Curriculum Units by Fellows of the Yale-New Haven Teachers Institute
2013 Volume IV: Asking Questions in Biology: Discovery versus Knowledge

Looking for Answers, Asking Questions with Data

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Introduction and Rationale

Like many of my New Haven Public Schools colleagues in the seminar, " *Asking Questions in Biology* " I encounter a lack of inquisitiveness from my students. There is a very strong effect at the high school level, and a very strong effect in the mathematics classroom. Math is most clearly associated with black and white, right and wrong answers. While creativity may be prized in writing, and strong opinions in social studies, science and math are cast as factual, not open to interpretation and nuances in methodology. I believe that the lack of questions comes in part from the students' lack of confidence in solving problems.

Curiosity is innate to us all. I do not think that the lack of inquisitiveness means that my students are not curious. Rather, the lack of verbalized questions may reveal a discomfort in public speaking or making oneself vulnerable by the admission of not knowing. Even in a classroom where inquiry-based learning is the norm, the underlying fear of "not being smart enough" pervades much of my students' behaviors. Many will not participate rather than risk failure. Others will act inappropriately as a distraction. Guided questioning and modeled inquiry immersed in subject content has a vital role in teaching students. Instruction needs to be geared not only to tapping students' interests but in teaching them to trust their thought processes, refine their questions, and seek their own answers whether through research or experimentation.

Many math teachers (and standardized tests) reinforce the one-right-answer thinking. This may be a result of a system too focused on memorized content. In order to emphasize process as well as content, the newly adopted "Common Core State Standards for Mathematics" have created explicit practice standards alongside content standards. These practice standards are emphasized in the document by applying to every grade level. The first practice standard is to "1. Make sense of problems and persevere in solving them." [1] Students really do need practice in becoming the drivers of this process. Too often they believe that there is one correct way to look at a problem and so they distrust their ability to make sense of the problem.

I teach Statistics at Hill Regional Career High School, which is an inter-district, urban high school with a magnet theme in health-science and business careers. Many of our students wish to pursue careers in health related fields. Biology, general science, and statistics are important subjects for these students. Helping my students succeed in these subjects has much to do with their comfort in asking questions and crafting problem-solving methods that will lead them to productive answers.

This unit will examine theories of why and how people inquire, and how teachers can cultivate question asking. I will discuss the way that questions can turn into plans to find answers. I will examine this process in the math classroom, and the way that asking questions and seeking answers has changed for students who have constant access to looking up information. I will relate this to the way that asking questions through data has changed in the era of online data collection and so-called "Big Data". This unit will also outline strategies to use in the classroom to create a culture of asking questions in order to "make sense of problems" and to encourage students to "persevere in solving them". [2]

Framing the subject matter – engaging in the process of inquiry

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John Dewey, the eminent philosopher of education, examines pure inquiry in *Logic, the Theory of Inquiry.* It is a fascinating and exhaustive dissection of the components of the process of forming questions. He describes the ecology of thought, stimulus, questioning and knowledge. He says that doubt leads to questions and calls doubt a result of "the disturbed relation of organism-environment". In his view, doubt is never fully removed, instead the inquiry process, "institutes new environing conditions that occasion new problems. What the organism learns during this process produces new powers that make demands upon the environment. In short, as special problems are resolved, new ones tend to emerge." [3]

Dewey sees the process of inquiry as an organism's natural search to achieve balance when presented with a stimulus. He also sees the inquiry process as growing and changing with a person as they adapt and learn. Finally, he does not expect a complete removal of doubt, but a forward moving process where new questions emerge as older questions are refined or resolved.

Now, cut to the classroom setting. What sort of "disturbed relation of organism-environment" will cause a student to react with productive questions necessary to stimulate learning and further the process of inquiry? As a teacher I have prepared many lessons that I was convinced would fascinate my students, and prompt engagement and questions, only to have students be mentally checked-out. At other times students have shown unexpected persistence in working through problems driving themselves forward to find an answer. The topic itself is not what engages students, it is the framework each student builds in order to examine the topic.

