Issues Associated with Hands-on Learning

by

Keith Bevans

Submitted to the Department of Electrical Engineering and Computer Science
in Partial Fulfillment of the Requirements for the Degree of
Bachelor of Science in Electrical Science and Engineering
and Master of Engineering in Electrical Engineering and Computer Science
at the Massachusetts Institute of Technology

May 26, 1996

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ABSTRACT

Before trying to integrate computer technology into hands-on learning environment, it is important to understand the issues that exist in that type of learning environment. During my observations of an 8th grade science class, issues related to the importance of students’ learning to construct meanings and explanations for the phenomena they observed and linking those phenomena with their scientific names. More importantly, the students had difficulty performing scientific research because they were expected to know how to ask questions, develop theories, perform experiments, and analyze data without any training. We must understand how these issues relate to the goals of the science curriculum before trying to enhance that curriculum with computer software and other technology.

Thesis Supervisor: Jeanne Bamberger
Title: Professor of Music and Education
Dedication

To my father, who has been one of my greatest teachers.
1.0 Preface

When I first met with Prof. Jeanne Bamberger to discuss my thesis, we decided that integrating computers into the science curriculum would be a great project. It would allow me to work with kids, and it would help the Cambridge public school system. After talking with numerous people, I established contact with the Technical Education Research Center, TERC, and found a software program that seemed to fit my project. I decided to use that software, CamMotion, with the eighth grade science unit that dealt with forces and motion, Bernie Zubrowski's *Tops and Yo-yo's*.

Rather than only discussing ways to use the software with the kids, Jeanne encouraged me to broaden my initial research to include an observation of how effective the kit-based, hands-on learning is, how effective are teachers at teaching with this approach, and how software can be integrated into the curriculum. I was surprised when my observations proved that it was more important to identify and understand the issues associated with hands-on learning before finding ways to build on that type of learning.

Until now, I believed that using a hands-on approach was the most effective way to teach science. I have found that using this approach doesn’t guarantee that the students will learn the material better than the traditional methods of text-based teaching. In fact, strictly hands-on learning has deficiencies that may cause some students to learn less material than they would if they had just read textbooks. It is my belief that a successful hands-on learning curriculum must combine the intuitive understanding that kids develop by experimentation and the concrete definitions and explanations that are found in traditional teaching.
2.0 Introduction

This section will describe the group of kids that I observed during my research. It will also briefly describe the 8th grade science curriculum, and where the segment I studied fits into the larger picture. Finally, it will explain the tasks associated with Tops and Yo-yos.

2.1 The 8th Grade science class

Although my research questions did not include the issue of how children of different backgrounds learned with the hands-on approach, I do feel that a description of the school and the 8th grade science class is useful. The school has 335 students in grades K-8. The eighth grade science class had 20 students from various ethnic backgrounds. The teacher is a young white female, who grew up in Cambridge. There were seven Black students in the class, which was the largest ethnic sub-group. The class also had Latino, White, and Asian students. There were seven male students, including one pair of twins.

The students worked in groups of three or four during science class. There were two groups of male students, one group that had a male and two females, and three all female groups. Many of the students in the class have known each other for a long time, and had the same science teacher during 7th grade. Science was the first period of the day at 8:30 a.m. This was the only eighth grade science class at that particular school.

2.2 The science curriculum

The 8th grade science curriculum is currently being changed from traditional “textbook” teaching to a hands-on approach. The students are now taught from a series of science kits that use hands-on experiments to teach science. Each kit usually takes about six to eight weeks to complete and contains nearly everything that a teacher needs to use them in the classroom. Each one contains all of the experiments, workbooks, and other related material needed to work through the subject matter.

By using kits to teach science through experimentation, the students are supposed to develop a better understanding of what it means to “do” science. Science is not supposed to be a

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1 Based on Cambridge Schools At a Glance. 1994-1995
process of memorizing facts and other information. Instead, it should be a process of asking questions, developing hypotheses, designing experiments, and seeking answers. The kits are supposed to allow students to develop hypotheses and perform experiments to prove or disprove those hypotheses.

Cambridge has divided its science curriculum into three main categories: Life science, Earth science, and Physical science. The kit that was used during my research, Tops and Yo-yos, was being used to teach five Physical science principles:

**Forces and Motion:**
- In the absence of retarding force such as friction, an object will maintain its direction of motion and speed. Whenever an object is seen to speed up, slow down, or change direction, it can be assumed that an unbalanced force is acting on it.
- All forces have magnitude and direction.
- Forces acting on objects as pushes or pulls can either reinforce or oppose each other.
- If an object exerts a force on a second object, then the second object exerts an equal an opposite force on the first object.

**Energy:**
- Energy cannot be created or destroyed but exists in different interchangeable forms, such as light, heat, chemical, electrical, and mechanical.

My research focuses on the issues that emerged when teaching science using Tops and Yo-yos. I believe that many of the same issues will arise regardless of the kit or subject matter that is being taught. They are uncovered by the hands-on approach to teaching science, not just Tops and Yo-yos or Physical science.

2.3 Description of Tops and Yo-yos

This kit was developed by Bernie Zubrowski and is being used in various Cambridge Public Schools during an evaluation phase. Once the evaluation phase is complete, this kit may, or may not, be used on a city-wide scale. Mr. Zubrowski believes that tops are a great way to teach students about rotational motion because they are intrinsically interesting, therefore, you will
not need “to motivate a students to do an in-depth exploration into the properties of tops.”\(^2\) Furthermore, the kit’s activities “provide an opportunity for students to acquire basic scientific skills as well as a positive attitude about the scientific profession.” Once the students have completed the activities associated with tops, they are supposed to solidify their understanding by doing another set of activities with yo-yos. Students should also develop the ability to keep good records of the data they collect, as well as the ability to represent it graphically. At the end of each activity, the students should participate in discussions. These discussions could be a simple report of the results, or higher level discussions that search for explanations to those results.

My observations were done during the first four activities in *Tops and Yo-vos*, which dealt with tops. Rather than using store-bought tops, the students made tops from everyday items. Students inserted a wooden dowel through a hole the circular item, then held it in place with two rubber stopper. The tops that came with the kit included: a wooden drawer knob, a 12” pizza pan (“small aluminum”), a plastic plant holder, an aluminum serving tray (“big aluminum”), an 18” piece of cardboard, and a paper plate holder (“purple plastic”). The students were encouraged to bring in objects from home to use as tops, and some of them became more popular than the tops provided in the kit. The plant holder and the wooden drawer knob were replaced by a Frisbee and a Tupperware lid, which two students brought to class.

