Freedom:	58	30	30
Tails:	2	2	2
P-Value:	**0.9976**	**0.6648**	**0.2826**

Qualitative Assessment

Quantitative measurements help researchers and instructors categorize learning, but limitations arise in the thoroughness and depth of the probing that expands across many different dimensions. A multiple-choice test possesses the least amount of instructor bias in grading, however a limited selection of answers ultimately guides students towards a thought process (and therefore a selection process). While there are many ways to help increase the depth and breadth of quantitative assessments, such as incorporating multiple-choice questions with more than one correct answer, it can be informative to understand more holistically the level of learning attained due to a given instructional technique.

In this regard, researchers often prefer to seek more detail on a particular delivery method, content question, or conceptual aspect, which can be provided through qualitative analysis techniques. Similar to quantitative methods, qualitative research uses evidence to support claims about instruction or student learning. In qualitative research, investigators use inductive analysis to “derive trends, concepts, themes, or model(s) through multiple reads of the data” (Otero & Boyd Harlow, 2009).

Qualitative assessment measures include, but are not limited to, written short answer response, modified multiple choice (where students write *why* they chose the answer they indicated), and oral examinations. On the surface, these can be difficult to measure objectively, but methods exist to help gain meaningful insight from these assessment methods.

For example, in a *semi-structured* oral examination, researchers can follow a pre-determined but open line of questioning to probe deeper within a concept. Questions should become more complex as the interview progresses, and students are ranked based on how far they are able to proceed on the pre-determined path as well as how well they perform on each level of questioning. This information can then be analyzed using a pre-determined rubric.

In a semi-structured interview, students are asked questions that are open-ended but guide students towards a particular topic. Conversely, in an *unstructured* interview, questions are very general and meant to let the student completely guide the topic of conversation. In a *structured* interview, questions are very straightforward and typically do not provide room for elaboration. For example, a question one could ask during an *unstructured* interview would be, “Can you tell me about the topics you understood the most in this course?” Conversely, in a *completely structured* interview, the researcher may ask, “Can you give an example where the concept of friction applies in driving your car?” While in *semi-structured* interview, the question may be, “Can you discuss the concept of friction and relate it to a practical example in the real world?”

These three formats of interview styles can all be informative but to varying degrees. In an *unstructured* interview, one may discover new opinions, trends, and student thought processes. In a *completely structured* interview, one may discover the ability of an individual to think or answer one particular question correctly. Additionally, in a *semi-structured* interview, one may gain an understanding of the confidence level of the individual but due to the freedom of discussion, may never get to a single, pre-defined (goal) answer. Analyzing information from qualitative investigations can be difficult, but overall it can provide a broad picture of student learning.

Outreach

In addition to developing novel methodologies for use in classroom settings, PER also investigates the perception and advancement of physics in the form of outreach. One goal of PER is to help the general public better understand how the concepts of physics pertain to everyday life. Concepts from both experimental classroom investigations and cognitive research can apply to outreach areas. Applications of PER in outreach areas include, but are not limited to, the development of in-class demonstrations, computer-based simulations, laboratory equipment, and interactive learning exhibits such as those found in museums.

Non-traditional learning environments, such as those found in museums and historical sites, are at the forefront of outreach in all disciplines. Specific to physics, many science-oriented museums draw a broad audience of both young and old visitors with a vast range of academic interests, abilities, and motivations. Consequently, understanding the most effective ways to reach the (target) audience to best convey the goals of the institution is extremely important.

In the creation of outreach-specific equipment there are three main areas of consideration: theoretical development, equipment design, and equipment fabrication. The theoretical development phase focuses on isolating the specific purposes of the equipment. The goal of this development phase is to answer the question, “What should the learner get out of this equipment?” Defining the answer to that question is complex and involves understanding the educational psychology of the target audience, physical limitations on the equipment (space, size, weight), accessibility goals for those with limited mobility, as well as cost considerations. Typically the development phase is tied very closely with the design phase of equipment production.

The design phase is a combination of art and science. Equipment that is not aesthetically appealing will never draw the learner in to experiment; equipment that does not meet the pre-determined goals does not serve its primary purpose and is therefore an expensive, non-educational toy. Tying the developmental goals of the equipment together with the realities of production involves a working knowledge of materials, fabrication, and safety considerations, as well as an understanding of the desired educational goals and outcomes.

The final product is an amalgamation of input from developers, designers, customers, fabricators, and other stakeholders for a given piece. As in teaching, outreach is a broad combination of a number of skill sets. Therefore, it is key to have an understanding of the overlapping nature of all processes involved to create quality, effective outreach pieces.

Cognitive Studies

The overarching concept that ties experimental pedagogy together with outreach lies in the area of cognitive research. Understanding how we appreciate, learn, and retain the concepts is fundamental to better teaching and outreach. Research in cognitive areas is broad and draws on a significant portion of research in educational psychology, but the focus is squarely on furthering our knowledge of how people understand and learn (Redish, 1994).

One of the primary academic concerns for those in PER is understanding whether or not students are learning and retaining information from their experiences in physics classrooms. One level of learning simply involves the memorization of basic facts. It is far more desirable to drive students towards the ability to assimilate information from one source and apply it to external situations. One of the pioneers in categorizing learning into different levels was Benjamin Bloom, the developer of what is now known as Bloom’s Taxonomy. After years of minor revisions to verbiage in Bloom’s original version, L. Anderson et. al. increased the scope by adding the *knowledge dimension* to Bloom's existing *cognitive process dimension* (Anderson et al., 2000; Krathwohl, 2002).

Bloom's revised taxonomy of educational objectives provides a framework for better understanding the differences in various levels of learning. On this scale, the original six major categories in the cognitive domain included knowledge, comprehension, application, analysis, synthesis, and evaluation. Pushing higher on the scale indicates an increased ability to apply one's skills in a particular area. In the revised version, the addition of varying levels of knowledge provides a two-dimensional matrix on which to rank student learning (Table (3)).

Table (3). Revised Taxonomy

	The Cognitive Process Dimension					
The Knowledge Dimension	1. *Remember*	2. *Understand*	3. *Apply*	4. *Analyze*	5. *Evaluate*	6. *Create*
A. *Factual Knowledge*						
B. *Conceptual Knowledge*						
C. *Procedural Knowledge*						
D. *Metacognitive Knowledge*						

This revised taxonomy helps educators better understand the level of learning attained by a student. Consider the following as an example: on completion of a classroom activity, students will be able *apply* the skills learned in the laboratory to write a thorough experimental procedure on the performed experiment. According to the original taxonomy, this learning goal could be categorized as #3 *Apply*, since students are asked to take previous experience and make application from that experience. However, by adding the knowledge dimension to the original taxonomy, it is now possible to further classify that learning goal based on the stated levels. In this example, without more information, it would be reasonable to classify the learning goal as A. *Factual Knowledge.* Additionally, if the student was directed to take skills learned in one experiment and apply them to a *different* experiment, the proper classification would be C. *Procedural Knowledge* as opposed to A. *Factual Knowledge*.

By understanding what constitutes different levels of student attainment on the revised taxonomy (not simply a test score), instructors can clearly investigate differences in student achievement and learning. Both quantitative and qualitative assessments can be designed and evaluated according to the revised taxonomy. The conceptual basis of the original and revised taxonomy can therefore be applied to further areas of cognitive research, in which investigators push students to higher levels by following the structure outlined in the taxonomies.

CHAPTER II

EXPERIMENTAL PEDAGOGY

Minds-On Audio-Guided Activities (MAGA) are podcast-delivered instruction designed to facilitate learning through all-body experiments. Instruction by MAGA was tested at Central Michigan University in a series of introductory physics courses. Topics focus primarily on conceptual areas of mechanics and range from discovering the differences between distance and displacement to momentum to the Coriolis effect (Table (4)). MAGA instruction emphasizes physical activity, encouraging learners to engage their bodies and minds simultaneously. It targets a combination of learning styles, stimulating group discussion by using technology familiar to the learners.

Table (4). MAGA Topics

Distance and Displacement	Coriolis
Speed and Velocity	Force, Action/Reaction
Inertia	Work, Potential Energy, and Kinetic Energy
Rotational Motion	Momentum
Oscillations	

Although MAGA was designed to be used as either an introductory activity or as a supplemental experience for students, in order to quantitatively compare results it was necessary to develop control and experimental groups within a classroom environment. Assessment methodologies include quantitative measures of learning gain and qualitative oral interviews designed to probe the effectiveness and student opinions of MAGA.

Motivation

Introductory physics courses typically place an emphasis on learning concepts and problem-solving skills over a period of one or two semesters. The topics covered in an introductory physics course usually focus on mechanics and include experiments and in-class demonstrations to help students gain a firm understanding of concepts discussed during class. However, developments in PER show changing the model from a large-scale lecture hall setting to incorporate more student-centered, interactive engagement-style instruction is beneficial for student learning (Bestwick & Campbell, 2010; Hake, 1998; Keiner & Burns, 2010; Mazur, 1999; McDermott, 1991; Meltzer & Manivannan, 2002).

This student-centered focus has driven the development of many unique ways to facilitate learning, including integrating lecture and lab instructional time, using clickers as an instantaneous response system, and incorporating other technologies in the classroom that help drive student achievement. One aspect explored is the use of podcasting to supplement material covered in a physics classroom (Glanville, 2010; McDonald, 2008).

A podcast is an audio recording played back on an MP3 player, similar to listening to a song or other music file (McDonald, 2008). With the advancement of technology, more and more students in high school and college have MP3 players and/or phones with the capability to store music built in. This increase in technology has driven the consumer cost down significantly to make MP3 players highly accessible to a wide audience.

Podcasting in education typically falls into two general categories. Users either utilize existing resources or rely on creating content-specific material themselves (Hew, 2009). When students create podcasts they are typically done as projects. When teachers create podcasts they generally fall into two categories: stand-alone lectures or supplementary material to a lecture.

When used in university-level physics courses, podcasts have typically consisted of a recorded lecture made available online to students. In practice, many students use these as a supplement to notes and have resisted the temptation to skip lectures in favor of solely listening to class in the comfort of their own home (Glanville, 2010; McDonald, 2008).

Despite podcasts designed to help students further explore material in a nonintrusive way to their daily lifestyle, Hew found that there is “no significant difference in students’ actual performance between those who use podcasts and those who did not” (Hew, 2009). The studies reviewed by Hew only focus on instructors using podcasts as lectures, supplemental lectures, or student projects.