The importance of framing the topic is to formulate an interest. It takes time and an amount of directed looking to begin to perceive patterns and take interest. Author Chris Barnard writes in *Asking Questions in Biology:* "Unfamiliar systems are often boring. The details may not reveal patterns and may seem to change at will and without direction and nothing 'significant' or worthy of mention may arise." [4] Without patterns, everything becomes monotonous or overwhelming.

So, even "culturally responsive" or "student-centered" content can be met with resistance. Even seemingly exciting topics take some time to lure us in, and to stimulate our individual interest. A classroom of twenty-seven individuals will frame the topic in equally different ways. It requires patience and process and a culture of the classroom to allow students to find the patterns that stimulate their interest and provoke the questions that promote seeking answers. So while almost any subject can feel boring at first, almost any subject can engage as one begins to see patterns in a piece of that subject.

How do we help students to make sense of problems in Math in order to begin finding solutions? The traditional expectations of a Math class are to learn the necessary skills within that subject, whether Algebra, Geometry or Statistics. The focus on skill alone removes the math from its application, and makes it more difficult for students to frame a problem for themselves. Yet, a focus on applications alone can be problematic, if the applications require skills and practices that students do not yet know. A working Mathematical process, like a Scientific Method can enable students to follow a consistent process to make sense of and persist in solving problems.

George Polya, in his influential book, "How to Solve it" published in 1945 and still widely referenced today, lists four phases to problem solving; understanding the problem, making a plan, carrying out the plan and reviewing the completed solution. [5] Actually solving, or carrying out the plan is only one component of a rather lengthy process. In his scheme, understanding the problem requires the same attention as solving the problem. Understanding the problem also means framing the problem to provide access and interest. Understanding the problem could involve "Google-ing" it, but as teachers we need to emphasize that reading about a topic, naming a topic or being able to look up a topic does not mean we understand the topic.

Understanding the Problem

If we provide a student with a process to frame a subject we can begin their steps towards asking questions about the subject and eventually solving problems within the discipline. One natural way to observe the subject is to measure it. Immediately, we encounter a set of questions about the subject itself. What can be measured or counted? What are the tools needed? What are the units of measurement? These initial questions can provoke deeper reading and engagement into the situation and provide a process for generating inquiry around a topic. If students are able to measure and collect data themselves, this allows for immediate engagement.

Another route into math and data is seeing. Math can be extremely visual, using graphs, tables, and geometric diagrams. In general, these objects can intimidate students and so a graph may not initially stimulate a student's curiosity. There is often too much to see for one to immediately perceive patterns. Mathematical visuals are densely packed information. A process for unpacking visual information can be vital to help our students to react productively to a visual stimulus.

To assist students to frame a subject through examining visuals also requires a process. Questions that can help students to unpack meaning are as useful as the framing questions above. Who or what is being measured? What are the units of measurement? In addition, students should deconstruct the two-dimensions of the graph. What does the x-axis show us as well as the y-axis? How are the actual measurements coded to fit into the graphic? What does each visual unit on the graph correspond to in the actual data?

Students who have begun to engage in the topic either through measured data or looking at graphs should be given the opportunity to formulate a pathway of inquiry. In the classroom a process for stimulating questions is necessary and should not be expected to arise naturally. Based on the book, "Make Just One Change: Teach Students to Ask Their Own Questions" by Dan Rothstein and Luz Santana, a *Question Formation Technique* can be used to stimulate student conversation around the topic and to formulate questions that can later be refined. [6]

In this process, students will work in groups with each other to generate as many questions as they can. The goal here is to ask unfiltered questions. The purpose of this process is to provide a safe space for asking questions, a place where questions are respected and rewarded, and practice in changing observations and statements into questions, so that students learn explicitly how to inquire.

Following the initial brainstorming of questions, students should share the group questions. A new phase can begin as the groups discuss the types of questions that have arisen, perhaps categorizing them in various ways. Some ways of grouping questions are as open versus closed, measurable versus opinion-based, and "answerable now" versus "needs more research."