There were four different launch methods that were used to spin the tops.\(^3\) For the “Hand Launch” method, the kids placed the top’s dowel between their palms and rubbed their hands in opposite directions to spin the top. The “Ribbon Launcher” used two pieces of ribbon to launch the tops. The ribbons were lined up, one on top of the other, and wrapped around the top’s dowel. Once it was wound up, the students would pull the two pieces of ribbon in opposite directions, which launched the top. For the “Rubber Band Launcher”, the students launched the tops by winding it up with rubber bands. At one end, the launcher has one hook for the rubber band. One the other end, it has two hooks to hold the dowel in place. Between the two hooks, students are supposed to wind the rubber band around the dowel. When the top is released, the rubber band unwinds, and the launcher can be slipped off the top of the top. “The Mixer” was a

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\(^2\) From the *Tops and Yo-vos* teacher’s guide

\(^3\) Appendix A contains illustrations of the four launchers.
three speed electric mixer that launched the tops. The student would insert the dowel into the mixer, turn it up to the “hi” setting, the remove it once the top was spinning.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Title</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>One</td>
<td>Assembling and Launching a Set of Tops</td>
<td>Gain familiarity with tops and launchers</td>
</tr>
<tr>
<td>Two</td>
<td>Comparing Tops</td>
<td>Collect data on all top/launcher combinations and compare results</td>
</tr>
<tr>
<td>Three</td>
<td>Designing a Top</td>
<td>Design various tops using six plastic plates</td>
</tr>
<tr>
<td>Four</td>
<td>Investigating Spin Time and Weight</td>
<td>Vary the weight of the top and study the effects</td>
</tr>
</tbody>
</table>

Table 2.3.1 Summary of Activities

The goal of the first activity was to familiarize the students with the different tops and the different launchers, which will help them in later activities. The students were told to build tops from the different materials and observe how they spun when launched with different methods. One student in each group was responsible for determining how long each top spun. For this activity, it was more important that the students mastered the different launching techniques rather than obtain consistent results. Students were encouraged to “observe the differences in how each top spins and in the launch techniques.” Near the end of this activity, students should realize that the two hand techniques (hand launcher and ribbon) are not as consistent as the two mechanical launchers (elastic and mixer). During this activity, students were asked to bring materials from home to see if those materials made good tops.

Activity two was the first major exercise for the students. It involved a comparison of the six different tops with each of the four launch methods. The students were told to collect three spin time measurements for each top using each of the four launch methods. At the end of this activity, each group put its results on a large poster board and compared their results with other groups. They were told to look for patterns in their data that may explain what characteristics of the tops seemed to give better spin times.

The third activity involved designing individual tops from six plastic plates. Students were given the plates and told that they would be able to vary the weight and location of the plates on the dowel. However, the diameter would remain constant. Students were encouraged to vary the number of plates, change the direction the plates faced (up or down), and vary the distribution of
the plates. In their notebooks, student drew the layout of the plates they used, as well as two spin time measurement for each different design. For this activity, students only used the mixer and the elastic launcher.

The final activity for the tops was an investigation into the effect of mass on spin time. Keeping size, launch speed, and the direction of the plates constant, students varied the weight of their top and collected two measurements for each weight. To vary the weight, they added plates, two at a time, to the top and launched it with the mixer. Through their observations students are supposed to observe occurrences of momentum, friction, air resistance, inertia, and torque. The students should see a trend developing during this activity: As more plates are added to the top, the spin time increases.
3.0 The issues that emerged

This section will describe the issues that emerged while the students worked through the four activities described earlier. My goal is to identify problems that occur with hands-on learning so people do not overlook them when using this teaching method. Many of these issues were evident in more than one activity. For that reason, I will discuss many of the issues independent of a specific activity.

3.1 Expression

Discussions in the classroom are one of the most important elements of a hands-on environment learning because it is a time for students to share their results and draw conclusions from each others’ results. Many of the students had difficulties trying to express what they observed because they did not have names for the phenomena they saw and they did not know how to recognize real-world occurrences of the words they had in their vocabulary. This inability to express themselves led to frustration and limited the quality of the discussions. In some instances students didn’t understand the meaning of words and misinterpreted their results.

In one discussion, I asked a student which tops had the most consistent results using the hand launcher. The information he had in front of him was:

<table>
<thead>
<tr>
<th>Top</th>
<th>Launcher</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purple Plastic</td>
<td>Hand</td>
<td>24</td>
<td>23</td>
<td>24</td>
</tr>
<tr>
<td>Big Aluminum</td>
<td>Hand</td>
<td>12</td>
<td>22</td>
<td>30</td>
</tr>
<tr>
<td>Small Aluminum</td>
<td>Hand</td>
<td>27</td>
<td>37</td>
<td>28</td>
</tr>
<tr>
<td>Cardboard</td>
<td>Hand</td>
<td>15</td>
<td>14</td>
<td>9</td>
</tr>
<tr>
<td>Tupperware</td>
<td>Hand</td>
<td>25</td>
<td>36</td>
<td>17</td>
</tr>
<tr>
<td>Frisbee</td>
<td>Hand</td>
<td>24</td>
<td>20</td>
<td>19</td>
</tr>
</tbody>
</table>

Table 3.1.1 Sample results

His first response was that the SA had the most consistent results, even though the PP is the clear winner. We agreed that there was a difference of 10 seconds between the highest and lowest trial for the SA, so I asked if any top was more consistent. He said that the Tupperware top (TP) was more consistent than the SA - it has a swing of 19 seconds between the best and worst trials.

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4 There were six sheets of paper, one for each top. Each sheet had a table that contained the result of three trials with each of four launchers. This table was extracted from those six pages.
After some discussion, it was clear that he had the wrong definition of the word “consistent”. He thought it meant that the spread between the highest and lowest trials were big, instead of minimal. While he knew which sets of numbers were closest to each other, and which weren’t, his definition was backwards. During our conversation, he became frustrated and aggravated because he repeatedly answered questions incorrectly, and he didn’t know why. Once we worked out the definition of “consistent”, he began to answer questions more confidently and correctly. His problem was not differentiating between variables, he needed help defining the words that were used in the classroom.

The concept of energy seemed to cause many problems for the students. Nearly every student believed that energy had some role in spinning a top, but many of them did not demonstrate an understanding of what energy really was when they answered different questions. When asked “What makes a top spin?”, the student responses included:

1. “Because we use potential energy to wind the top and kinetic energy to make it spin. So the answer is kinetic energy.”
2. “Energy makes it spin.”
3. “Energy and air keep [the top] spinning.”
4. “What makes a top stay up is energy. Without energy, the top would not be able to stand or spin.”

On another occasion, I asked two students what role weight played in affecting the spin time of different tops. They replied: “If the top is too light, wind may affect it. If the top is too heavy, it won’t have enough energy to spin.”⁵ The problem was that they could see the heavier tops were harder to spin, and that you had to “give” the tops something to keep them upright, but they had not developed an understanding of concepts like: energy, inertia, force, or momentum to describe those observations. I believe that this caused many students to feel uncomfortable discussing their results with others. Many times during our conversations, the students seemed to detail observations that were best described by those words, but without a “science vocabulary”, they could not get their point across.

⁵ Although I did not pursue it, future research could examine what the students meant when they used the word “energy”.
The problem of expression is not caused because students only lack definitions for science words. If the students were told that energy was "the capacity of a physical system to do work"\(^6\), they would not understand energy’s role in the experiments any better. Definitions to "science words" must be tied to some particular context so that the students can understand what those words mean and how to identify occurrences of those words. Likewise, simply defining the words "inertia", "force" etc. will not help students much either. I have seen that if you only give students definitions, those words will be linked to other words in their head, but there will not be any connection to the real-world phenomena that those words represent. This means that they will memorize the definition of energy, but they will be unable to identify it in their experiments.