In an effort to help students gain an increased conceptual understanding of basic mechanics topics, podcasts were created as MAGA. This approach uses materials commonly found in playgrounds or homes along with audio-based instruction to connect the physical world with concepts typically covered in an introductory physics class.

Many students do not connect essential concepts (mass, inertia, action-reaction, etc.) learned in the classroom to their daily lives. MAGA was developed to guide students through a hands-on mechanics “experiment,” stimulating exploration and discussion between group members. This student-centered approach is different than textbook-style learning because it is designed to draws students into all-body experimentation. By completing MAGA exercises, students are primed to connect physics concepts to “real life” experiences. Although at this point claims on long-term effectiveness are untested, MAGA experiences are designed to help foster long-term learning and appreciation for physics and science in general. In addition, the collaborative discussion nature of MAGA, coupled with MP3 technology many students are familiar with, helps to engage students in the activities.

Methodology

MAGA instruction places an emphasis on group learning and discussion between members. Podcasts are recorded using Apple’s GarageBand software and converted to MP3 format for distribution. Each group is provided with MP3 players loaded with the MAGA podcasts as well as any materials required for the experiment. Alternatively, students have the option of streaming the audio files from the course’s Blackboard website to their personal web-connected device (typically a laptop computer, tablet, or smart phone). Podcasts are broken down into anywhere from seven to twenty tracks and focus the group on a specific activity to investigate. Each track directs groups to complete an activity, followed by questions prompting students to discuss thoroughly the concepts before proceeding to the next track. Each subsequent track begins with a brief review of the previous concept, allowing students to immediately correct any misconception on the desired learning target.

MAGA-style instruction was tested at Central Michigan University in PHY 127, “Table Top Physics” from the fall semester of 2010 through the spring semester of

2012. This course is part of the university program (general/basic courses) and it is taken separately from a number of applicable physics lecture courses. Class size is typically between 18 and 30 students and the course meets once per week for one hour and 50 minutes. Most students are non-science majors enrolled concurrently with a conceptual physics lecture course; however, students are not required to take both the lecture and the lab course during the same semester.

In order to familiarize students with MAGA-style instruction, the first exploration (Distance and Displacement) is done with the entire class via MAGA. Subsequent experiments are done with half of the class as a control group and half of the class serving as the experimental group. Groups of two to three students are created on the first day based on alphabetical order, with alternating groups beginning MAGA instruction versus traditional instruction. These groups swap delivery methods each week, in an effort to normalize students' instruction experience and provide a more homogeneous study. Average learning gain is calculated according to Hake's formula based on pre- and post-test assessment (Hake, 1998).

Comparisons were made between instruction done by MAGA versus "traditional" lecture and demo-based instruction. In addition, qualitative user comments were recorded at the end of each semester about effectiveness, usability, clearness, and preference for instruction styles. Students were interviewed in their MAGA group, with each member choosing a different topic covered in the semester to discuss. After their presentation the instructors probed for deeper learning by connecting their topic to other topics from the course. For example, if a student chose to discuss a comparison of speed and velocity, the instructors would have asked the student to make connections between those concepts and that of centripetal acceleration for an object moving at constant speed around a circular path.

Example: Teaching Inertia by MAGA

As an example, the inertia MAGA script is included in Appendix A; the following is an illustrative example of the process used to teach inertia by MAGA. In this example, users progress through two activities. The first activity asks students to create a straight rope path on the ground using a provided length of rope. At the end of the path they place a bucket or container. Students are prompted to briskly walk along the path at a roughly constant speed and, at the end of the path, drop a tennis ball from shoulder height into the container. Students quickly realize in order to get the ball into the container they must release the ball *before* reaching the container (Figure (1)).

Figure (1). Investigating Inertia By MAGA.

To help quantify their results the group is prompted to measure the average horizontal speed of the ball from the release point to the bucket and compare that to the average speed of the walker. They are then asked to discuss exactly why those two horizontal speeds are similar, therefore leading the group to “discover” the concept of inertia by investigating the motion of the ball.

In order to help drive learning to higher cognitive levels, students complete a second activity designed to help reinforce the concepts learned in the first activity. In the second activity, students use a stool or chair that is able to freely rotate. One student sits on the stool holding the tennis ball at shoulder height while his or her partner begins to rotate the stool. A bucket is placed a short distance away from the stool, and the test student is prompted to release the ball so it will land in the bucket. The group quickly realizes the path of the ball is tangential to the path of rotation, which helps to debunk the common misconception that the ball will move in the radial direction when released by the rotating student. Prompt questions lead the group to recover the concept of inertia from the previous activity and relate the two experiences.

In our experience teaching with MAGA, students exhibit misconceptions on many topics that can be corrected through hands-on and minds-on activities. Further work on changing students’ cognitive perceptions specifically on the concept of inertia is presented in Chapter III.

Experimental Setup

In educational research, the quantification of experimental results involves human and social dimensions that can be difficult to analyze. Variations by semester in students' background knowledge, motivation, academic attitude, and other personal factors present complicated barriers to assess learning. Despite these difficulties, statistical methods exist that help researchers understand the validity of their conclusions. In a thorough educational study in which differentiated instruction or experimental pedagogy is being tested, it is necessary to incorporate both a control group and an experimental group in the study.

In an effort to provide a homogeneous educational experience for students, groups were subject to alternating delivery methods for a particular topic. In a given class period, the control group participated in traditional lecture-based instruction and demonstrations while the experimental group covered the same topic using MAGA. In the following class period the control group and experimental group would switch delivery methods for a new topic to be covered that day. This method was repeated throughout the semester, with groups receiving alternating instruction by MAGA or traditional methods throughout the course.

Experimental learning gain can be quantified by assessing pre- and post-knowledge on a topic. In this method, previous to any instruction (traditional or MAGA), students completed an in-class pre-test. The class was then split into the group that would receive traditional instruction (control group) and the group that would receive instruction by MAGA (experimental group). Materials, if necessary, were gathered for MAGA instruction and those students left the classroom. MAGA groups then proceeded through the audio prompts, directing them to complete their work either in the immediate vicinity (typical) or at a local park (atypical, but necessary for investigations on oscillations and the Coriolis effect in which swings and a merry-go-round were required, respectively).

A post-test assessment was delivered at the beginning of class during the next meeting period, which for PHY 127 was the following week. The cycle of pre-test, instruction, and post-test was then completed for other course topics.

In addition to quantitative measurement, qualitative assessment was also conducted in the form of a semi-structured oral interview at the conclusion of the semester. In this setting, students were allowed to choose a topic covered in class, on which they were asked to prepare a short introductory explanation for their group and instructor. Instructors then asked the students probing questions to identify connections between the chosen topic and others covered in class. Additionally, user attitudes, preferences, and opinions were isolated in an effort to help better understand thoughts on working with MAGA.

In the original design for testing experimental and control groups, all topics were to be covered using both MAGA and traditional methods throughout the semester. However, after further investigation in both the course content and the limitations of MAGA instruction, it was decided to alter the plan to incorporate some topics delivered *only* by MAGA and some topics delivered *only* by traditional instruction.

Since PHY 127 is a laboratory-based course, the first day is spent reviewing the structure of the semester, MAGA instruction, experimental measuring techniques, and error analysis. Groups are also created and required to write a group contract, designed to facilitate the management of potential problems associated with group work. On the second day of class, students take the first pre-test on Distance and

Displacement. Typically the class then splits into the group learning by MAGA and the group learning by traditional instruction, however, in an effort to normalize the overall experience, all groups participate in the MAGA on the first day. This is done to help alleviate any technical problems students have with interfacing with the MP3 players as well as to assist in building group discussion skills, which is a major component of education by MAGA.

Additionally, every teaching methodology has a learning curve for the student. Effective teachers lead students through the first steps of the approach, giving time for the class to adjust to the particular methodologies used. Incorporating new teaching methodologies requires a small transition period where students adapt to the new style in an environment that is conducive to learning. By including the entire class in the first experience with MAGA, students are better able to make the transition to learning in this new format.

The following class period begins with the Distance and Displacement post-test, followed immediately with the Speed and Velocity pre-test. The class then splits according to a pre-determined (and alternating) division, with half of the groups participating in MAGA while the other half remains for traditional instruction.

However, due to the limitations of MAGA, it was decided early on to only use the novel instructional method where it fits best – that is, not to force MAGA-style instruction awkwardly for the sake of keeping to an experiment. Therefore, in covering the topic of Acceleration, it was decided to only offer traditional instruction. In keeping with the theme of the experiment, pre- and post-tests were still given, although there can be no comparison made between learning gain by traditional versus MAGA instruction for this topic.

The remaining topics (Inertia, Rotational Motion, Coriolis, and Energy) were all offered in the split format. Force, Action/Reaction was covered using only MAGA. Oscillations, covered as a split format for the first two semesters, migrated into only instruction by MAGA during the third and fourth semesters. While the mid-fall weather in the central Michigan vicinity is pleasant, running an experiment outside in the middle of February can be potentially difficult for obvious reasons. It was decided to offer this entirely as a MAGA experience for the following two semesters, but the instructors took into consideration the weather outlook.

Results

Regardless of the form of instruction, pre- and post-test data were gathered on every topic for all four semesters. This section includes the presentation of analyzed data; discussion is in the following section. The MAGA methodology was tested over consecutive semesters from the fall of 2010 to the spring of 2012. In the fall of 2010, 16 students enrolled in PHY 127. 28 students enrolled in the following spring. 20 students and 19 students enrolled in the fall semester of 2011 and spring semester of 2012, respectively.

For the study of experimental pedagogy, the use of hypothesis testing is standard protocol. As described in Chapter I, by analyzing pre-test data, one can determine the probability that any difference between the control and experimental groups is attributed to chance. In this case, the null hypothesis maintains that any difference in groups is due to random chance. Therefore, the alternative hypothesis is that any difference in the groups is due to a significant bias in the group's makeup. In Table (5), the p-values calculated for each topic covered by both MAGA and traditional methods are shown.