Making a Plan

Subsequent to developing and honing questions, students should begin to select questions that they may decide to pursue. These will probably come from the "needs more research" list. Again, a group process is supportive for students and may aid in organizing a plan of attack. Returning to the framing questions can be useful: What can be measured? What are the tools needed? What are the units of measurement?

In addition, students can be asked to focus on the unknown. They should determine whether the variable is categorical or quantitative. They can list what conditions are already known. They can relate this problem to other problems they have previously solved and list any known formulas used to solve that problem. The goal is to generate a list of steps to take, in answering the questions that they wish to pursue. Those steps should include any data collection needed, any formulas to look up, any calculations to perform, and any symbolic notation to be defined.

It bears mentioning that we have only now arrived at Polya's second phase of problem solving: "making a plan". We are taking our time because we are engaging in sophisticated problem-solving. In order to solve a layered problem we need to understand the layers. We need to know what we are measuring, what we know and what we do not know. Without the layout before us, we cannot choose the appropriate methodologies for collecting the necessary information, or the correct algorithms to calculate the unknown.

High school math can be less focused on calculation and more focused on modeling natural phenomena with math, and using the tools of math to solve for unknowns in the physical world. However for students who struggle with calculation, the process of organizing and performing multiple calculations can exhaust their working memories. This is why the process of organizing needs to be taught and students need to be encouraged to practice and form habits of simpler calculations.

If we have a good plan, we simply need to follow the steps we have devised and collect the tools and information we need. In the (grown-up/out-of-school) world we have access to books and search engines to find the formulas needed. Looking up needed information in problem-solving is a real part of the process and should be taught and planned for. With tools like excel or powerful graphing calculators, students may not need to perform complex calculations themselves. However, we can't use the tools effectively without knowing what we our doing. Even the simplest step of substituting known information into an equation is impossible without knowing which piece of information belongs where, and why. This is why building our framework and planning are so crucial. Twenty or thirty years ago there was much more emphasis on the actual calculation; in the current information age, there should be much more focus on planning for and interpreting mathematics.

If students routinely struggle with simpler calculations, then they need to create more sophisticated organizational processes to free-up workspace in their brains. Calculators and multiplication and conversion tables, as well as formula sheets should be easily accessible. Delays to "look things up" can distract and disrupt flow unless prepared for and planned for. A planning and note-taking guide and problem-solving outline, just as one would use in writing an extended paper, can be an extremely helpful technique. This is another technique that should be explicitly taught. Students are often averse to "showing the work" in Math, as though it takes away from the finished product. Teachers can model the organization necessary in an extended problem and ask students to show the prior planning as part of their solutions.

Carrying out the plan

Many times, carrying out the plan is the exclusive focus of the math classroom. Students are often not responsible for the earlier steps of defining and organizing the plan for solving problems. When they do set out a plan for themselves it becomes a higher priority for them to find an answer. Actual calculation is a multi-step process. In order to calculate, a translation occurs between actual data and their abstract representation as symbols. It is the manipulation of the symbols that is the calculation. After the calculation, the translation occurs again as the results are interpreted not simply in the abstract symbols but in the context of the original problem.

The more complex the calculations, the more time is required to be spent in the symbolic area of thought. The anchors of context must be put aside to be picked up later. Here students can rely on their plan, and the tools that they have collected to perform the calculation. When the object of calculation is understood, students will correctly substitute within formulas and correctly interpret calculated values.

In order that this process is not continually frustrating and exhausting, some parts of the process need to pass from being true inquiry to being habit. Dewey describes phases of reactions to stimuli. There is an open or excitation phase, as the organism experiences a stimulus, and reacts. As the organism becomes familiar and "learns" about the stimulus, it may enter a closing or integration phase. When a student experiences a similar stimulus repeatedly, it may begin to form habits. These habits may behave as intellectual shortcuts to understood knowledge.