In another discussion with a student, I asked what conclusions she could reach after measuring the spin times for different tops. She replied, "The smaller [the top], the longer it spins." She was considering the fact that the (12") small aluminum top (SA) was lighter than the (18") big aluminum top (BA), and it had spun longer. To explore her theory, we considered the 18" cardboard top (CB) along with the SA and BA. I asked her to reconcile her theory with the fact that the CB was lighter than the SA, yet it spun much worse. After some hesitation, she uncomfortably replied that the SA was smaller than the CB. We talked a little bit longer about this problem, and she became more and more frustrated because she was using one pair of descriptors to describe two different variables, the mass of the top and diameter of the top. When comparing two tops, there was no problem because she would use those descriptors for one variable, and ignore the other variable altogether. In our initial discussion, this approach worked fine, however, problems occurred when she began to compare three tops with each other because there was no way to compare them without considering both variables. In order to consider both variables effectively, she needed to differentiate between them and assign a different pair of descriptors to each one. She recognized the conflict created by using only one set of descriptors and it made her very uncomfortable and unsure of herself. Unfortunately, she did not create the second pair – which would have solved the problem. This is interesting, because the students generated a list of "significant characteristics" of tops very early during Activity One. Both diameter and mass were on that list, but, she did not connect the words on the list to the different things she observed.

Other conversations indicated that the students had trouble describing their observations. Many of the students used awkward hand gestures and phrases like: “like this” or “you know” when they compared results and answered questions. Many times, there was no problem getting their point across to other students, but they would probably have a difficult time writing down their results or explaining them to someone unfamiliar with the activities. Often, the problem was that students were not distinguishing between the characteristics they were trying to describe.

In this kind of learning environment, students are either given definitions, which doesn’t work, or they are expected to “discover” different phenomena during their investigations. My research has shown that students do not realize they’ve discovered those phenomena because they don’t know they should be looking for them. Students may make observations that deal with inertia and force, but they don’t realize they are witnessing two different phenomena. Instead, they tend to describe them as one single phenomenon. They lump all the details of their observations into one word, and produce one messy explanation to summarize their results. This is a problem of being able to differentiate among various aspects of their observations and looking for words to describe each aspect. It is not only a problem of searching for words to describe the things they’ve discovered.

3.2 Buzzwords

At one end of the spectrum, I saw that students couldn’t express what they saw because they didn’t have a large enough functional vocabulary, a vocabulary that contains words students understand and can recognize in the real world. At the other end, I saw that students used words they didn’t understand to describe what they saw. Although they are at opposite ends of the spectrum, in both cases, students were struggling to construct meanings for science words. In the case of buzzwords, they would hear a word from someone in the class, and soon, everyone would be using that word to describe different observations. My belief is that the students were just regurgitating words that they heard hoping that those words would answer the questions that were being asked. I call these words “Buzzwords”.

“Energy” was the first buzzword that emerged during the students’ activities. As I described in the previous section, the students used the word “energy” in numerous ways. Early on, they worked it into nearly every answer to all of the questions we asked them. The word
"friction" was another very popular word when the students first heard it. It was an answer to all of the following questions: Why does a top stay up? Why do some tops spin longer than others? Why is one launcher better than another? The last major buzzword that the students used was "trend". During Activity Four, the students were told to "look for trends in the data" as they critiqued and graded each other's "Spin time vs. Number of Plates" graphs. Their comments on each other's graphs reflect the desire to use "trend" as much as possible. The following quotes represent a sample of the way the students used the word:

<table>
<thead>
<tr>
<th>Grade Assigned</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>A++</td>
<td>Because there's a trend and everything is consistent.</td>
</tr>
<tr>
<td>B</td>
<td>It's not consistence [set], on some parts there's a trend.</td>
</tr>
<tr>
<td>C+</td>
<td>It has a lot of ups and downs and [it] didn't keep the trend.</td>
</tr>
</tbody>
</table>

Table 3.2.1 Sample of student comments

After that activity, I had a conversation with the two students that wrote down the third comment. Since they used the word "trend" in three of the six comments they made during that activity, I asked them to define "trend". They told me they had no idea what it meant. They said, "If you were talking about fashion, you'd be fine. But we don't know what [the teacher] means when she says 'trend'." We talked for some time, and I reached the conclusion that they only used the word "trend" because they were told to look for one in the data. The way they used it seems to indicate that they understood it is related to a pattern in the data, but they felt that a trend was a particular pattern.

My observations of other students' usage of buzzwords indicates that most of them used those words vaguely to hide the fact that they really didn't have a solid grasp of their meaning. When they responded to questions in class, the teacher and I would use variations of their responses when explaining the correct answer to the class. After a while, it became clear that they kept using a buzzword frequently to learn more about it's usage. Each time the teacher and I gave the correct answer and incorporated their comments, they would learn more about how to use the word, not what the word really meant. Simply put, the students were using "quizmanship" techniques to learn how to use buzzwords. In a hands-on learning environment, it

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15 This refers to describing as clothing as "trendy" etc.
may be easy for students to make the teacher believe they understand what they are observing – even when they don’t. If the students demonstrate the ability to use certain words, they hope to impress the teacher and get better grades. In one conversation, a student looked at a graph and said, “The trend is very consistent.” We can easily look at this remark and assume that the student is learning what these words mean. In fact, the student only learned how to use those words in a way that is not wrong. However, since there is no real information in that comment, it isn’t really right either.

3.3 Experimental method

One of the benefits of hands-on learning is that students can observe their own experiments and collect their own data, rather than reading material from a textbook. However, I have found that many students do not understand the real purpose of the experiments or how to perform those experiments. Therefore, a lot of their data is tainted, and it is very difficult for the groups to compare results beyond a basic number comparison. Without proper experimental methods, it is nearly impossible for the students to reach any meaningful conclusions, much less to reach the correct conclusions.

Occasionally, students would not spend enough time assembling their tops carefully and the tops spun wildly out of control. Students were supposed to discover that a well balanced top spins better because the forces acting on it keep it balanced. However, they were more interested in achieving the task of collecting spin time data. At one point, two groups were next to each other launching identical tops with the mixer. There was a large difference in the spin times because one top was off center and the other was well balanced. Unfortunately, the students were so anxious to collect numbers and finish their task, they didn’t realize that identical tops should have identical spin times. Students also allowed the tops to bump into things and occasionally fly up in the air when released without performing the trial again. Since they didn’t understand what the experiments could explain about how a top spins, they didn’t see how these things would contaminate the data. Furthermore, they collected numbers that had little meaning because the reason for collecting them in the first place was vague. Students must collect numerical data in the context of proving/disproving a hypothesis, otherwise that data will not have any meaning.
As the students collected spin time measurements, there were two major problems that occurred in the classroom. Although these problems were corrected when they were identified, there is a lot to be learned from the fact that they existed in the first place. Since there were not enough stop watches, one group was counting out loud to measure the spin times – which is obviously a flawed way to measure time. To set a standard for the class, we told the groups to stop timing the tops when they came to a rest. During the activities, I observed one group that kept counting long after the top stopped moving. It was clear that the effects of the launcher had disappeared, but often, there were barely noticeable movements in the top from people walking around in the room or a breeze through the windows. In both cases, the groups did not see a problem with their timing methods because they performed the measurements the same way each time. Unfortunately, they didn’t realize that it would be difficult for the groups to compare results if the experiments were not as standardized as possible. The groups stretched the boundaries of the rules because their objective was to compete with each other rather than carefully observing the behavior of their tops. To the students, it seemed like getting a longer spin time meant their group was doing better than other groups, when in reality, we expected all of the groups to have similar results.