Table (5). Pre-test Data

Topic	**t-score**	**Degrees of Freedom**	**p-value**
Speed and Velocity	1.29	77	0.20
Inertia	0.80	77	0.43
Rotational Motion	0.05	79	0.96
Oscillations	0.62	80	0.54
Coriolis	0.31	76	0.75
Energy	0.39	78	0.69

It can be seen in Table (5), all of the p-values are greater than the standard criterion of 0.05; therefore, we cannot reject the null hypothesis. We can conclude any difference that does exist between the control and experimental groups is due to random chance. Conducting an assessment on average learning gain between control and experimental (MAGA) groups is an appropriate measurement, based on the similarities of the two respective groups.

In order to calculate average learning gain over an instructional period, students must complete both the pre- and post-tests. If a student attains a perfect pre-test score the learning gain formula is not defined and learning gain cannot be calculated for that individual. In addition, if a student is not present for both pre-test and post-test assessments on a given topic, learning gain cannot be calculated for that individual. Therefore, the number of data points is highly variable from topic to topic.

In Table (6), average normalized learning gain for the control and experimental groups over the four-semester test period is presented with the corresponding p-values, when appropriate. In this case, the null hypothesis still maintains any difference in groups is due to random chance, while the alternative hypothesis now maintains any difference present is due to differences in the group makeup, possibly due to instructional methods. Standard error is included in the 95% confidence interval, indicating a 95% chance that the true mean value is within that range.

Table (6). Average Normalized Gain and P-Values

Topic	**<g> (Control)**	**<g> (MAGA)**	**p-value**
Distance and Displacement	▨	0.57 +/- 0.08	▨
Speed and Velocity	0.33 +/- 0.13	0.33 +/- 0.13	0.97
Acceleration	0.52 +/- 0.14	▨	▨
Inertia	0.36 +/- 0.18	0.28 +/- 0.13	0.46
Rotational Motion	0.30 +/- 0.19	0.21 +/- 0.17	0.50
Oscillations	0.30 +/- 0.25	0.15 +/- 0.09	0.15
Coriolis	0.26 +/- 0.13	0.29 +/- 0.14	0.73
Force, Action/Reaction	▨	0.35 +/- 0.21	▨
Energy	0.21 +/- 0.14	0.04 +/- 0.20	0.17
Momentum	▨	0.29 +/- 0.12	▨
AVERAGE:	0.35 +/- 0.07	0.30 +/- 0.04	0.23

One interesting component to investigate is the difference between genders on learning gain for the course. Tables (7) and (8) present the control and experimental group data separated by gender.

Another interesting difference could be related to the semester in which students take the course (fall versus spring). Tables (9) and (10) present the normalized learning gain and p-values for the two combined fall and two combined spring semesters.

Additionally, students completed an oral exam at the end of the semester. They were to come to the exam prepared to discuss briefly one topic learned over the course

Table (7). Gender Differences for Learning Gain (Control)

Topic	**<g> (Male)**	**<g> (Female)**	**p-value**
Distance and Displacement	▨	▨	▨
Speed and Velocity	0.56 +/- 0.23	0.26 +/- 0.14	0.04
Acceleration	0.53 +/- 0.20	0.50 +/- 0.17	0.85
Inertia	0.41 +/- 0.30	0.34 +/- 0.23	0.74
Rotational Motion	0.52 +/- 0.35	0.25 +/- 0.22	0.30
Oscillations	0.40 +/- 0.19	0.23 +/- 0.40	0.50
Coriolis	0.29 +/- 0.23	0.25 +/- 0.15	0.83
Force, Action/Reaction	▨	▨	▨
Energy	0.33 +/- 0.19	0.15 +/- 0.17	0.23
Momentum	▨	▨	▨
AVERAGE:	0.44 +/- 0.10	0.33 +/- 0.10	0.11

Table (8). Gender Differences for Learning Gain (MAGA)

Topic	**<g> (Male)**	**<g> (Female)**	**p-value**
Distance and Displacement	0.50 +/- 0.18	0.59 +/- 0.09	0.31
Speed and Velocity	0.38 +/- 0.23	0.30 +/- 0.15	0.58
Acceleration	▨	▨	▨
Inertia	0.28 +/- 0.45	0.28 +/- 0.13	0.98
Rotational Motion	0.26 +/- 0.31	0.18 +/- 0.21	0.64
Oscillations	0.09 +/- 0.30	0.26 +/- 0.08	0.12
Coriolis	0.33 +/- 0.33	0.27 +/- 0.15	0.72
Force, Action/Reaction	0.52 +/- 0.39	0.30 +/- 0.25	0.40
Energy	0.07 +/- 0.32	0.03 +/- 0.24	0.90
Momentum	0.47 +/- 0.30	0.23 +/- 0.13	0.10
AVERAGE:	0.35 +/- 0.09	0.30 +/- 0.05	0.47

of the semester, with the understanding they would need to be able to relate their chosen concept to other topics covered during the semester. For example, if a student chose to discuss acceleration, we would probe their understanding of both linear acceleration and acceleration for circular motion. Additionally, we could ask about the origination of acceleration (force) and the concept behind the resistance to acceleration (inertia).

Table (9). Normalized Learning Gain for Fall and Spring Semesters (Control)

Topic	<g> Fall	<g> Spring	p-value
Speed and Velocity	0.36 +/- 0.11	0.32 +/- 0.08	0.76
Inertia	0.39 +/- 0.12	0.35 +/- 0.13	0.83
Rotational Motion	0.09 +/- 0.15	0.39 +/- 0.13	0.13
Oscillations	0.30 +/- 0.07	0.33 +/- 0.19	0.91
Coriolis	0.40 +/- 0.09	0.20 +/- 0.09	0.12
Energy	0.29 +/- 0.07	0.16 +/- 0.09	0.37
AVERAGE:	0.37 +/- 0.12	0.32 +/- 0.08	0.42

Table (10). Normalized Learning Gain for Fall and Spring Semesters (MAGA)

Topic	<g> Fall	<g> Spring	p-value
Speed and Velocity	0.31 +/- 0.10	0.35 +/- 0.08	0.71
Inertia	0.27 +/- 0.09	0.29 +/- 0.09	0.90
Rotational Motion	0.36 +/- 0.10	0.10 +/- 0.12	0.15
Oscillations	0.41 +/- 0.03	0.07 +/- 0.10	0.001
Coriolis	0.31 +/- 0.13	0.34 +/- 0.07	0.83
Energy	0.13 +/- 0.07	-0.04 +/- 0.18	0.42
AVERAGE:	0.33 +/- 0.07	0.30 +/- 0.06	0.50

Over the course of the four semester trial period, a total of 83 students completed the oral examination, in which they chose a topic to discuss from those covered in class. Of the 83 total students, 48 chose topics they learned by MAGA instruction, 33 chose topics they covered by traditional instruction. Data for two students in the spring semester of 2011 is incomplete. Table (11) shows the breakdown of topic choice and instructional style by semester.

Students were provided MP3 players with the appropriate tracks pre-loaded into the memory. However, during the first semester a student asked if he could use his own MP3-device to stream MAGA. Therefore, audio tracks were made available to the students via the course’s Blackboard website. During the oral interviews for the spring semester of 2012, students were asked about the method they used to listen to MAGA. A collection of their responses is in Table (12).

Table (11). Oral Exam Topic Choice by Semester

		Precision and Accuracy	Distance and Displacement	Speed and Velocity	Acceleration	Inertia	Rotational Motion	Oscillations	Coriolis	Force and Action/Reaction	Work and Energy	Momentum	Total
F-2010	MAGA	▨	3	1	▨					1	2		7
	Traditional		▨	2	2	2				▨	3	▨	9
Sp-2011*	MAGA	▨	6	1	▨	2				3	1		13
	Traditional	2	▨	2	2	3				▨	4	▨	13
F-2011	MAGA	▨	4	3	▨					1	3	5	16
	Traditional		▨		1		1	▨	1	▨	1	▨	4
Sp-2012	MAGA	▨	1	1	▨			1	1	4	1	3	12
	Traditional		▨	2	2	1		▨		▨	2	▨	7
*Data is incomplete for two students during the Sp-2011 semester													

Table (12). MAGA Audio Interface Preferences (Spring 2012)

	Individual MP3 Players	Communal Speakers (Laptop, Tablet)
Number of Responses	3	16

In addition to audio interface preferences, students were asked to list which MAGA topics stuck out to them as either positive (worked well, concept was understood, etc.) or negative (did not work well, concept was hidden, inefficient methods, etc.). Their responses are included in Table (13).

Lastly, during the oral exam, students were asked to provide comments on their overall thoughts of MAGA-style instruction. A selection of responses is below.

Table (13). MAGA Topic Preferences

	Distance and Displacement	Speed and Velocity	Inertia	Rotational Motion	Oscillations	Coriolis	Force and Action/Reaction	Work and Energy	Momentum
Positive	26	1	5	2	3	6	5	1	19
Negative	3		1	10	9	4	1	2	7

- “The audio files were more enjoyable than learning from lectures because they were easy to follow and overall the concepts (topics) covered were good.”
- “I didn’t enjoy the logistics of finding the merry-go-round.”
- “Audio files would be great if they were used as a supplement to lecture and not a stand-alone instructional method.”
- “MAGA track length is important – too long isn’t good.”
- “Audio files helped with ‘sensory memory.’”
- “Audio files helped me get the basic concepts but didn’t help me with vocabulary. But building concepts first and adding vocabulary later might help.”
- “…but in ten years I will definitely remember the concepts learned from the audio experiment more than I will from the lecture.”
- “Traditional instruction made the concepts stick more, but the audio made a big impact if we had discussed the concept in a previous class (prerequisite class).”
- “Class should be formatted to lecture about a topic and then do an audio experiment about the same topic.”
- “It was nice to bounce ideas off each other during MAGA.”

- “We’re conditioned to learn from traditional methods – transferring over to MAGA was difficult.”
- “MAGA would be a good supplement to lecture.”
- “MAGA is learning by talking.”
- “Bring a speaker or computer so everyone can listen together.”
- “MAGA instruction made preparing for tests difficult.”
- “Mass HAD to matter for the period of a pendulum but the MAGA exercise proved me wrong!”
- “MAGA forces you to make your own explanations, but you can’t ask MAGA questions! You’re forced to be attentive.”

Discussion

MAGA-style instruction induces learning through several coupled channels: auditory stimuli, visual input, kinesthetic experimentation, and group discussions. Providing MAGA users direction by audio instruction requires students to carefully listen to the narration and focus their attention. In addition, students need to create images of the physical scenarios in their minds as they proceed through the Podcast track. If students would be given similar instruction with video, pictures, or written instructions to supplement the audio directions, the process of mental image creation from audio-only instruction would be lost. We observed substantial student engagement and the creation of healthy learning environments during MAGA instruction (discussions, debates, re-examinations, etc.).

