INQUIRY-BASED LEARNING

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Introduction

Have you ever stopped to admire a beautiful plant and then turned one of the leaves over to see the underside?

Have you ever taken up an old British book (circa 19th century) and observed that the chapter headings are written as "Chapter the First," "Chapter the Second," etc., and wondered why?

Have you ever used the Internet to put a face with a name? Or are authors', composers', and scientists' names merely adjectives by which you refer to favorite works? (such as <u>Beethoven's</u> Fifth Symphony, or <u>Gauss's</u> Binomial Theorem, or <u>H. G. Well's</u> War of the Worlds)

Have you ever opened a book of Einstein's published papers just to see what his work looks like even though you may know nothing about advanced physics or mathematics?

Have you ever gone to places like Williamsburg and noticed that the gunsmith's shop has an odd looking letter in the name: Gun∫mith? If so, did you wonder about the odd letter, what it was, and what became of it?

Have you ever taken a word and traced its origin using a dictionary?

Have you ever looked at a polka-dotted dress and wondered how you would describe the boundary between the two colors?

Have you ever watched falling snow and asked yourself how few snowflakes it would take to completely cover a section of sidewalk? Or, have you ever wondered how long after the snow starts the sidewalk first becomes completely covered?

Have you ever looked at another person and realized in the core of your being that he/she is a living soul just like you? Have you thought about how it would feel to be inside that person's head, thinking that person's thoughts?

Have you ever wondered what the electric current that flows in a wire IS? Or whether the light from a light bulb takes any time at all to get from the bulb to the farthest corner of the room?

Have you ever held an arrowhead and tried to imagine the hand that shaped the flint? Or held an old letter and tried to imagine how the sunlight looked on the very day on which the letter was written?

Have you ever stood in a centuries old European cathedral and wondered what the floor looked like when it was new?

Have you ever wondered what happens to the wick of a burning candle?

Have you ever tried to imagine what a spider feels when it is spinning a web? Or a humpback whale feels when it is singing a song?

If you have ever thought about things like this and have explored the answers to your questions, then you have already engaged in inquiry-based learning and probably know a great deal about it. You probably realize that, as a result, your view of the world was forever changed from that moment on....

Of Jigsaw Puzzles, the Scientific Method, and Reality Maps

Have you ever assembled a jigsaw puzzle and analyzed what you were doing during the process of putting it all together? If so, did you know that you were dealing with an analog for what philosophers call, “The Epistemological Question?”

“The Epistemological Question!” you say. “Yikes—what’s that!!!???”

Well, I could explain but...

Here’s our chance to do a little inquiry-based exercise and see where we get! Ready?

OK. First of all, we all know what a question is. So any problem with understanding the phrase “the epistemological question” must lie, primarily, with the word “epistemological.”

In the phrase “the epistemological question” the word “epistemological” appears as an adjective modifying the word “question.” OK. So *an* epistemological question must be a type of question—a subset of all possible questions. Let’s start there and worry about the article “the” later.

By analogy, we know that there are a variety of types of question. There are mathematical questions, scientific questions, artistic questions, historical questions, legal questions, and so on. A mathematical question deals with mathematics; an artistic question deals with art. So let’s guess that an epistemological question deals with something called “epistemology.”

So what is “epistemology”? Well, “epistemology” is a word with two parts: “epistemo-” and “-logy.” We should already know that “-logy” derives from the same Latin root as “logic” which deals with thinking or knowledge. So “epistemology” must deal with knowledge of or thinking about whatever “epistemo-” means.

Let’s pause for a moment to take account of what we have done so far.

Although it may not seem so, we have actually made considerable progress. We have narrowed down our inquiry as far as our unaided intellect will allow. Pretty good! Let’s give ourselves a pat on the back. We deserve it!

It is always fun to see how far we can go in an inquiry before having to turn to outside sources. In fact, Enrico Fermi (1901-1954), the nuclear physicist of atomic bomb fame, always challenged his students to progress in this way. We will also speak of the famous *Fermi Question* a little later on.

But now, getting back to “epistemology,” we finally appear to be stuck. We’ve gone as far as we can in breaking down the word, and we have hit a roadblock. Let’s turn to the dictionary to complete our inquiry.

> "Epistemology *noun* (circa 1856): the study or a theory of the nature and grounds of knowledge esp. with reference to its limits and validity [Gk *episte me* knowledge...]" (Merriam Webster, 10th Collegiate Dictionary).

So epistemology is the theory of knowledge. Now let's work backwards. What is "the epistemological question"? Well, we know that a mathematical question deals with mathematics, and a legal question deals with the law. So, *an* epistemological question must deal with knowledge or the theory of knowledge.