Perhaps the biggest indication that groups were collecting tainted data, as opposed to reliable, scientific data, was the methods they used to accept/reject trials. In Activity Two, the students were told to collect three time measurements for each top/launcher combination. They agreed that gathering only two data points was not acceptable because something could have been wrong during a given trial. The students felt that three trials was good because they would be able to tell if something went wrong during a trial if its result was excessively different from the other two results. Unfortunately, some groups would collect two results, then repeat the third trial until they found a well matched result. For example, the first two times measured could be 30 seconds and 25 seconds. After that, the group may get successive results of 45, 48, 50, 47 and 34. The third, fourth, fifth and sixth trials would be discarded because they didn’t match the first two trials. and the seventh result, 34, would be added to the data. I believe that the students focused on finding a result that matched the data they had already collected, rather than stepping back and looking at the data they were throwing away. When this is the method that is used to collect data, it is nearly impossible to compare data between groups.
It is safe to say that a hands-on learning environment provides an excellent opportunity for students to see the physical phenomena that traditional teaching methods only describe in textbooks. Unfortunately, these phenomena only emerge when experiments are carefully performed. Many times the data students collected seemed to indicate that the tops were some sort of random number generators. It did not seem like the students really understood how tainted experiments severely limited the conclusions they could draw from the results. The students were preoccupied with collecting numbers and spinning the tops longer than the other groups, which made it difficult for them to discover anything at all.

3.4 Comparing Results

Even though some groups had trouble gathering reliable data, they were able to compare their results with other groups. The amount of discussion that took place seemed to indicate that the students were reaching some of the expected conclusions. However, a closer look at the actual interactions shows something very different. When the students compared results, it was very different from a team of researchers looking at data critically. Often, the competitive spirit of many groups hindered the "comparison discussions". The students compared the results to see if their results were "better" or "worse" than other groups. One student described nearly every difference in the results as a consequence of one group doing things worse than the other. She felt that if the other group's times were shorter, they probably messed up the experiment or performed it differently. Because she was determined to compare results in terms of "better" and "worse", it was very difficult for her to realize that the hand and ribbon launchers were naturally inconsistent launchers. When explaining the different spin times for different tops, some students ignored the physical differences in the tops, and only gave reasons related to the construction of the tops. If the 18" cardboard top (CB) spun much worse than the 18" big aluminum top (BA), it was because the CB was poorly assembled, not because it's mass was different. These discussions became an opportunity for some groups to show that they had "outdone" the other groups in the class, not an opportunity for "research groups" to share results and combine experiences to discover scientific phenomenon.

Most of the time, the students were doing a simple, first level analysis of the results. They only compared the actual numbers with each other, as opposed to looking for similar patterns in
the data and finding opportunities to generalize the results. Furthermore, they rarely tried to explain why their results didn’t seemed to match. Consider two groups comparing these results with the BA and the elastic launcher:

<table>
<thead>
<tr>
<th>Group</th>
<th>Top Launcher</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>BA</td>
<td>12</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>B</td>
<td>BA</td>
<td>22</td>
<td>24</td>
<td>23</td>
</tr>
</tbody>
</table>

Table 3.4.1 Sample results

I asked a member of group A if their results matched the result from group B. She replied “No, all of their numbers are about 10 seconds longer than ours.” The data indicates that her statement is correct, but it also begs for a closer look. I asked her why she thought group B’s results were all 10 seconds longer. She said, “We stopped timing the tops when they first touched the floor. They stopped when the top stopped moving.” Aside from the fact that this exemplifies one of the points I made in the previous section, it also shows that the students are not going very deep in their analysis. After some conversation, she agreed that if she compensated the results for the different measurement techniques, the two results would be nearly identical. Many students simply followed the instructions “Compare your data with the other groups and look for similarities in the results.” To scientists this implies that they should be comparing various characteristics of the data and developing explanations for the discrepancies. To the students, this simply meant they should see which numbers match. This problem indicates that students have difficulties identifying what relationships are relevant when looking at data. When comparing data, students only compared the numerical results for each trial which each other. So the two results for “Trial 1” were compared, then results for “Trial 2” were compared, and so on. Instead, they should have been comparing some of the possible relationships within the data from each group’s three trials, like the trends that were present or the consistency of each group’s results.

This type of problem surfaced again when students “compared” results of 18, 23, and 22 with results 19, 21, 20. The students would say that these results are not the same because the numbers do not match. Although this is true, the actual number don’t match, there are other ways to compare the data and conclude that the two set of number do have similarities. Conversations
with the students showed that they usually just looked to see what sets of numbers were bigger and smaller (which they considered "better" or "worse") than other sets of numbers. Most of the time, students didn’t search for reasons to explain the differences in results. This is an important observation because the whole premise of hands-on learning is that students will be naturally motivated to search for a deeper understanding of the results they obtain from their own experiments. The problem may be that we assume telling students to “compare” results implies that they should be comparing those results based on numerous criteria. I noticed that most of the students only used one criteria, the actual numbers. If the students are not explicitly told to compare data on various, well-defined criteria, it is dangerous to assume that they will generate those criteria on their own. For students to compare results at that level of generalization, they need to learn how to “step back” from the results and look at the big picture. Without this skill, which probably needs to be taught and reinforced, it is difficult for students to put together all of the information they gather from various activities and experiments.

3.5 Graphs and Numbers

After Activity Two, I created a set of data and graphs that contained fictional spin times for each top/lanceh combination. Based on this data, I had discussions with every student in the class regarding what they could tell about tops from the data. As mentioned earlier, students also constructed their own graphs after Activity Four to help them study the effect of mass on spin time. Many people believe that if students draw graphs, it will be easier for them to make sense of the numbers in front of them. Watching the students answer questions about these graphs proved that graphing doesn’t always make it easier for students to understand their results. Furthermore, studying graphs can become an exercise that seems completely unrelated to the experiments that produced those graphs.

Students seemed to have a very difficult time moving between numerical and graphical representations of data. Most of the students I spoke with would only use one representation or the other to answer my questions. This caused many incorrect answers because bar graphs help students identify trends and qualitatively examine data, but numerical results are useful when the resolution on the graphs is not high enough. For example, if I asked a student: “Which top was
better using the mixer, the Frisbee or the Tupperware?”, most students would answer, “The Tupperware.” Looking at the graphs, the resolution is not good enough to determine the correct answer. Most students simply chose the Tupperware because its graph looked bigger.