While proceeding through an activity, students create a physical relationship between the concept and the required bodily motions. This kinesthetic aspect turns physical concepts into memorable experiences for students. These memories are then reinforced through group discussions, which are promoted by MAGA instruction. In the group discussions students are asked to explore the concept and the results of the activity. This process of investigation and justification forces students to formalize the physics concept at hand before proceeding to the next track.

During the four trial courses average learning gain varied from topic to topic. Experimental significance is minimal due to the small sample size (on average less than 80 total students). Preliminary observations show some experiments are more effective than others. On initial speculation, this could be due to an ineffective MAGA design for a given topic. However, it is possible that MAGA instruction may not fit for those topics, or users come with pre-knowledge that MAGA-style instruction is unable to change.

Although MAGA-style instruction encourages an all-body experience for more of a “sense” of the topic, it is very possible the specific experiments performed do not draw students to the concept as well as traditional instruction. In addition, students are very likely to have significant prior knowledge from previous courses, which may be difficult to transfer to the MAGA style of learning. Lastly, the multiple-choice assessment used to quantify learning gain is by nature more of a “traditional” multiple-choice assessment, which may favor instruction provided in the traditional method.

Based on only pre- and post-test data, there are no statistically significant differences between average normalized learning gain for groups covering topics in traditional (control) methods or MAGA (experimental) methods (Table (6)). The null hypothesis is maintained due to p-values all higher than the previously set criterion of 0.05. Any difference in gain may be due to random variation, not instructional methodology. Similarly, no conclusion can be drawn on the effect of gender on the success of MAGA (Tables (7) and (8)).

Since MAGA is, by nature, a very hands-on learning method, one area of interest is the effect of academic fatigue on student performance. Spring break splits the spring semester into two halves, and it is the experience of the investigators that overall energy in the classroom tends to drop after spring break. Therefore, comparing average normalized learning gain from the fall semester to the spring semester would hopefully provide insight on students' academic fatigue. However, the data still does not meet the confidence level of 0.05 to show any statistical difference between groups (control vs. control and MAGA vs. MAGA) for the fall and spring semesters (Tables (9) and (10)).

In addition to pre- and post-test data, students were interviewed at the end of the semester to probe conceptual learning and their opinions, thoughts, and preferences of MAGA instruction. Using a semi-structured oral examination allowed the instructors to discover the level of understanding each student had on their chosen topic and other topics covered in the course. Over the course of four semesters, 48 of 83 students chose to discuss topics they covered with MAGA instruction.

Throughout the semester, the concepts became more difficult as the transition was made from linear systems of motion to rotating systems of motion. However, students were typically more familiar with the concepts of force, energy, and momentum at the end of the semester. Interestingly, if a student chose a topic he or she covered by MAGA for the oral exam, most of those topics were on linear motion (distance and displacement or speed and velocity) and force, energy, or momentum. Less than 5% (2) of 48 students chose topics on oscillations or the Coriolis. This suggests that, especially in a testing environment, students will gravitate towards topics they feel can be easily discussed in the oral exam. Those that did choose more advanced topics or topics they did not see in prior physics courses typically relied heavily on the MAGA to explain the concept. Students that chose less complex topics (Speed and Velocity, Force), did not typically draw on MAGA experiences during the oral exam.

In the interviews we found on more than one occasion students made physical gestures similar to those learned in MAGA when explaining concepts they covered by MAGA. For example, when discussing the Coriolis effect, which involves experimenting on a merry-go-round during MAGA instruction, we observed students “mentally” placing themselves on the rotating platform – students closed their eyes and imagined themselves on the rotating frame. This was done in order to recall the path a ball takes when thrown to a stationary observer from the moving merry-go-round. Likewise, in discussing the concept of distance versus displacement where students used rope to mark a walking path, they gestured to moving along on the curvy path compared with the straight path they created in the MAGA experience.

Student comments at the conclusion of the exam show some level of frustration in learning by MAGA but an overall appreciation for active learning methods. Due to the nature of some topics, track length and overall MAGA length varied. Students preferred MAGA instructions that were shorter and more to the point. However, one must strike a careful balance between making an exercise quick and making it thorough so students are able to observe and comprehend the concepts.

In addition to track length, group dynamics play a large role in learning by MAGA. As one student said, “You can’t ask MAGA questions.” The need to clarify a point before moving on is evidence of the need to either use MAGA as a preview or supplemental activity to a class on that topic. Most students that offered responses of this type were split on when to offer MAGA – either as a preview or as a supplement.

Including qualitative and quantitative assessment methods into this investigation provides insight into the ability of students to think through a problem related to the concepts covered during class. In multiple choice pre- and post-tests, it is impossible to know what level of complexity students reach during the formulation of their answer. However, in a discussion setting, probing questions can be used to pinpoint (and immediately correct) student misconceptions. Despite inconclusive quantitative data, at this point, the qualitative investigation provided interesting information on students’ level of understanding.

More work is needed to increase the sample size in order to make appropriate claims on the effectiveness of MAGA instruction. From student opinions and instructors’ observations, MAGA should be used as a supplement activity either before or after instruction, providing students with a different form of instruction. Since MAGA instruction is based on small groups, it would be reasonable to provide these Podcasts for student use on their own time. Material requirements are minimal and are (primarily) readily available in the household or local playgrounds.

Student comments during interviews indicate the potential for longer-term learning compared with traditional lecture instruction. Future studies should be focused on establishing this indication on quantitative ground. Additionally, incorporating a device into the audio presentation that would limit students' ability to proceed through tracks prior to completing a selected question may help keep students from prematurely listening to the correct answer to a proposed question at the beginning of the following track. This could possibly to be done via online web forms to be used on a laptop or tablet-style computer, however other methods of delivery should be investigated.

CHAPTER III

OUTREACH AND COGNITION

In addition to experimental pedagogical studies in PER, two other areas of research focus on outreach and cognitive studies as they relate to the concepts of physics. Outreach focuses on the presentation of physics content to both traditional (students) and non-traditional (general public) learners. Developments in this area can take many forms, from the construction of museum-based exhibits to the design of laboratory-scale equipment for specific demonstration or dissemination purposes in physics. Cognitive studies serve as a foundation to better understand how students of all ages learn physical concepts. Most research in this area focuses on secondary and lower-division post-secondary physics courses in an effort to reach the broadest audience. Recently, investigators have begun to increase research on various topics in upper-division and graduate courses, despite statistically small sample sizes.

Outreach

The presentation of physics and physical concepts to traditional and non-traditional learners draws on research in pedagogy, cognition, sociology, and psychology. Effectively conveying material to an audience involves knowing the best methods to deliver the content (pedagogy), understanding how that content will be received (cognition), knowing the target audience (sociology), and generalizing the method of delivery to match the predicted reaction of the learner (psychology).

While the foundations of traditional pedagogy in the physics classroom are changing as more work is completed in the field of PER, the primary results show the need to involve active methods in the learning process. In short, to capture the learner one must engage the learner. As mentioned previously in the foundation of the MAGA study, this kinesthetic, active involvement helps learners to assimilate the content into their own framework of knowledge.

The most significant concern in outreach is understanding the target audience and the best ways to capture that audience. Some of the best examples of outreach in physics occur in science museums. Locally, the Mt. Pleasant Discovery Museum (MPDM) contracted KidZibits, an exhibit design firm in Minneapolis, Minnesota, to design and fabricate the exhibits and interior layout of their new facility.

The process of developing, designing, and fabricating museum-quality exhibits is guided by three main considerations: the target audience, the customer's vision and budget, and the physical space available for the exhibit. The considerations of target audience are of utmost importance, as the design and development process of a piece for use in a children's museum is radically different than the process when the target audience is an older teenager or an adult.

In an effort to learn the development and design components of exhibit creation, work was completed in an internship with KidZibits on two exhibits for the MPDM. The development phase focused on the theoretical nature of the exhibits. Isolating the target audience, learning goals, cost considerations, and accessibility issues are all at the focal point of the developers. In contrast, the exhibit designers, working closely with the developers, make the concepts come to life in the form of drawings and 3-D models. Both developers and designers interact with the customer to better focus the process on the goals of, in this case, the museum.

Design firms do their best to create exhibits that are fun, interactive, and educational for the target audience. However, it is sometimes difficult to know exactly how a particular audience will interact with a given exhibit. Therefore, one of the components linking the development, design, and fabrication phases of exhibit creation is the prototyping process.

The main goal of prototyping any exhibit piece is to provide a small basis of information on which to evaluate and potentially revise the exhibit design. Prototypes were tested in a local summer park program office and in the KidZibits complex. In one prototype, a building plan was designed and kits were assembled for young kids (ages 5+) to build a Lego Mindstorms pre-programmed robot. From the small sample of participants it was decided to limit the target age group to ages 6+, due to difficulties in robot assembly.

The second prototype developed was a paper rocket-launching device. This exhibit prompts users to create paper rockets and determine the characteristics used to change the rocket's flight path. The rocket assembly portion of this exhibit was highly successful, however, after the prototype activity, it was decided to change the rocket launching chamber dramatically. Initially the 3' wide by 20' long chamber, extending from floor to ceiling, was to be positioned against a wall. However, after the prototype activity, it was determined the chamber needed to be significantly longer to achieve the desired goals (Figure (2)). This redesign forced significant changes in the layout of the surrounding exhibits, but was an essential process to go through to ensure the success of the overall exhibit.


Figure (2). Rocket Prototype Facility

The experience and knowledge gained in exhibit development while at KidZibits provided a platform on which to begin an outreach project for the Department of Physics at Central Michigan University. One component already developed in a MAGA relies on the use of a merry-go-round to investigate the Coriolis effect. However, many merry-go-rounds located in public or private playgrounds across the country have been removed due to liability concerns. Therefore, using experience from KidZibits in exhibit development and design, preliminary plans have been developed for the construction of a safe, functional, and possibly transportable physics merry-go-round.

In physics, the use of a rotating platform can be applied to many concepts including the relationship between angular measurements, rotational motion, the Coriolis effect, inertia, the conservation of angular momentum, planetary motion, and others. Additionally, with only slight modifications to the design, a rotating platform could be used to illustrate a large-scale centrifuge.