Let's use ratios as an example. The more times a student considers a problem with ratios, the more solid is their conceptual ability in that arena. Initially, a student may learn concretely what is meant by one half, as in one half of an apple. This may move to abstractions like shaded blocks and eventually to a symbolic notation as in: 1/2. Repeated trips through these thought pathways may form habits of comprehension, as a student begins to see two halves of an apple are a whole and $1/2 + 1/2 = 1$

The problem $1/2 \times 1/2 = 1/4$ is much more difficult conceptually than $1/2 + 1/2 = 1$.

The application of $1/2 \times 1/2 = 1/4$ to the problem of conditional probability is still more difficult. Without a mental construction of why and how these symbols operate, students fail to recognize similarities among problems. Once they see patterns in the process they can gain a repertoire of known approaches.

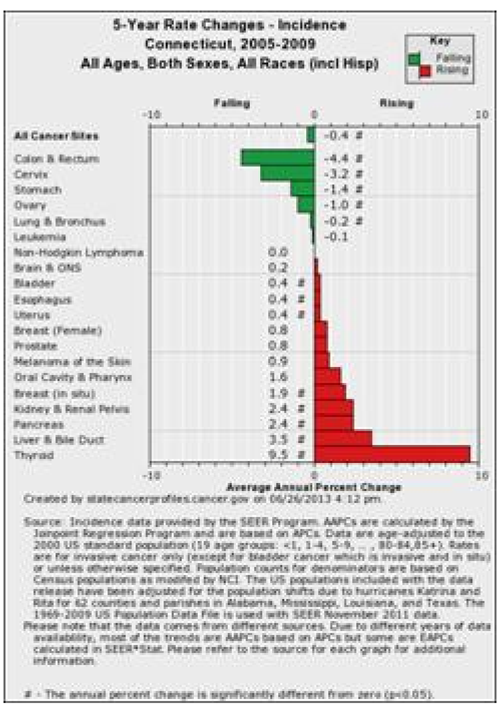
Reflecting on the solution

After completing the calculations to arrive at an answer, many students stop completely. Even after all of their previous preparation, students often report their answer as a naked number, say 36. Without units, 36 is a meaningless value, so answers must always include the unit of measure. In addition the answer should be framed in the context of the problem. 36 inches: Is that average height of girls in a kindergarten class or is 36 mm the average difference in height between boys and girls in that same class? The answer should make sense, too. When reflecting on the solution, students must be encouraged to ask themselves, "Is this answer possible?" If the answer reached is that there is a 36-inch difference between heights of boys and girls in a kindergarten class, something went wrong.

Teaching Strategies

Practice in Asking Questions: Initiating Question Formation

As an example of a classroom approach to the process of generating questions in statistics we will look at a health topic. Initially we will examine a graph as a framing device. Students will work in groups to examine the graph and eventually generate questions on topic. A questionnaire is useful in helping to unpack the visual density of the graph.



http://seer.cancer.gov/faststats/

Student group questionnaire:

What measure is on the x-axis?

What measure is on the y-axis?

Which type of cancer has increased the most in this five-year period?

Which type of cancer has decreased the most in this five-year period?

Interpret the red bar with the 1.6 label to its left.

What questions do you have after looking at this graph? List all you can imagine.

Share-out of the Question Formation Session

Student groups can share-out the questions generated, sorting them into open/closed, answerable now/more research needed. Working together, the students can choose several questions for further research. If the questions relate to data-collection, students can research as assigned work, looking into the method of data collection used in the SEER cancer studies http://seer.cancer.gov/. Classroom access to the internet is desirable for this activity. Discussion may include observational studies, experiments similarities and differences between experiments, surveillance, sampling and completeness of dataset.

The introduction of the idea of the dataset is very important from the beginning of the year. Students should see that a dataset is a real thing, based on actual people or objects that are being studied. In many cases, the data can be traced from a news blurb, to an actual study (like the SEER data). It is important to look at how the data was collected and who collected it, in order to check for bias. In addition, students should be made aware of the choices in sampling; whether to use all available data or samples, whether the data came from subjects of an experiment or from observational studies.