![Graphs of Frisbee and Tupperware tops using the mixer](image)

<table>
<thead>
<tr>
<th>Top Launcher</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frisbee mixer</td>
<td>43</td>
<td>44</td>
<td>45</td>
</tr>
<tr>
<td>Tupperware mixer</td>
<td>41</td>
<td>41</td>
<td>40</td>
</tr>
</tbody>
</table>

Table 3.5.1 Graph of Frisbee and Tupperware tops using the mixer

When I asked students if they were sure, they usually indicated that they weren’t positive, but it seemed like the correct answer. Without help, the students rarely realized that they could go back to the numerical data for a clearer look. The graphs were like another set of data that had no relation to the numerical data. It is not beneficial for students to generate graphs from their data if this new analytic tool replaces existing ones. Both ways of analyzing data must coexists in the student’s skill set. Students must be able to see the connection between a numerical representation of data and a graphical representation of the same data. It would be even more helpful if they understood the advantages and disadvantages of each representation.

Students also had a difficult time answering questions about consistency using graphs rather than numerical data. When discussing graphs, “consistent” seemed to mean that the bars either increased, decreased, or stayed the same for each trial. I asked a number of students which launchers were consistent for the PP based on the data in front of them.

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8 Appendix B contains the numerical data and the graphs used during discussions with the students.
Purple Plastic

![Graph showing bar chart for Purple Plastic with Launcher Method]

Table 3.5.2 Sample results

<table>
<thead>
<tr>
<th>Launcher</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic</td>
<td>28</td>
<td>26</td>
<td>27</td>
</tr>
<tr>
<td>Ribbon</td>
<td>21</td>
<td>13</td>
<td>22</td>
</tr>
<tr>
<td>Hand</td>
<td>24</td>
<td>23</td>
<td>24</td>
</tr>
<tr>
<td>Mixer</td>
<td>28</td>
<td>28</td>
<td>29</td>
</tr>
</tbody>
</table>

If the students were looking at the graphs, most of them said that the hand and the mixer were the only consistent launchers. However, when I showed the same students the numerical data, they said that the elastic was also a consistent launcher. After having the same conversation with numerous students, I realized that the order of the bars in the graphs was confusing them. Since the numbers for the PP with the elastic launcher are close together, most students felt they were consistent. However, the students felt that a bar graph of 28, 26 and 27 “jumped around” too much, and should not be called consistent. They did not realize that the order of the bars on the graphs did not matter -- graph of 26, 27, and 28 could be considered just as consistent as 28, 26, and 27. The students did not try to manipulate the graphs in their head the same way they shifted around the numbers. The graphs became static pictures that they would only analyze in the form presented to them.

The graphs that were created after Activity Four highlighted another problem that students had while graphing their results. Although the students were supposed to be looking for trends in the data, they were preoccupied with the absolute shape of the graph. After looking at the graph below, one pair of students commented that, “It should be least to greatest. It’s too wild.” Other students said that some of the graphs would have been better if the bars were “in order”.
<table>
<thead>
<tr>
<th># of Plates</th>
<th>Trial 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>25</td>
</tr>
<tr>
<td>4</td>
<td>25</td>
</tr>
<tr>
<td>6</td>
<td>56</td>
</tr>
<tr>
<td>8</td>
<td>56</td>
</tr>
<tr>
<td>10</td>
<td>67</td>
</tr>
<tr>
<td>12</td>
<td>60</td>
</tr>
<tr>
<td>14</td>
<td>57</td>
</tr>
<tr>
<td>16</td>
<td>102</td>
</tr>
<tr>
<td>18</td>
<td>105</td>
</tr>
<tr>
<td>20</td>
<td>95</td>
</tr>
<tr>
<td>22</td>
<td>120</td>
</tr>
<tr>
<td>24</td>
<td>121</td>
</tr>
<tr>
<td>26</td>
<td>145</td>
</tr>
<tr>
<td>28</td>
<td>144</td>
</tr>
<tr>
<td>30</td>
<td>139</td>
</tr>
</tbody>
</table>

Table 3.5.3 Sample results

This is interesting because as mass increases, the spin times should get longer, therefore, the bars should be in ascending order. Since every experiment has some amount of human error, most of the graphs had an increasing trend, but it wasn’t perfect. Many students could not move to a level of generalization where the trend was evident – which is the same problem describe in the previous section. Instead, they were stuck comparing the sizes of the bars and saying which were too big and which were too small compared to the adjacent bars.

Graphing results from experiments does not guarantee that students will be able to understand their data any better. Furthermore, students do not seem to have a strong understanding of when graphs are more useful than the numerical data. Graphs can magnify tiny errors in data and prevent students from reaching the correct conclusions. Without the ability to see the relationships between graphs, numerical data, and actual experiments, students cannot experience the full advantage of using graphs to analyze data.

3.6 Student Theories

After conversations with the students as they performed experiments, I realized that some students were developing theories about “What makes a top spin?” This indicates that a hands-on learning environment can encourage students to develop a deeper understanding of the
phenomena they are studying. However, getting students to develop theories is not grounds to declare victory. Students must be able to develop theories and prove/disprove them with the data they have collected from their experiments.

Some of the students that developed theories ignored their data when developing those theories. The acts of collecting data and developing theories were separate and did not relate to each other. One student felt that: “The lighter a top is, the better it will spin.” I asked her to rank the tops in weight order, and she arranged them (heaviest to lightest):

<table>
<thead>
<tr>
<th>Lightest</th>
<th>Heaviest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purple Plastic</td>
<td>Tupperware</td>
</tr>
<tr>
<td>Cardboard</td>
<td>Big Aluminum</td>
</tr>
<tr>
<td>Small Aluminum</td>
<td>Frisbee</td>
</tr>
</tbody>
</table>

Looking at the numerical data, she could see that the Purple Plastic top (PP) spun better than the Cardboard top (CB) and Small Aluminum top (SA), which agreed with her theory. However, it was also clear that the Frisbee (FR) also spun longer than the CB and SA, which were lighter. She had created a theory that she could prove wrong with the data in front of her. Two weeks later, I had an identical conversation with another student that had a similar theory. These students were able to perform all of the tasks given to them: collect spin time measurements, compare your data with other groups, and try to understand what makes a top spin. However, they did not combine all three of these tasks to develop an accurate theory. Collecting the data was a task associated with spinning tops and comparing data between groups was a simple number comparison. Unfortunately, to develop theories they only drew upon what they could remember about spinning the tops, as opposed to knowledge they obtained from the data or comparison discussions.

By definition, inquiry-based learning seems to imply that students can prove or disprove their theories by making their own inquiries into the material. However, the experiments that students perform are prescribed in the teacher’s manual. Students are not encouraged to “break away” from the class and perform their own experiments. This is problematic because some students develop faulty theories and never get a chance to disprove them. One student believed:

“The top is using so much kinetic energy, it actually catches air and [that] keeps it up. But when it slows down, it can’t catch that much air and it falls…”
A simple experiment could prove his theory incorrect, but he never had the opportunity to test it. A learning environment with prescribed experiments gambles that students like him will eventually discover the correct theory and will abandon the incorrect one. However, if he already feels like he knows why a top "stays up", then chances are he will just "go through the motions" for the rest of the activities without searching for another theory.