Conceptually, the primary goal of the physics merry-go-round would be to investigate various physical concepts in a hands-on, kinesthetic, enjoyable setting for both traditional and non-traditional students. In order to accomplish this, the design of the exhibit must be safe, with clear instructions, and effectively guide the user through a given activity. In addition, portability would be a consideration for future designs, depending on the evolving goals of the exhibit.

From a development perspective, it is important to outline the learning goals of each possible activity. Focusing on the Coriolis effect, individuals should be able to *feel* the effect on their body as they move about on the rotating platform. Therefore, the platform should be able to support one or more adults and still rotate freely. Since users will be theoretically riding *on* the rotating platform, the instructions for any given activity should be affixed to the platform as well, in a clear, easy to read, eye-catching format.

From a design perspective, space limitations, user safety, and overall cost are all points to consider. Based on experience with a merry-go-round located in a local park, it was decided that the ideal size of the platform should be at least six feet across. As the platform gets larger there is more room to experiment (move around), however space and transportability considerations necessarily limit the size. A design that promotes user engagement is equally as important as safety, as mentioned previously. Therefore the rotating platform should be on a level surface, with a rigid skirt, or covering, reaching from the platform to just above the flooring surface to limit safety hazards. Traditionally, merry-go-rounds located in public parks are center post-mounted with a large (and potentially dangerous) open area beneath. It is essential to close this open underside area of the physics merry-go-round to alleviate safety concerns. Likewise, the overall height of the merry-go-round should be minimized, in the event someone were to fall off the surface. Additionally, a railing extending from one edge of the platform to the other should be solid and of adequate height to provide a secure grab point while moving on the surface.

Figures (3) and (4) illustrate preliminary plans for the physics merry-go-round designed to account for the considerations brought forth in the development and design components mentioned before.

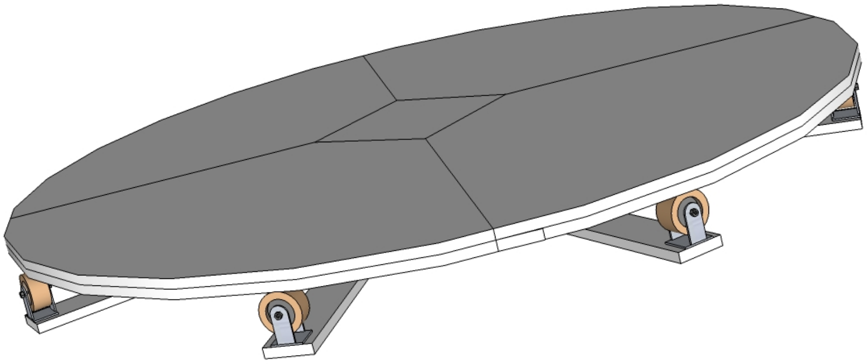


Figure (3). Rotating Platform
Design by Ray Clark, Department of Physics at Central Michigan University.

As mentioned previously, one crucial component of any exhibit is the aesthetic and inviting nature of the design. The goal of the rotating platform is to invite students to participate in an activity that will educate them on a topic in physics while providing an environment that is conducive and fun for learning. In this matter, the instructions for a given activity may be printed on large paper and mounted under a durable, clear

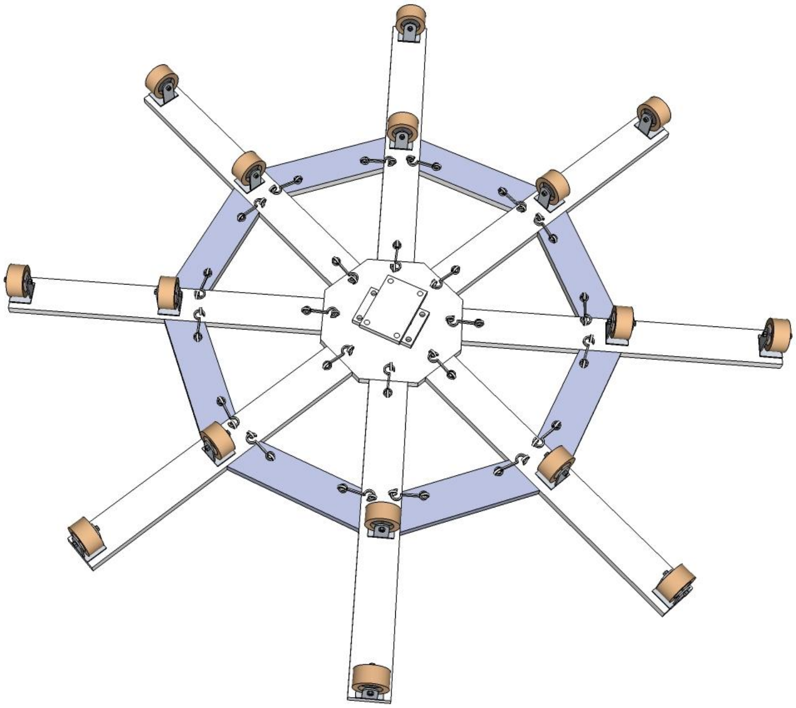


Figure (4). Rotating Platform Structure
Design by Ray Clark, Department of Physics at Central Michigan University.

plastic sheet on the top portion of the platform, or provided to students in audio (MAGA) format, depending on the activity. Regardless, reducing the potential barriers to learning is key, as the platform needs to provide an educational experience, not just an enjoyable ride.

As an example, consider the following activity prompts to help students discover the concept of the Coriolis effect. Prompts are included in Table (14) along with the corresponding learning goal. For production purposes, the following prompts would be printed in an inviting format underneath the clear plastic sheet on top of the rotating platform. It is important to consider text size, graphics, color, and overall readability for the creation of user instructions. Table (14) is not meant to be representative of the final format for such instructions.

Table (14). Coriolis Prompts

Prompt	Learning Goal
Sit at the center of the moving, rotating platform and toss a tennis ball to your partner on the ground. Describe the path *you* see the ball follow. Have your partner describe the path *he or she* sees the ball follow.	Indicate the direction of the fictitious Coriolis force on an object moving radially outward.
Walk radially from the center of the rotating platform first slowly and then quickly. What do you feel?	Indicate the dependence of radial speed on the Coriolis force relative to an object moving radially outward.

The design and implementation of a physics merry-go-round will help students make connections between physics and areas outside of the classroom. The goal of this outreach activity is to encourage students to think of physics concepts the next time they travel to a park and sit on a merry-go-round, and to be able to apply these concepts to other areas outside of the traditional classroom environment. Additionally, one could envision other departments at Central Michigan University finding use for this educational device.

Cognitive Studies

In education, Benjamin S. Bloom is considered to be the creator of a framework for classifying statements on what we expect students to learn from a given educational experience. In today’s terminology, Bloom’s Taxonomy provides us a guide of how different learning goals or statements correlate with the level to which the student attains in the material. As an educator, it is important to define learning goals and outcomes for students, to provide both the student and the educator a metric on which to classify the level of learning expected and attained.

However, on the whole, the study of physics is difficult for many secondary and post-secondary students. Therefore, while defining appropriate and measurable learning outcomes is beneficial for both the student and the educator, the process by which students assess their own learning is an invaluable tool to learn.

Particularly in the post-secondary setting, it is not uncommon for students to feel rushed through material and consequently left behind. While a portion of this falls on the student’s possible lack of effort to maintain the rigorous pace held in many introductory physics courses, the other component to consider is whether or not the student even recognizes he or she is falling behind to begin with.

The concept of a self-monitoring guide was developed to help keep the learner engaged in material but in a format that represents traditional methods of teaching and learning. Since physics is a body of information that continuously builds on previous knowledge, when a student stumbles, it can be very difficult to continue learning along with the pace of the course. However, isolating concepts not fully developed is particularly difficult for someone who *does not know whether or not they understand the concept!*

Developing students’ critical thinking capabilities is a pivotal component of secondary and post-secondary education. Self-monitoring techniques will help students develop learning independence and strengthen their ability to use class time (typically lecture) as a *guide* for learning and not the as the primary *method* of learning.

Self-monitoring guides are designed to help physics students learn to recognize when they do not understand a concept and to expand the depth of the learning process. This is done by using activities that are hopefully engaging, enjoyable, short, and to the point, while still delivering physics content. For example, in order to help students better understand the concept of inertia, three self-monitoring activities based on delivery methods easily transferrable to other concepts in physics have been developed. Keys for all activities are included in the appendix.

(1) Crossword Puzzle

Using a crossword puzzle to guide students through a narrative of a physical concept allows the student to partake in a non-intrusive educational experience. Working through a crossword puzzle as a tool to better self-monitor learning is largely different than completing an in-class assigned worksheet or covering suggested textbook readings due to the perception of the work. The simple “story” format connects the concepts together, compared with the traditional list-style presentation of clues in a traditional crossword puzzle. Additionally, since this crossword is not written to draw on correct answers in a specific textbook, students would potentially need to use alternate resources in order to complete the task. Figure (5) is an example of how one could use a crossword puzzle format to strengthen students’ concept of inertia.