Questions will have arisen in the brainstorming sessions. An attempt must be made to frame those questions as potentially answerable by the students later in the year. Questions can be posted, in categories that relate to the topic where they will be answered.

Combining Process and Content

In the statistics classes that I teach, we open the course with topics of data production and collection. I have often felt that this section was "not math-y enough", and have worried about emphasizing the material because it is very accessible and can give students a false sense of the rest of the class. I have come to see that this section is very important and when seen as the set up for the rest of the year, can be taught in a manner that foreshadows future learning and builds good process habits at the onset of the class.

All maths can be seen as emanating from measurement, or quantification. The ways that we choose to quantify inform our data collection, processing and analysis. Therefore, from the outset, we need to think carefully about what we want to know, how we can find what we want to know and how we can quantify it. Given any topic of interest that the student generates, we begin by asking our framing questions:

What can be measured? What are the tools needed? What are the units of measurement?

From the outset, teaching will include vocabulary of the sampling and experimental procedures. Variables can be quantitatively measured (pounds lifted), or categorized and counted (girls who performed a memory task successfully). For example, perhaps a student expresses interest in body-building and exercise. We can ask our framing questions: What can be measured? (pulling or lifting strength); What are the tools needed? (weights, sophisticated lab tools, pushups); What are the units of measurement? (pounds, kg if using weights lifted, # pushups). These are simple questions that lead to the next set of questions: How could data be collected? Should we use an observational approach or an experiment?

We can design simple studies. In another example, if we want to observe gender differences in performing memory tasks, do we need to study equal numbers of boys and girls? Can we observe just the students in our class? Can we prove causation? Using small groups and partners to listen and react with questions, students should plan and refine studies. Students should produce a written reflection on the evolution of their study and notice any improvement in the results, based on how the questions were framed.

Exploratory analysis of our initial data should help us to see patterns in our results. By quantifying the results and organizing into tables or graphs, we may see patterns that lead us to predict outcomes, or ask further questions. In particular, we often ask: How unusual are these results? The question of usualness leads us to the study of variability, and in turn probability.

In addition, each step of organizing the problem leads us through the process. Categorical data should be compared using proportions and displayed in bar graphs, quantitative data with histograms. The standard deviation of a sampling model for categorical data is computed by using the formula sqrt(p(1-p)/n), while the standard deviation of a sampling model for quantitative data uses the formula sx/sqrt(n). Categorical data relies on the normal model for calculating probabilities; with quantitative data it is t-models.

Formal Inquiry – Hypothesis Tests

At the time in the year that we begin formal testing, students should be well immersed in their questions of interest. Having looked at survey or experimental data, hopefully students have recognized trends, and possibly generated more questions. The question that students will want to know is: Can I trust my results? How do my results apply to the world at large? These are the questions we can finally emphasize within inference.

Students begin inference by drawing confidence intervals. These begin the construction of what is reasonable to expect based on sampling variation. It bears repeating again and again that sampling distributions rely on the assumption and condition that the data are not biased. Rather than this being a purely theoretical consideration, it should be a habit to question sources of bias in data at all times.

Moving into hypothesis testing, the components of a successful test can be broken down into four basic procedures.

1) Formal statement of the question or hypothesis (symbolically and verbally)
2) Examination of the conditions that exist, and any assumptions.
3) Selection of an appropriate test and the calculations
4) Interpretation of results and statement of the conclusion.

With so much familiarity with their own questions of interest, we can segue into a hypothesis, by forcing the question into a narrower frame: H_0 and H_a. This hypothesis should arise in a natural fashion from the previous data collection and analysis around the students' questions of interest. The previous Question Formation Techniques can be used to form a hypothesis. This time we practice with the formal structure. We first use language to state the null and alternate hypothesis, and later state it symbolically.