Hands-on, inquiry-based learning allows students to develop theories as they work through the different activities, but this can be very dangerous. If a student develops an incorrect theory, it is easy for him/her to move through the rest of the activities without correcting that theory. Furthermore, it is not safe to assume that students feel a sense of ownership during these activities simply because they perform experiments and collect their own data. They are not automatically excited about performing these experiments because they were not involved in designing them. In industry, a good manager knows that the easiest way to get employees to "buy into" a plan is to let them help develop that plan. The classroom is not any different. If students do not feel like they helped design an experiment, there is no reason to think they feel a sense of ownership during those experiments.
4.0 Conclusion

The main goal of a hands-on, inquiry-based learning environment is for students to learn about scientific phenomena through experimentation. Hands-on learning environments allow students to develop theories from their results, but there is nothing magical about these environments that forces student to develop accurate theories. We should not be surprised or discouraged when students develop inaccurate theories. In fact, many of them will develop faulty theories -- just like real scientists. That being the case, they need to develop skills and have opportunity to test their own theories. If we are not going to encourage students to test their own theories, we should use textbooks to teach them about force, inertia, energy etc., then use the experiments and activities to supply examples of those phenomena. If we are going to use the experiments as a vehicle for “discovering” those phenomena through inquiry, then we have to help students understand concepts like “proof” and “evidence”, and give them sufficient freedom with the inquiries they make.

These are issues that emerge in this kind of learning environment and not in traditional teaching environments. All of these issues, and many of the ones that were described earlier, are related to the students’ ability to perform scientific research. The remaining issues deal with students’ ability to understand the concepts and principles that they are studying during their experiments. If we want them to learn in a hands-on learning environment, teaching them how to perform scientific research becomes our most important goal, especially when considering the different “variables” in a hands-on environment. When students learned science from textbooks, it was assumed that they all had the same information available to them. In this environment, where students collect their own data, every group may have different information so there is no simple way to make sure everyone has the same opportunity to understand concepts. If a student has unreliable data, he/she may not understand certain concepts as well as a group that collected reliable data. If students understand how to perform scientific research, they will be trying to draw conclusions from reliable data. Although possessing reliable data does not guarantee that a student will reach accurate conclusions, it certainly seems like a reasonable prerequisite.

This section examines the issues identified earlier in terms of their relationship to the goal of helping students learn to perform scientific research. It also discusses the relationship between the experiments and a student’s ability to construct meanings for the things they have observed.
In each case, it describes symptoms of different problems and strategies to address those symptoms. It also states some of the questions that emerged during my analysis.

4.1 Learning how to do research

Developing students’ abilities do scientific research is a goal that can be broken down into four sub-goals. First, we want students to have the ability to ask scientific questions, which are questions that occur when students are trying to understand something or when they encounter something puzzling. If they do not know when and how to ask questions, they will not learn much from an inquiry-based learning environment. Second, we want students to develop their own theories. Students need to the ability to develop preliminary answers to their questions based on past experience or “gut feeling”. This does not mean that these theories should always be correct, they are simply starting points on the path to finding the correct answer to a question. Next, we want students to know how to design and perform experiments that will test their theories. Finally, we want students to have the ability to draw conclusions from their experiments. This means that they will be able to determine if their theory is correct or incorrect based on their experimental results. Furthermore, students should be able to develop new theories from their data if they prove their original theory wrong. My observations show that these goals are not being met in some cases.

<table>
<thead>
<tr>
<th>Element of research</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>One</td>
<td>Asking questions</td>
</tr>
<tr>
<td>Two</td>
<td>Develop theories</td>
</tr>
<tr>
<td>Three</td>
<td>Design and perform experiments</td>
</tr>
<tr>
<td>Four</td>
<td>Draw conclusions</td>
</tr>
</tbody>
</table>

Figure 4.1.1 Four important elements of research

Throughout these four phases of scientific research, we need to remember that students should be evaluated on their ability to do scientific research and their understanding of the phenomena they are studying. When students are evaluated primarily on criteria that have nothing to do with their understanding of the subject, like how neat their graphs are, they usually don’t focus their efforts towards understanding concepts. Instead, they try to become experts at performing mechanical tasks, like assembling and spinning the tops or making bar graphs from a
series of numbers. Ideally, the experiments would give students the data they need to reach meaningful conclusions. However, without having learned about experimental methods along with competition among groups, causes students to rush their experiments and collect unreliable data. If the experiments are not performed carefully, it will be very difficult for the students to reach the correct conclusions and understand the concepts they are studying.

Perhaps the biggest barrier to students learning how to do research is that hands-on learning and research are often viewed very differently, even though they both depend on experimental method and careful data analysis to reach conclusions. Over a period of years, scientists learn how to ask probing questions, design and perform experiments, and analyze their data. On the other hand, students are expected to do all of those things naturally, without any substantial training. Inquiry-based learning works best when the students know how to make inquiries. Although “making an inquiry” is a complicated process, it starts when there is a question to be answered – preferably a question that the students helped create. Learning how to ask scientific questions is not a natural ability; it is an acquired skill. Students need to learn this skill before they can be expected to learn in an inquiry-based learning environment. It is true that the act of performing an inconclusive, scientific experiment may force students to ask questions in order to understand their results, but my observations have shown that students will rationalize conclusions from any results they obtain. Therefore, it is not safe to assume that they will learn how to ask questions by simply performing experiments and analyzing their data.

How do you teach students to ask scientific questions so they can begin the process of making a scientific inquiry? The answer to that question is something that teachers will probably need to learn so students can teach more effectively in this environment. The teacher could ask the students questions that probe for other questions, which may provide the students with examples of the types of questions they should be asking themselves. Of course, this raises the issue of how to teach the teachers to ask the students those types of questions. Furthermore, the discussions may take a lot of time, and at first, it may be difficult to have them with every group. However, after a while, I believe that teachers will be able to have shorter, effective conversations with the students because they will recognize common difficulties and problems that students have.
Often, it seems like students develop theories as they perform experiments, which is one of the positive aspects of inquiry-based learning. As Mr. Zubrowski claims, “problems and questions are a natural outgrowth of the properties of the materials and the students’ interest.” Although many students may have curiosities, they may not have the chance or they may not know how to organize those curiosities so as to turn them into appropriate questions or potential hypotheses. If the activities encourage students to develop their own theories, then it makes sense for us to let students address those theories through experimentation. We do not fully realize the potential of this learning environment by telling students to develop theories, and not letting them “explore” those theories. In the case of Tops and Yo-yos, the activities move students through a series of activities that were designed in advance. However, if a student’s incorrect theory is not explored during those activities, that theory may never be addressed. Therefore, he/she may never discover the correct theory. During my observations, I saw a student that believed tops “catch air” to stay upright. He never abandoned that theory because it was never directly addressed in a discussion or an experiment, which is a possible explanation for why he didn’t learn the correct theory from the remaining activities.

4.1.1 Testing theories and designing experiments

Is there a way to allow all of the students to test their own theories, and still move through the curriculum? If the teacher could identify the conflicting theories and discuss them with the class, then students may not need to actually perform experiments to prove/disprove their theories. In any case, students need to understand the rationale for moving to the next activity, otherwise, they will lose interest – even though they are the ones performing the experiments and collecting data.