CLUES: Inertia Crossword Puzzle

The Greek philosopher, ________________(22d), theorized that an object’s velocity was proportional to the amount of ________________(2a) on the object. While it took time to develop the connection, an Italian scientist, _______________(23a), used an ____________ ______________(7d) to study the motion of rolling balls. In doing so, he discovered the concept of ______________(4d). In addition to studying the

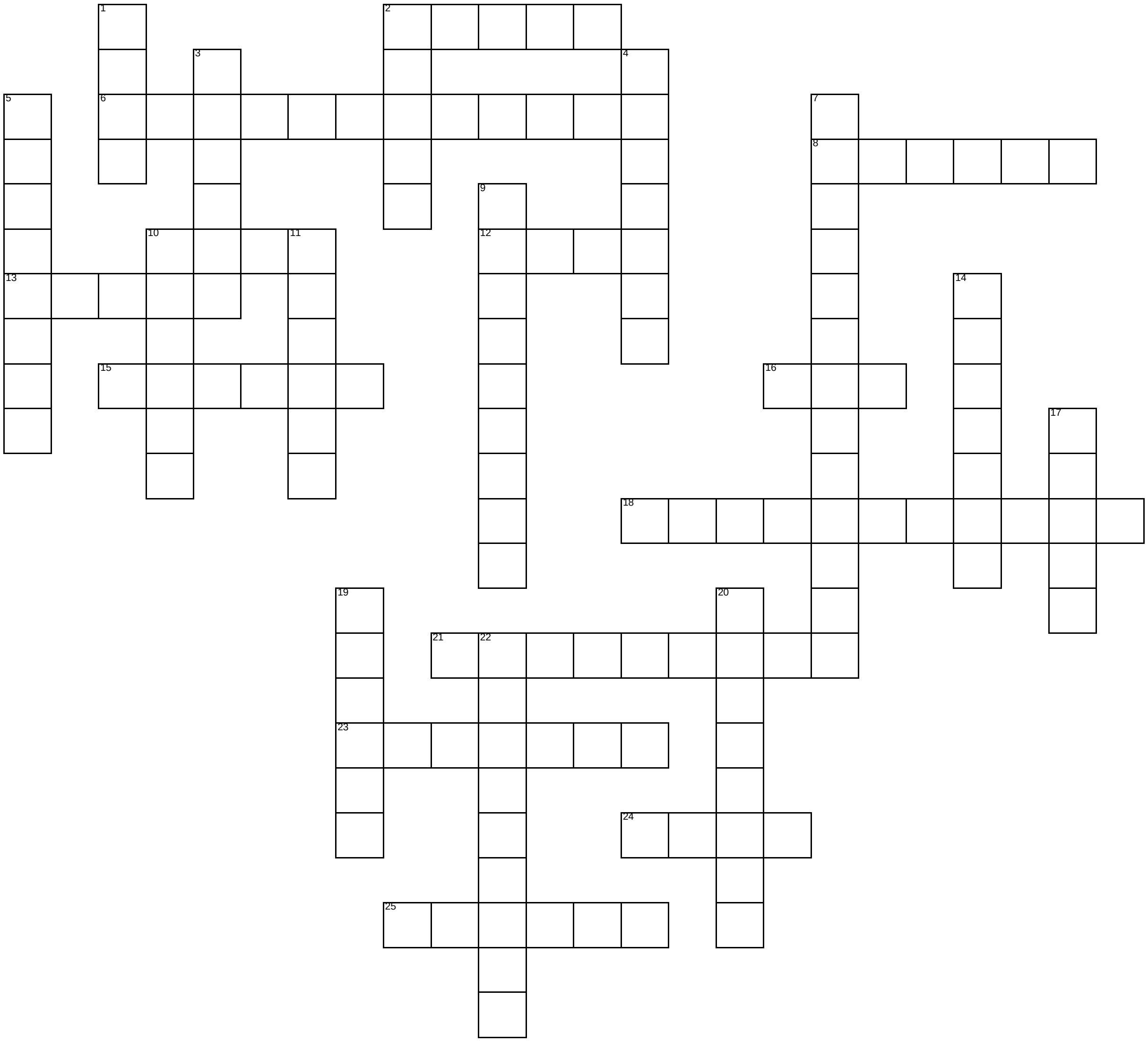


Figure (5). Inertia Crossword Puzzle

motion of balls rolling down a ramp, he also made detailed studies of falling objects. One can just imagine the scientist dropping balls of different weight off of the leaning _____________(13a) of Pisa. From his observations, he deduced that all objects fall at the same rate, neglecting air resistance.

A few years later, _____________(8a) extended the thoughts of his predecessor into what we know as the three laws of motion. His results were published in the year

1687 in Philosophiae Naturalis _______________(9d) Mathematica. He wrote the majority of this historical work while in the "country" recovering from sickness.

One concept present in all of the laws of motion is that of force. In simple terms, a force can be thought of as a ________ or a ________(20d) on an object. For example, think of an overzealous dog walking his or her owner down the sidewalk. The dog is exerting a constant force by pulling on the owner! Likewise, when you apply the brakes in your car, the pads apply a force on the rotors, which helps your car slow down.

The _____________(2d) law of motion states that an object at _________(12d) will remain motionless and an object in ___________(25a) will maintain unchanged unless acted on by a net, external force. Although this is theoretically a simple statement, it is difficult to observe in our natural world because ________________(5d) is very difficult to reduce. However, if you think of an impeccably smooth and slippery surface, like ice, you can imagine the two scenarios (motionless versus constant motion) and how external forces would change the state of motion.

*The concept of force can be viewed in a cause – effect relationship with _____________(6a), as stated in the _____________(11d) law of motion (F = m*a). In this relationship, the concept that connects force and acceleration is ______________(10a). But in reality, the tendency of an object to maintain its motion is what we call inertia. Imagine having to stop a moving bus compared to a bicycle moving at the same speed. Why would it be "easier" to stop the bicycle? The bicycle, with significantly less mass, has significantly less resistance to maintain its current state of motion. How does this relate to the inertia of each object?*

In physics it is often necessary to relate numerical quantities with physical concepts. Therefore, in the S.I. (International System) of measurement, the base unit of kilo_________(1d) is assigned for mass. Typically we include the prefix kilo- to for more massive objects, such as a car, but drop the prefix for less massive objects, like a paperclip. However, in the English system of measurement, the _______(24a) is the unit in which mass is measured.

*Likewise, at the shopping center in the U.S. we sometimes buy fruit and vegetables based on their ____________(19d), which is a measurement of the force of an object due to the acceleration of gravity. The unit of this force in the S.I. system is the Newton (named so appropriately), but in the English system the unit is called the __________(17d), not to be confused with the monetary system! The Newton, a force, can be derived from the second law, therefore it has base units of kilogram * __________(10d) per square second.*

By measuring this quantity we are relying on a scale, which provides an upward _____________(14d), or normal, force that is equal in size but opposite in direction to the force on the object due to gravity. In this case, since the forces are balanced, or in ______________(18a), the ______(16a) force is zero. By adding forces together this way we have actually added ____________ (15a) quantities, which are quantities that have both ______________(21a), or size, and direction. This type of quantity provides more information than a _____________(3d) quantity, which has only a size.

(2) What's Wrong With This Picture?

Consider the following series of time-lapse snapshots in Figure (6), depicting a package being dropped from a supply airplane flying horizontally at a constant velocity. Neglecting air resistance, what's wrong with the picture? Draw the correct path for the falling package, considering the concept of inertia in your thought process.

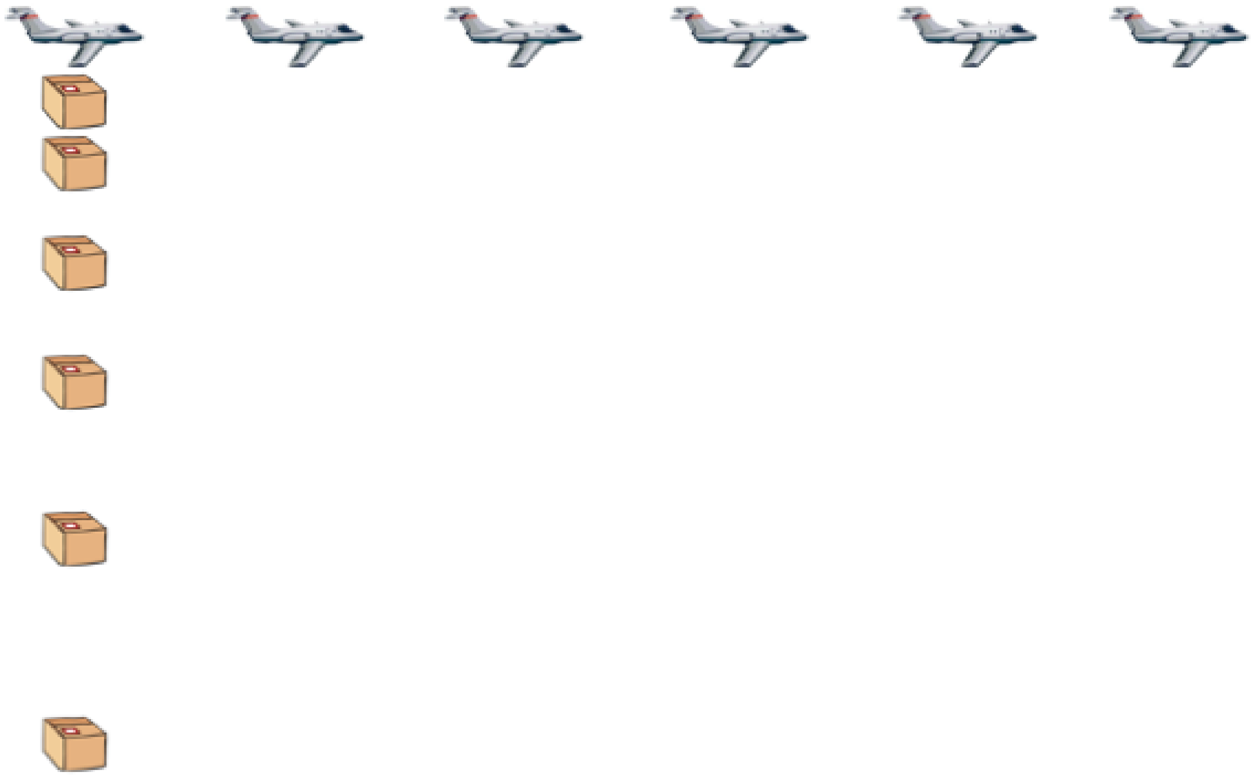


Figure (6). What's Wrong With This Picture?

The scenario described in this activity probes the student's ability to connect physical concepts with common misconceptions in nature. At first, students may question whether or not the illustration is inconsistent with nature, which should point them in the direction of understanding how the physical concepts relate to the given scenario. This method of delivery and self-monitoring would be especially useful to those learners that are more artistic, as it provides an opportunity to connect concepts in physics to a medium in which they are familiar.

(3) Examining Equations: Newton's 2nd Law?

For the following in Figure (7), evaluate the effect of changing parameters in physics equations.

Equation	**Assuming *constant mass*, by pushing harder on an object, the acceleration…**	**Assuming *constant force*, by increasing the mass of an object, the acceleration…**	**Does this make physical sense? Why or why not?**
$F_{net} = \frac{m}{a}$			
$F_{net} = \frac{a}{m}$			
$F_{net} = m * a$			

Figure (7). Evaluating Equations

Additionally, students would be prompted with the following:

- *Circle the equation that correctly relates the concepts of force, mass, and acceleration.*
- *How does the net force on an object relate to the concept of inertia?*

- *Can you establish a cause and effect relationship between force and acceleration? Which of the two is the cause, and which is the effect? What links the two concepts?*

In addition, one skill essential for physicists is the ability to work through the physical meaning of units:

If you ever forget the relationship between force, mass, and acceleration, one easy way to recover the correct form is to investigate the units in each quantity. For Figure (8) (containing the same three equations as listed above), what are the correct units of force if mass is measured in kilograms and acceleration is measured in meters per second squared?