If the student has pursued the question of gender difference and memory tasks, and collected data around that question, we can formalize the hypothesis in words. The null hypothesis assumes that there is no difference, no association, or no change from the status quo. Therefore in this instance the null hypothesis should be that there is no difference in performance between girls and boys. Simply put, the proportion of girls who succeed equals the proportion of boys that succeed; symbolically: ($H_0\ p_g = p_b$) .

The alternative hypothesis is the one that arises through consideration of any ideas based on exploratory data analysis. Perhaps our data shows that girls have a slightly higher proportion of successes at the task than boys. The question is not whether our sample favored girls, but whether this edge experienced by the girls is significantly better, or simply due to sampling variation. We state that our alternative hypothesis is that girls have more success at memory tasks than boys. Simply put the proportion of girls who succeed is greater than the proportion of boys that succeed; symbolically: ($H_0\ p_g > p_b$).

While some students will not maintain a single question throughout the year, the plan is to emphasize working through each level of statistics content while referring back to the students' initial questions of interest. Students have been encouraged to change and refine their questions, focusing on how we measured outcomes. Inference computes the probability of students' findings if the hypothesis that we are focused on is true. The calculation of that probability gives us a measure of the certainty that our results match or do not match the hypothesis.

Hypothesis Formation Worksheet

State your question of interest:

Ex. I want to know if girls are faster than boys in solving math computations.

What did you measure?

Ex. I measured the time it took girls and boys to finish several computations

Was your measurement Quantitative (Can be averaged) or Categorical (counted)?

Ex. Quantitative

H_0 (null hypothesis) is a statement that there is nothing different, no association or nothing changing in the subject of your interest

In words:

Ex. Girls and boys will have the same speed when solving computations

In symbols: $H_0\ p_1 = p_2$ for categorical data $H_0\ \mu_1 = \mu_2$ for quantitative data

Ex. $H_0\ \mu_g = \mu_b$

H_a (alternate hypothesis) is a statement that there is a measurable difference, an association or a change the subject of your interest

In words:

Ex. I think that girls and boys will not have equal speeds when solving computations

In symbols: $\mathrm{H_a}\, p_1 \left(\begin{matrix} \neq \\ > \\ < \end{matrix}\right)\ p_2$ for categorical data $\mathrm{H_a}\, \mu_1 \left(\begin{matrix} \neq \\ > \\ < \end{matrix}\right) \mu_2$ for quantitative data

$$Ex.\ \mathrm{H_a}\, \mu_g \neq \mu_b$$

Big Data – changing the way we ask questions with data

Hypothesis tests end with clear answers stated in terms of probability. We either decide to reject H_0 or we fail to reject $H_{0,}$ based on our p-value. This is as solid an answer as we get in statistics. Changes in the way that data is collected has changed the way hypotheses are evaluated. Data collection has exploded and data storage costs have decreased dramatically. Some of the approaches in a traditional introductory Statistics courses are reversed in this trend.

For instance, I teach that a random sample is more powerful in predicting population outcomes than a poorly attempted census. Now with large datasets this may not be as true. The enormity of data in certain instances drives the size of standard deviation so small, that the traditional precautions about data collection are less relevant. Students should become familiar with the ways that these trends have changed data production.

Other changes brought by big data allow for real-time prospective studies. The quickness of accumulation and turnaround of data provide extremely lively observations.

An example of this is the correlation data developed by Google to predict spread of flu in the United States. By comparing incidence of searches made in a geographic region with the incidence of flu that developed in the days following these searches, Google developed a powerful real-time flu predictor. It was nearly as accurate and available significantly earlier than information gathered by Centers for Disease Control, who used reports from doctors who had seen flu patients for surveillance data.

Viktor Meyer-Schonberger and Kenneth Cukier relate this groundbreaking work in the book *Big Data* . They describe how Google's "...software found a combination of 45 search terms that, when used together in a mathematical model, had a strong correlation between their prediction and the official figures nationwide. Like the CDC they could tell where the flu had spread, but unlike the CDC they could tell it in near real-time, not a week or two after the fact." [7]

This method provides a new type of powerful exploratory analysis. Although some of the tools may not be within classroom reach, the imagination of how one could use searchable and stored data to create models, is within the realm of classroom discussion and will add a valuable component to the study of data production. There are many ways that accumulated data can be repurposed for analysis.