In this kind of learning environment, encouraging conflict between theories may be very helpful. After some activities, a teacher could poll the students to find out the different theories that have emerged. Once the teacher sees which students have similar theories, they could rearrange the groups for a “fact finding” activity that addresses where the students could create an experiment to test their theories and collect the data to prove/disprove those theories. In fact, groups may be more motivated to design experiments that prove a dissenting theory incorrect

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9 From the Tops and Yo-yos teacher’s guide, page 6.
than trying to prove that their theory is correct. This is interesting because, in this case, competition between groups is beneficial. If teachers decide to let the groups prove each other incorrect, they must be careful that students are not compromising the integrity of their experiments in order to prove each other wrong. Again, students will probably need help defining a theory and understanding how to find evidence that proves/disproves a theory.

**Focus question:** Why don’t some student theories emerge during the activities?

Although working in groups is supposed to enhance learning, is it also one possible reason for why some student theories do not emerge. Often, teachers split the class up into groups during the first activity and keep those groups together for a period of weeks. This limits the variety of ideas that students express because groups tend to give similar answers, even though they may have developed a number of different theories. Evidence of this can be found by examining the groups’ responses to the question: “What makes a top spin?”

**Group A. Student 1:**

“What makes a top spin are many things working together. Energy, air, gravity, weight, balance, height, and material. Gravity keeps it on the ground so does weight. Balance helps keep it steady. Energy and air keeps it spinning. The material and height helps determine how long it will spin. In conclusion all these things put together shall make the top spin.”

**Group A. Student 2:**

“Energy makes the top spin. Weight balances. The material and height helps determine how long it spins. Gravity keeps it on the ground. The balance helps it keep steady and in place. Energy and air keeps it spinning. All these things put together help make a top spin.”

Aside from the fact that “What makes a top spin?” is an ambiguous, poorly phrased question and this duo has used most of the major buzzwords, their responses are virtually identical. Two members of another group answered that same question with responses that were identical to each other. When groups have different opinions, they have the opportunity to debate with each other to find a reasonable conclusion. However, groups are often composed of friends, who don’t want to compete with each other. One member usually “gives in” the others’ theory, so they can reach a consensus and move on.

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10 The first question to ask students is “Which top spins the longest?” Once they have identified that top, they should try to identify its distinguishing characteristics. Now they are ready to figure out “How does a top stay upright while it is spinning” or “What may cause a top’s speed to decrease while it is spinning?” The answer to the first question may deal with different forces, while the answer to the second question may deal with energy or friction. Because the question was ambiguous, the students’ responses were very broad and non-specific.
As described earlier in the “Experimental method” section, many students didn’t know what aspects of the experiments to watch carefully because they didn’t understand the goal of that experiment. Because the goal of each activity was not always clear, competition between groups usually became the students’ goal. In this case, competition was damaging to the learning process because it compromised the integrity of the experiments. One possible way to minimize the competition between groups is to emphasize that the class, as a whole, is trying to understand a variety of different phenomena. If students feel that their group is being graded on how many numbers they collect or the graphs they create, their focus will be on collecting more numbers and creating more colorful graphs than other groups. When this type of competition occurs, students will perform the experiments carelessly to gather as many numbers as possible. For example, when checking on the students’ progress during Activity Four, a teacher may ask each group how many plates they have tested. A group that is testing 24 plates may get a response like, “Good work, keep going.”, while a group still on 14 plates may hear, “Let’s get going, you have a lot more to do.” While those comments may seem harmless, my observations indicate that the “slower” group begins to focus its efforts on getting more numbers quickly, rather than getting reliable numbers at a manageable pace. Their goal becomes getting numbers faster than the other groups, which usually causes them to compromise the integrity of their experiments. Competition between groups may also limit the insight students reach from their data; because once the data collection is complete, they may spend more time thinking about how to graph the results than trying to understand them.

4.1.2 Drawing conclusions

Getting students to draw meaningful conclusions from their results once they have collected their data was also difficult. Before comparing results with each other, students should generate a list of important characteristics and develop preliminary conclusions from their own results. It is important to help them draw conclusions from their own data before they examine other group’s data, because if they have not drawn any meaningful conclusions from their own data, there is no reason to expect them to gain anything from looking at another group’s data. I have seen that students can generate a large list of characteristics during discussions with the entire class, however, teaching them to draw conclusions from their own data is much more
complicated. One potential way to teach students how to draw conclusions, which is similar to a strategy described earlier, is for the teacher ask questions that probe for accurate and meaningful conclusions. For example, a student may claim that most of the tops seemed to have very inconsistent results for the Big Aluminum top using the hand launcher. Probing questions from the teacher may help that student realize that the “hand launcher” is usually inconsistent. They may even lead to an understanding of inertia.

After the groups have reached preliminary conclusions from their own data, they are ready to interact with each other. During their discussion, the groups should try to reconcile the conclusions they reached from their own results with other groups’ data. For example, one group may conclude that wider tops seem to spin longer, while another group may feel that lighter tops spin longer. Together, they may realize that both characteristics seem to affect spin time and search for an new explanation. However, if students are only comparing numbers during their discussions, this synergy will not exist. Post-activity discussions with the entire class should be a model for the types of discussions the students should be having in their groups. This is one way to show the groups how to reconcile different conclusions with each other and use each others’ observations effectively.

4.1.3 Linking representations

My research has shown that linking representations is difficult because graphing numbers is not a guaranteed way for students to understand their data any better. Since graphing data is very mechanical, the ability to produce a graph from data does not indicate that a student understands anything at all. In this kind of learning environment, students need to construct a link between hands-on experiments, data, and graphs before they will realize the full benefits of graphing. To an experienced eye, graphs make it easy to spot trends or make comparisons. To younger students, graphs are like pictures that are unrelated to the data; not to mention the experiments that produced the data. The goal of these activities is not to produce graphs, it is to reach an understanding of scientific concepts. Graphing is one of the vehicles that students can use to reach that understanding, not an end-product of the experiments they perform.

One plausible way to help students connect graphs and numbers is to use a computer spreadsheet like ClarisWorks, a program that was installed on many of the computers in the
school's computer lab. Altering numbers on the spreadsheet will simultaneously alter the graphs, which may help students make the link between the two representations of data. However, this type of solution raises many other issues. First, many schools have a single computer lab and scheduling conflicts make it difficult to bring an entire class to lab very often. Left on their own, most students will not play with spreadsheet programs in a way that will help them see the link between graphs and numbers. This means that someone will need to carefully design an activity that walks students through different exercises. Finally, this still does not help students connect the data and the experiments they used to generate that data.

The biggest flaw with solutions like the one described above is that they are possible solutions to a poorly defined problem. Despite my efforts to do so, my observations did not show me what the students really thought their numbers represented. Furthermore, I also have not discovered exactly what they think the graphs represent. Strategies for helping students with graphs and numbers will be most effective when we understand what students see when they look at those two representations. Without this knowledge, it is likely that “mechanical” solutions will be ineffective because they do not address the root of the problem. Unfortunately, the difficulties that students have understanding numbers and graphs are a discussion too big for this paper and they are beyond the scope of my research. Understanding and drawing conclusions from graphs is much more complicated than many people think. Graphing can confuse students and actually distract them from trying to understand their results, especially when they feel that drawing a nice graph is more important than understanding that graph.