Equation:	$F_{net} = \frac{m}{a}$	$F_{net} = \frac{a}{m}$	$F_{net} = m * a$
Units of Force:			

Figure (8). Evaluating Units

Pushing students to better understand the actual meaning of equations in physics is the primary goal of this category of self-monitoring activities. Making connections between the concepts discussed in class, their physical meaning, and the mathematics that tie them together is an advanced skill that will help students better understand the concepts. Additionally, connecting physical units to the mathematics in an analysis format aims to drive home the meanings of various physical concepts.

The three activities provided are only examples of investigations related to the concept of inertia and venture briefly into Newton's second law of motion. However, the specific formats chosen show the ability of self-monitoring to push students further on the Bloom's scale of learning levels. The crossword with a narrative format primarily reaches only the knowledge level of learning of the taxonomy – students are only asked to recall previously known facts of physics. Should students not immediately know the appropriate words to fill in the puzzle, they could potentially gain more general physics knowledge by looking up the information online or in many basic physics textbooks. Additionally, the story format should start students on the path to make vertical connections between the development of physics content and the historical perspective.

The picture-format of the second example pushes students towards the synthesis level of Bloom's Taxonomy. In order to properly draw the position of the package relative to the moving airplane, students must be able to apply information and make predictions to the solution. Similarly, in the third example, students are primed to learn the meanings of variables and concepts in physics beyond their definitions. On the taxonomy scale, this pushes students beyond the synthesis level and into the evaluation level of learning. At this level, students are able to judge between the physical and non-physical nature of physical concepts based on the validity of proposed arguments (in this case, equations).

Incorporating self-monitoring activities into the learning process is designed to help students learn to recognize when they have conceptual difficulties for a given subject. Traditional methods of assessment (multiple-choice, true false, or short answer questions) may still prove difficult for students that participate in self-monitoring activities, particularly if they do not spend time to correct any misconceptions before moving on. Difficulties in truly assessing student knowledge will be present in any method of assessment, but it is the goal of self-monitoring activities to help students close the gap between *what they know* and *what they think they know*.

CHAPTER IV

CONCLUSIONS

The aim of this project was to develop and test a new pedagogy for introductory physics courses, create the framework for an outreach exhibit, and design materials to help students develop self-monitoring skills of their learning progress in physics. Minds-on Audio-Guided Activities (MAGA) were developed and tested over four semesters of PHY 127, Table Top Physics, at Central Michigan University. Quantitative analysis of the experimental pedagogy does not indicate any statistical difference in learning over the course of the instructional period. However, MAGA is designed to help foster longer-term retention of topics, therefore further assessment is needed to determine the overall effectiveness of the technique. Qualitative analysis of connections made between physical concepts is promising.

The basis for the physics merry-go-round was formulated from experience learning the design, development, and fabrication process during an internship with KidZibits. The development and design phase of this exhibit is complete. With additional resources, the physics merry-go-round could be constructed and marketed to various educational institutions (museums and schools). In combination with MAGA-driven instruction and other self-monitoring techniques, there are many possibilities for the use of such an exhibit.

Additionally, cognitive studies in physics were applied to the development of three activities designed to help students self-monitor their learning in physics. Further research needs to be completed to study the incorporation of self-monitoring techniques into introductory physics courses. Developing students’ awareness of their own cognition is key in developing their ability to think critically and increase problem solving capabilities.

APPENDICIES

APPENDIX A

EXAMPLE SCRIPT AND ASSESSMENT: INERTIA MAGA

Script

TRACK 1

PBL Podcasting – Inertia

Written and Presented by Brian Hancock

The purpose of today's experiment is to investigate the concept of inertia. The procedure follows in order, from track 1 to track 15. It is important that you take your time and discuss topics with your group when prompted. This experiment is designed to move at YOUR own pace, so do not feel rushed. If you need to repeat a track or activity specified on a track, or if you just need more time to discuss topics amongst your group, please do so.

Today you'll be going on a short trip. It is important that you are in an open area, away from other people. You will need one long rope, a stopwatch, a tennis ball, a bucket, a meter stick, a calculator, and the data table provided to you in class. In addition, for the second part of this experiment, you'll need to find a stool or chair that rotates very easily.

When you have the materials and are in your chosen location away from people and potential obstacles, move on to the next track.

TRACK 2

To start, place the rope on the ground and position it as straight as possible on the ground. Pick one end to be your starting location and the other to be your ending location. If necessary, secure both ends with a small piece of duct tape. Measure the length of the rope to the nearest centimeter and record your value in your data table. When you've done this, continue to the next track.

TRACK 3

Now that you have measured the length of the rope it is time to experiment! First you will need to practice walking at a consistent, brisk speed along the entire length of the rope. If you want to compute average speed, what two quantities will you need to measure? Take a moment to talk about this with your group. When you're ready, proceed to the next track.

TRACK 4

In order to compute average speed you'll need two measurements – the length of the rope and the total amount of time it takes to walk over the rope's length. Use the stopwatch to measure the time it takes for your partner to *briskly* walk from the starting location to the ending location. A brisk pace is not a run but it is not a slow walk – you'll want to be moving fairly quickly for this experiment. Repeat this measurement for a total of five trials and compute the average value of these average speed measurements. Record your data and calculations in Section 1 of your data table.

When your group is confident the walker can traverse the entire length of the rope with a relatively constant, brisk speed, proceed to the next track.

TRACK 5

Now that you have your average speed calculated, it is time for some fun physics! Position the bucket at the end location of the rope. The goal of this exercise is for the walker to drop the tennis ball into the bucket at the end of the rope while he or she maintains a constant, brisk walking speed. To do this, hold the ball directly out to the side of your body approximately at shoulder height. Next, walk next to the rope path at the same brisk pace from before, but this time, as you near the end, try to drop the tennis ball into the bucket. Don't throw the ball into the pail as you walk by or try to steer the ball before it leaves your hand. Instead, let the ball fall freely from your outstretched hand into the bucket. Try this activity a few times – when you're confident you can consistently drop the ball into the bucket, proceed to the next track.

TRACK 6

Notice anything? Most likely it took you a few trials in order to consistently get the ball to drop into the bucket. In relation to the bucket, where did your first few trials land? Were you long or short? Take a moment to discuss this with your group. When you're ready, proceed to the next track.

TRACK 7

Now that you can consistently drop the ball into the bucket as you walk by, it is time to take a few more measurements. You'll need the stopwatch and meter stick for this portion of the experiment. Once again, either you or your partner will walk briskly over the length of the rope, dropping the ball into the bucket at the end. However, this time pay attention to exactly where the walker lets go of the ball in order to make it land in the bucket. It may help to mark this location on the floor with tape. Measure the distance from this mark to the center of the pail and record your result in Section 2 of the data table. Repeat the dropping experiment and corresponding measurement until you have five total measurements. Using these measurements, compute the average horizontal distance. When you have done this, proceed to the next track.

TRACK 8

Now that you know the horizontal distance the ball traveled, repeat the experiment but this time use the stopwatch to measure the amount of time it takes for the ball to fall into the bucket. It is important that the walker maintain the same (or close to) brisk pace from the beginning of this experiment. Also, it is important that the walker does not give the ball any push when dropping it into the bucket from shoulder height – the ball should fall on its own accord. Use Section 3 to record your data. Repeat for a total of five measurements and compute the average time of free fall. When you've done this, proceed to the next track.

TRACK 9

Now that you have the average horizontal distance covered and the average time it took for the ball to cover that distance, compute the ball's average horizontal speed and record this value in Section 4 of the data table. How does this compare with the walker's calculated average speed from before? Take a moment to complete these calculations and discuss their meanings amongst your group. When you've done so, proceed to the next track.

TRACK 10

Interesting, isn't it? You should have found that the ball's average horizontal speed is very close to the walker's average speed! Why is that so? If the ball is no longer connected to the walker as it falls, why does it move at close to or precisely at the walker's average speed? Discuss this with your group, and when you're ready, go on to the next track.

TRACK 11

Come up with anything? The reason the ball continues moving at approximately the walker's average speed is because of inertia. Inertia is the tendency of an object to resist changes in motion. You may remember Isaac Newton's first law of motion (or law of inertia): *An object at rest will remain at rest, and an object in motion at constant velocity will keep moving at the same velocity unless acted on by a net, external force*. While you were moving along the rope, the tennis ball was attached to you, therefore moving at the same instantaneous speed as you. When you let go of the ball, it started to fall due to gravity. However, the tennis ball continued to move in the "forward" direction since you gave it an initial horizontal speed!

But what is inertia? Let's do one more experiment before we go deeper into that concept.

For the next experiment you'll need either a stool or a chair that can freely rotate. You'll also need the tennis ball from the previous experiment. If you haven't done so already, clean up the rope and any tape on the floor before moving on. When you're ready, proceed to the next track.

TRACK 12

Once again, the goal of this experiment will be to observe the motion of a tennis ball once it is given a certain initial speed. This time, however, instead of walking along a straight path, you'll be rotating on a stool or chair.

Before experimenting, predict what the path of the ball will look like if the ball is released from a person rotating about a fixed point, such as a figure skater spinning in a tight circle. When you have come to a consensus as a group, proceed to the next track.

TRACK 13

Now that you've come to a consensus on the predicted path of the ball it is time to test your predictions!

If you're able to kneel on the stool, do so, but if you'd prefer to sit that is fine too. Hold the tennis ball out to the side of your body again at shoulder height. Have your partner start spinning you on the stool. Don't get sick or fall off, but make sure it is rotating at a brisk pace.

When you're ready, drop the ball from shoulder height. Observe where the ball lands. Does it hit the ground where you'd expect it to? Take a moment to discuss the results with your group. When you're ready, proceed to the next track.

TRACK 14

What did you notice about the ball's path? If you followed directions correctly, you should have noticed that, when the ball was released, it followed a linear path from the release point to the ground. Is that what you predicted would happen?