But in the original phrase, the words "...epistemological question" were prefixed by the article "the..." suggesting something specific, not "an..." (as we have been writing) suggesting something general. We need to turn to philosophy. When we do, we discover that *the epistemological question* is the philosophical question "What is knowledge?" And it is related to questions such as, "How do we learn?" or "How do we remember?" This article is about a part of the epistemological question: inquiry-based learning.

OK. So what does all this have to do with jigsaw puzzles? (Remember the jigsaw puzzle that I introduced several paragraphs ago? You might want to check back, just to be sure!)

Well, let's embark on another little inquiry-based exercise and analyze the process of putting together a jigsaw puzzle.

- First, we dump out all the pieces. (I do, anyway.) Then we turn them over so that we can see the picture sides.
- Next, we search out a particular subset of all the pieces, the border pieces, which we fit together to establish a boundary in which to work.
- Then we try to sort the remaining pieces by color, texture, etc., so that all the green leafy ones are together, the brown rocky ones are together, etc.
- Next we begin a long course of selection of individual pieces, comparison of these pieces with other pieces, and, eventually, assembly using trial and error to build up larger pieces of partially assembled puzzle.
- Finally, we fit the partially assembled pieces into a larger whole and work our way toward completing the puzzle.

What does this have to do with epistemological questions and the scientific method? And what does this have, in turn, to do with inquiry-based learning?

Just this:

- The scientific method is a means of acquiring knowledge. So, an understanding of what this method is and how it works is intimately linked to the epistemological question.
- The scientific method is actually applied to some extent in assembling a puzzle, so the puzzle provides an excellent analogy for learning the scientific method.
- And finally, the scientific method is a superb example of inquiry-based learning.

So...let's begin drawing a direct comparison between the scientific method and assembling a jigsaw puzzle.

- *First, we dump out all the pieces. (I do, anyway.) Then, we turn them over so that we can see the picture sides.*

Nature provides the scientist with the puzzle pieces that must be studied and assembled. Einstein once remarked, “Out yonder there is this huge world, which exists independently of us human beings and which stands before us like a great, eternal riddle [puzzle], at least partially accessible to our inspection.” Sometimes a scientist has to sort through the raw data that Nature provides so that he/she can get the picture sides up, so to speak.

- *Next, we search out a particular subset of all the pieces: the border pieces, which we fit together to establish a boundary in which to work.*

To begin an investigation, a scientist chooses a particular aspect of Nature to study. Once this selection has been made, the scientist is able to begin sorting through pertinent raw data and developing a general picture. Initially, the picture is crude, but it helps to establish the boundaries for later work.

- *Then we try to sort the pieces by color, texture, etc., so that all the green leafy ones are together, the brown rocky ones are together, etc.*

The scientist looks ever more deeply into the raw data to discover hidden patterns, clues to some sort of possible underlying structure(s), and sorts the clues into bins for later analysis.

- *Next we begin a long course of selection of individual pieces, comparison of these pieces with other pieces, and, eventually, assembly using trial and error to build up larger pieces of partially assembled puzzle*.

The scientist begins to develop correlations between the bins of data, assembling detailed partial pictures of the topic being studied. The scientist refers to this trial and error as experimentation, or the empirical method.

- *Finally, we fit the partially assembled pieces into a larger whole and work our way toward completing the puzzle*.

With good correlations in hand, the scientist can now gain a larger, more complete view of the subject at hand. A fuller picture begins to come into view.

The end result of such a course of research is a theory or model about how something works, sometimes called a reality map. With such a map in hand, the scientist, engineer, or doctor, etc., can steer a course through uncharted waters.

The Fermi Question

So far we have been investigating inquiry-based learning through examples that give mental pictures, models, analogs. Here is one more example of inquiry-based learning—one of my favorites, in fact.

The puzzle section dealt with the empirical approach of experimental science. In tracking down the meaning of the word “epistemological,” we followed a slightly more theoretical tack. This section goes again into the theoretical.

(Please do not let your hackles rise; I assure you that this will be painless!!!)

Enrico Fermi was a superlative physicist and teacher. His classes were always filled to capacity, and he was often the terror of his students.

Let's imagine that we are in Professor Fermi's class. The good professor walks to the front of the room and smiles. "I want to give you a little test," he says with a mild Italian accent. "Please take out paper and pencil."

There is a rustle of materials.

"OK," he continues. "Listen closely. There are 3 million people currently living in Chicago. I want you to estimate, to within a factor of two, or so, how many of them are professional piano tuners. You have 20 minutes. Go!"