4.2 Understanding concepts

When describing the issues related to a student’s ability to develop an understanding of scientific principles and phenomena, the focus was on “words”. Students’ incorrect use of “science words” indicated that they may not be developing an understanding of the relevant phenomena. However, the strategy for addressing those issues is more specific than just focusing on “words”. Students may use words to describe an observation, but a long-winded monologue could possibly be simplified by using a “shortcut word”, like “momentum”. Furthermore, we must examine the process that a student uses to assign a word, or name a observed phenomena.
On many occasions, students had trouble expressing themselves because they had a small functional science vocabulary. Many times they didn’t know how to express their observations using a few specific science words. Instead, they would make awkward hand gestures and use very wordy explanations when describing their observations. Attempting to teach students “science words” so they understand those words in every context is an unreasonable goal. Instead, it is better to teach the meanings of certain words in a context related to the current activities. In future activities, a student may encounter the same science words in a new context and link the two activities together to form a more general understanding of that word. For this approach to work, I believe that there should be continuity and repetition in the science curriculum. Otherwise, students may only learn the meaning of those words in a single context, and they will not understand them in broader contexts.

The underlying problem in all of this is that there is not enough value placed on noticing when and understanding why a student may be confused. In order to help students understand something it may be useful to determine what is confusing them. This implies that helping students understand why they are confused goes hand in hand with helping them construct “meaningful meanings” to science words. Simply defining the words is not enough, because they will not be connected to a real-world example. Students that seem confused and cannot express themselves have probably observed something new, which is what we should expect to occur during these activities. These occurrences are opportunities to help those students name different phenomena. It is also a chance for students to learn some new words by using them to describe their observations. Teachers need to value times when students have trouble expressing themselves because each one is a window of opportunity to teach students new science words. That raises these two important questions: “How can you teach teachers to uncover the source of a student’s confusion?” and “How can you teach students that when they see something they don’t understand, they are actually on the way to learning something new?”

Rather than embarrassment, there needs to be a positive value put on confusion. Unfortunately, when students see something they don’t understand, they usually try to hide it from the teacher, which makes it very difficult for the teacher to realize and address their confusion.

Another symptom was that students used buzzwords when answering questions and discussing results. Many times, they were either hoping that those words were names for the
phenomena they observed or they were just trying to impress the teacher. On other occasions, students had incorrect names tied to different things. For example, when the students were told to look for "trends" or the effects of "friction" in their experiments, their statements at the end of the activity often included those names. They may use "trend" incorrectly because they are using that name for something we call "consistency". This means that student make look at a series of increasing numbers and say there is no trend, even though he/she can see that the numbers are increasing. It is difficult to determine why a student uses a word incorrectly in a particular instance, but it may be helpful if words that have the potential to become buzzwords were given meanings before the activities began.

When teaching the names of some phenomena, definitions need to be combined with demonstrations and exercises that help kids can construct meanings for those words in the current context. For example, "momentum" can be taught using the actual definition, the equation $p=mv$, and a demonstration that involves collisions with balls of different mass. Using all three approaches may be difficult for students to grasp at first, but they will eventually see the connection between all three representations of momentum. This is analogous to my belief that students will eventually piece together multiple encounters with certain words and phenomena to develop a broader understanding of them. The fact that some of these concepts are studying are inherently complex cannot be overlooked. Even the greatest strategy for teaching science words and different names may not be enough to help some students.

Another way to approach this problem is to give students instructions that avoid the use of science words altogether, which gives them the opportunity to discover the properties those words represent. Rather than telling them: "Look for a trend in your results," we may say: "Do you notice any patterns in your results?" For example, students may notice that the results for a particular launcher are similar, and afterwards, learn that the name for that property is "consistent". If students are told to look for a specific property in their data, teachers may need to explain, or illustrate, those properties in the current context because students that haven’t constructed meanings for those properties may spend time looking for the wrong thing, or not looking for anything at all. Otherwise, the instructions should avoid the use of those words altogether.
Also, if students feel that impressing the teacher will lead to better grades, they will use buzzwords as often as possible. If they will be evaluated by how well they understand different concepts, that criteria should be explained to them before the activities begin, so they understand that it is in their best interest to ask for explanations of words they don’t understand. I have seen that students will use words they don’t understand because they think nobody will notice that they don’t really understand the concepts behind those words. The challenge for the teacher is to develop situations and questions that will help him/her decide if a student has constructed appropriate meanings for those words or if she/he is just regurgitating words heard earlier.
5.0 Postscript

Hopefully, this paper has shown that hands-on learning is not a simple solution to the problem of teaching science. Letting kids play with things will not automatically teach them anything about science, although it may teach them how to spins tops or perform other actions. Inquiry-based learning is a new way to describe something that people have been doing for centuries – research. For this type of teaching to be effective, students need to learn how to act like scientists. That includes teaching them how to develop hypotheses, perform experiments, analyze data, and draw conclusions. If they don’t have these abilities, at some level of proficiency, they will not benefit from an inquiry-based learning environment.

I am not suggesting that hands-on learning is too complex for the students to grasp. Instead, I am convinced it is the best way to teach students, but they are not equipped with the necessary tools to thrive in this type of learning environment. Once these issues have been addressed, students will learn much more than they could by only reading textbooks. With hands-on learning, the students learn “real” science. Reading textbooks, students only learn about real science.

Ultimately, the teachers will carry the biggest burdens associated with this kind of teaching. They will need to be experts at understanding what a student is trying to say, and helping that student make sense of his/her observations. They will also need the ability to ask the right questions, so students can arrive at the right conclusions and feel a sense of accomplishment. Finally, they will need to have a broad knowledge of the material if they hope to understand the various observations and discoveries that students can make.

In a way, I am jealous of the students that I worked with during my research. Going up and down the rows, with each student reading a paragraph from a textbook, was the extent of the creativity in my elementary school science classes. In years to come, these students may not be able to fathom any other way of teaching science. With the exception of a virtual learning environment, no other learning environment has the potential to teach students so effectively. After all, much of the science we know was discovered with hands-on experiments – so why would a hands-off way be an effective way to teach it?
Bibliography


Futernick, Ken, 1988 *A critical examination of computer programming as educative experience* University of California, Berkeley. Advised by James Jarrett.


Appendix A

This appendix includes illustrations of the launchers used by the students during Tops and Yo-yos. The launcher and tops are explained in Section 2.3.
Hands moving in opposite directions

Hand Launcher

Ribbon pulled in opposite directions

Ribbon
Elastic

Mixer

rubber band
on dowel

mixer hole restinglightly on dowel
top spinning tomaximum speed
Appendix B

This appendix includes the data and graphs that were used during many of the discussions I had with the students. The data was created based on the results that the students obtained during their experiments. During the actual discussions, the numerical data was not displayed on a single page. Instead, each top had its own page that contained the results of three trials with each of the four launchers.
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