For fun, position the bucket from the previous experiment as a target. While rotating on the stool, try to release the ball so it lands in the bucket. However, if you're crunched for time, feel free to proceed to the next track.

TRACK 15

So it seems that regardless of the initial motion – whether linear or rotational in nature – the ball will fall along a straight, linear path from the release point to the ground. Why is this so?

Remember from before, Newton's first law of motion pertained to changing the velocity of an object – whether starting from rest or with an initial velocity. This resistance to changing motion is inertia! But quantitatively, what is inertia? Simply stated, inertia is proportional to the mass of an object.

Think about the amount of force it would take to get a tennis ball rolling on the ground if it starts from rest. Probably not much. How about a basketball? A bowling ball? A car?

Each of those objects have mass – the tennis ball has the least mass and would be the easiest to start moving. The car, on the other hand, obviously has the most mass and would be very difficult to place into motion.

So, inertia is the tendency to maintain a constant velocity (where velocity consists of both speed and direction). When you’re on your way home today, pay attention to all of the changes in inertia around you – from the bus at the bus stop to the refrigerator door in your house. Physics is truly everywhere – you just need to keep your eyes open!

Assessment

1. Inertia is proportional to an object's ______________.
    a. Acceleration
    b. Displacement
    c. Mass
    d. Velocity

2. An apple is dropped from the passenger side window of a quickly moving car. Neglecting air resistance, which of the following statements are true?
    a. The apple will fall to the ground with a horizontal displacement equal to that of the car.
    b. The apple will move horizontally with the same speed as the car before hitting the ground.
    c. The apple will fall straight to the ground with no horizontal displacement.
    d. Both (a) and (b) are correct.

3. Zeek, an alien, is floating in space millions of kilometers away from any other object. If Zeek throws a rock he found in his pocket, which of the following statements are true? (Assume the rock does not interact with any other objects in space.)
    a. The rock will continue moving in the same direction at a constant speed.
    b. The rock will continue moving in the same direction but with varying speed.
    c. The rock will eventually come to a stop.
    d. None of the above.

4. An MP3 player rests on the smooth dashboard of a car being driven down the road. Which of the following statements are correct?
    a. If the car is turned to the right, the MP3 player will slide to the right.
    b. If the car is turned to the right, the MP3 player will slide to the left.
    c. If the car speeds up, the MP3 player will slide forward toward the windshield.
    d. Both (b) and (c) are correct.

5. A mass rotating with constant speed around a central axis is released. Which of the following statements are correct?
    a. The mass will continue to move on a “circle-like” path; the radius will gradually increase.
    b. The mass will stop moving once it is released.
    c. The mass will move in the direction it was going the instant it was released.
    d. Not enough information is provided.

6. A passenger on a train notices she moves forward every time the brakes are applied. Which of the following statements are correct?
    a. The passenger’s inertia is trying to keep her moving forward.
    b. The train’s inertia is trying to keep her moving forward.
    c. The passenger is actually being pushed forward.
    d. Not enough information is provided.

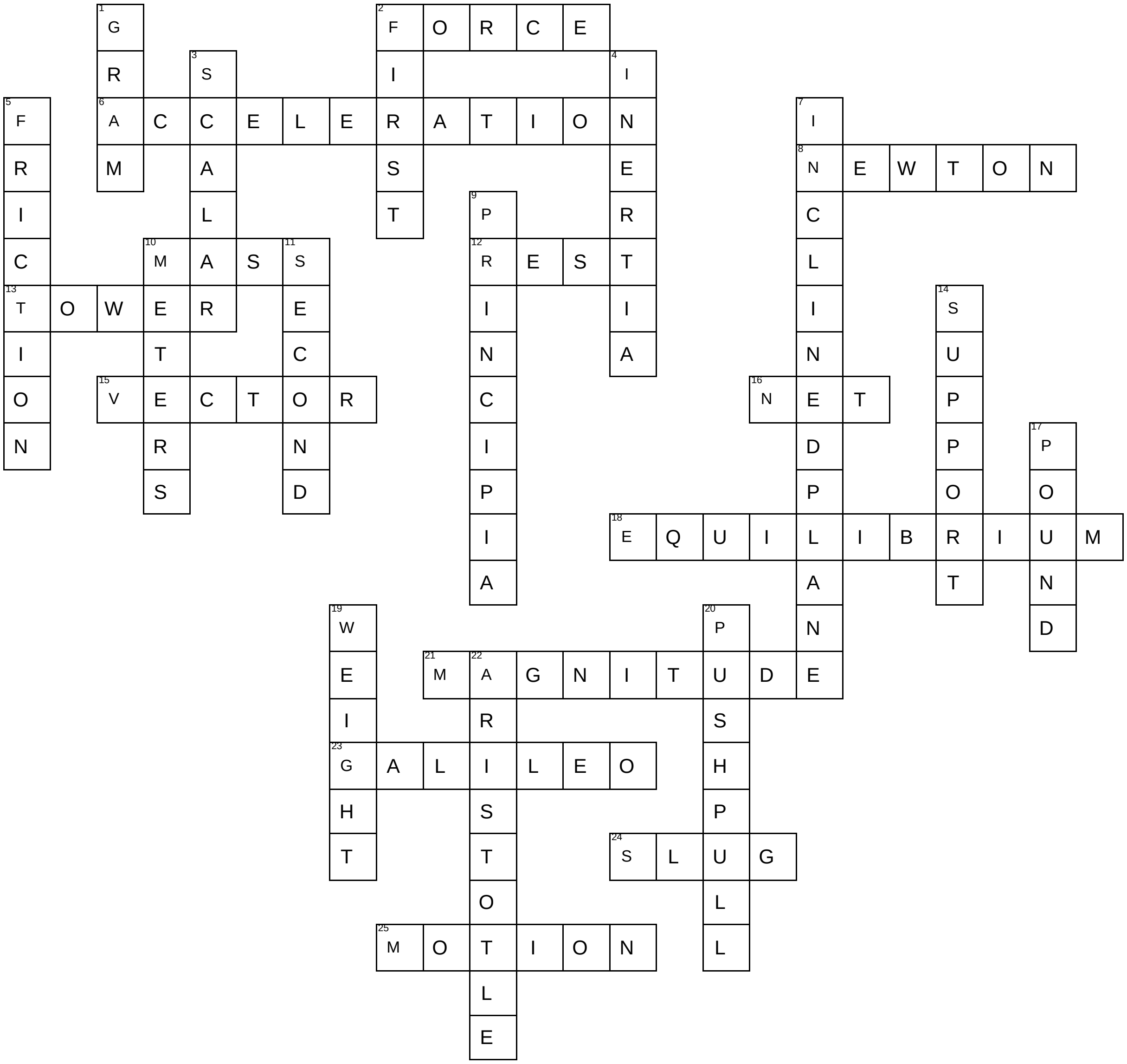
7. Inertia is the tendency for an object to maintain a constant ___________________.
    a. Acceleration
    b. Displacement
    c. Velocity
    d. None of the above.

8. A supply helicopter drops a large bag of aide rations to researchers on an isolated island. If the helicopter is moving horizontally at a constant velocity when it drops the bag, which of the following statements are correct? (Assume air resistance is negligible.)
    a. The bag will maintain the same horizontal speed as the helicopter as it falls to the island.
    b. The bag will fall vertically with no horizontal velocity.
    c. The bag will cover the same horizontal distance as the helicopter during its fall to the island.
    d. Both (a) and (c) are correct.

APPENDIX B

SELF-MONITORING CROSSWORD KEY: INERTIA

Inertia Crossword Puzzle



KEY

Across		Down	
2	Force	1	Gram
6	Acceleration	2	First
8	Newton	3	Scalar
10	Mass	4	Inertia
12	Rest	5	Friction
13	Tower	7	Inclined Plane
15	Vector	9	Principia
16	Net	10	Meters
18	Equilibrium	11	Second
21	Magnitude	14	Support
23	Galileo	17	Pound
24	Slug	19	Weight
25	Motion	20	Push Pull
		22	Aristotle

APPENDIX C

SELF-MONITORING PICTURE KEY: INERTIA

KEY: **What's wrong with this picture?**

Consider the following series of time-laps snapshots, depicting a package being dropped from a supply airplane flying horizontally at a constant velocity. Neglecting air resistance, what's wrong with the picture? Draw in the correct path for the falling package, considering the concept of inertia in your thought process.

APPENDIX D

SELF-MONITORING EQUATIONS KEY: NEWTON'S SECOND LAW

KEY: **Evaluating Equations: Newton's Second Law?**

For the following equations, evaluate how increasing the net force on an object changes the object's acceleration, if mass is assumed to remain constant.

Equation	**Assuming *constant mass*, by pushing hard on an object, the acceleration…**	**Assuming *constant force*, by increasing the mass of an object, the acceleration…**	**Does this make physical sense? Why or why not?**
$F_{net} = \frac{m}{a}$	Decreases	Increases	No, applying more force should accelerate an object more, not less.
$F_{net} = \frac{a}{m}$	Increases	Increases	No. Although applying more force correctly indicates an increase in acceleration, for a constant force increasing mass should *reduce* the acceleration.
$\boxed{F_{net} = m * a}$	Increases	Decreases	Yes, an increase in applied force will cause an increase in acceleration, and for a constant force, an increase in mass will decrease acceleration.

Circle the equation that correctly relates the concepts of force, mass, and acceleration.

See above.

How does the net force on an object relate to the concept of inertia?

Inertia is a measure of how difficult it is to accelerate an object.

Can you establish a cause – effect relationship between force and acceleration? Which of the two is the cause, and which is the effect? What links the two concepts?

Force is the cause and acceleration is the effect. By applying a force (cause), the result is an acceleration (effect).

If you ever forget the relationship between force, mass, and acceleration, one easy way to recover the correct form is to investigate the units in each quantity. For the same three equations as listed above, what are the correct units of force if mass is measured in kilograms and acceleration is measured in meters per second squared?

Equation:	$F_{net} = \frac{m}{a}$	$F_{net} = \frac{a}{m}$	$F_{net} = m * a$
Units of Force:	$\frac{(kg)}{\left({}^{m}\!/_{s^2}\right)} = \frac{kg * s^2}{m} \neq N$	$\frac{\left({}^{m}\!/_{s^2}\right)}{(kg)} = \frac{m}{kg * s^2} \neq N$	$(kg) * \left({}^{m}\!/_{s^2}\right) = \frac{kg * m}{s^2} = N$

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