Researchers, including Karen Seto at Yale, have used satellite images from NASA to measure urban sprawl and greenspace. By observing coloration in the images and changes over time, they can use the data to survey geographical regions and estimate the areas of different land-uses. This is a form of data mining that uses historical data to create a time-series study of changes in the environment. [8]

An enormous study of brain cancer and cell phone use was completed in Denmark and published in 2011. Rather than using a random sample, the study attempted to observe all cell phone users in Denmark, using mobile phone records. Although some records were excluded, overall the study was able to accumulate observations of 3.8 million person-years of data. By linking the cellphone records with the national registry of health, researchers were able to analyze length of exposure to cell phone use with cancers of the brain. They concluded that there was no correlation between brain cancer and cell phone use. [9]

This search for correlations and the attempt at using ALL the data, not just a sample is the essence of Big Data. Again Cukier and Meyer-Schonberger describe the findings of a study by the University of Ontario Institute of Technology and IBM searching for correlations in health outcomes and patient data for premature infants. The study used real-time patient monitoring systems that captured about 1260 data points per second for one child. They found an unexpected correlation that showed very constant vital signs could be an early warning for a serious infection. [10]

Searchable text is another example of the innovative ways in which the accumulated data from the internet can be used. Google has a data analysis tool based on Google Books called N-gram http://books.google.com/ngrams Words and phrases can be searched and quantified, predicting popularity in items being frequently mentioned (for business purposes), allowing searches for the first occurrences of phrases (historical purposes).

Correlation in statistics can indicate a probability that two variables are associated. It can't prove causation, but it can indicate relatedness. As statistics grows to incorporate new practices as a result of the enormity of available data, the search for correlations may provide us with a new and powerful means of exploratory analysis. These exploratory analyses will undoubtedly lead to more questions about the nature of the relationships that have been observed.

It is easier than ever to use our interactions as data, as many of them have become codified and searchable electronically. This electronic trail offers many possibilities for analysis of what has occurred. The "what" that we see in correlations can help us to point towards the future, and yet knowing the "what", we are still left with the question of why.

Appendix

The standards attended to in this paper come from the Common Core State Standards for Mathematics.

Those standards address both content and practices.

The content is from the section that addresses Statistics and Probability.

Interpreting Categorical and Quantitative Data

- Summarize, represent, and interpret data on a single count or measurement variable

- Summarize, represent, and interpret data on two categorical and quantitative variables

- Interpret linear models

Making Inferences and Justifying Conclusions

- Understand and evaluate random processes underlying statistical experiments

- make inferences and justify conclusions from sample surveys, experiments and observational studies

Conditional Probability and the Rules of Probability

- Understand independence and conditional probability and use them to interpret data

- Use the rules of probability to compute probabilities of compound events in a uniform probability model

Using Probability to Make Decisions

- Calculate expected values and use them to solve problems

- Use probability to evaluate outcomes of decisions

Mathematical Practices

1. Make sense of problems and persevere in solving them.

2. Reason abstractly and quantitatively.

3. Construct viable arguments and critique the reasoning of others.

4. Model with mathematics.

5. Use appropriate tools strategically.

6. Attend to precision.

7. Look for and make use of structure.

8. Look for and express regularity in repeated reasoning. [11]

Notes

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1. (National Governors Association 2013)

2. (National Governors Association 2013)

3. (Dewey 1938)

4. (Barnard n.d.)

5. (Polya 1945)p5

6. (Rothstein)

7. (Cukier 2013) p 2

8. (Boucher 2006)

9. (Frei 2011)

10. (Cukier 2013) p 60

11. (National Governors Association 2013)

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This is a great book with comprehensive strategies to infuse question asking into the curriculum.