"What!" you think to yourself. "Did I hear this guy right? How can he possibly expect..."

But then you begin to think:

- 3 million people or 3,000,000...hmmmmm....
- Well, an average family has around four members. Right. That would give – uh – 750,000 families.
- OK, so far. Now, how many families have pianos? Let's see...I know about 50 families – what with school and church and all—and there are about 10 pianos distributed among them. So, let's guess that one out of five families owns a piano. That gives 150,000 pianos in Chicago.
- There might be 20 more pianos in the local conservatory, and there is 1 at the local church; but 21 pianos out of 150,000 is not a big enough difference to worry about. Let's just leave it at 150,000.
- Ten minutes to go. Good!
- Now, if I were a piano tuner, how many pianos could I tune in a day? Say 1½ hours per piano, eight hours per day, with lunch and coffee break and time to travel from place to place—OK, that comes out to four pianos per day.
- Let's say that I tune each piano once a year. Well, maybe twice a year. No, the professor said to within a factor of 2. Just go with once a year.
- There are 52 weeks in a year. Take 2 weeks for vacation—that leaves 50 weeks. Take 2 more weeks for sick time (you never know!). That leaves 48 weeks. And I want my weekends off. That gives 5 workdays per week or a total of $48 \times 5 = 240$ workdays per year.
- 4 pianos per day $\times$ 240 workdays per year gives 960 pianos per year. Let's round that up to an even 1,000. But there are 150,000 pianos. So there must be $150{,}000 \div 1{,}000$ = about 150 piano tuners in Chicago.

"Time's up!" the professor calls. "Please hand in your work!"

What is the lesson here? Simply this: We usually have at hand more information than we realize. Most problems are amenable to this sort of approach if we stop to think a little. The solution is not precise; it is approximate. But often approximate is good enough.

Look carefully at how we approached the phrase, “the epistemological question.” Did it seem long and drawn out? Maybe. But I did it that way to introduce you to Fermi’s method of reasoning—the same method that we just applied here.

If we needed a more accurate number for the piano tuner problem, the next step would be to consult the Chicago telephone directory.

Anyway, it is often worth the effort—and a lot of fun!—to see how far we can actually go with a problem, given nothing more than intuition and some paper and pencil, before giving in to the dictionary or the directory.

Inquiry-Based Learning: A Definition

Now that we have had some examples, let’s finally ask: What IS *inquiry-based learning*? Let’s do another inquiry-based exercise to find out!

According to Merriam Webster:

- A *definition* is “a statement expressing the essential nature of something.”

Well, we want to express the essential nature of inquiry-based learning.

- An *inquiry* is an, “examination into facts or principles; research; a systematic investigation...”
- A *basis* is, “something on which something else is established...”
- And *learning* is the “act or experience...of acquiring knowledge or skills,” (Merriam Webster, 10th Collegiate Dictionary).

OK. We have the pieces. Now let’s put them all together!

- Inquiry-based learning must be: *The act of acquiring knowledge or skills based on a systematic investigation into facts or principles*.

A moments’ reflection will show that this definition perfectly expresses the essential nature of what we have just been doing throughout the last few pages.

Now, let’s take the definition apart again, and examine it a little more closely, piece by piece.

“*The act...*” An act is “something done voluntarily.” So inquiry-based learning is something that we must want or desire to do—a voluntary act [voluntary *adjective* (14th Century) proceeding from the will or from our own choice or consent—Merriam Webster, 10th Collegiate Dictionary].

Remember the movie *Jurassic Park*? You might recall that the character, Mr. Hammond, makes the remark, “Creativity is an act of shear will!” So, I venture, is learning. We have to want to learn in order for anything useful to happen.

“*...of acquiring knowledge or skills...*” To acquire is to obtain. We usually obtain what we seek. So, we must seek knowledge—we must want to know. Knowledge is, “the fact or condition of knowing something with familiarity gained through experience or association.” Skill is “the ability to use ...knowledge effectively...” (Merriam Webster, 10th Collegiate Dictionary).

Acquiring knowledge or skills, therefore, means to seek out and obtain (because there is a desire to do so) familiarity with things unfamiliar, and to learn to put that newfound familiarity to use in some effective way.

"*...based of a systematic investigation into facts or principles.*" We already know that a basis is something on which something else is established. In this case, learning is based on systematic investigation. To be systematic is to be methodical. Thinking must proceed in a directed manner—either on your own, or with the help of a parent or teacher.

"*...facts* [and] *principles...*" are the *content* of knowledge. Put another way, human knowledge is stored in facts and principles (much like honey is stored in honeycombs), which, in turn, are kept in books and libraries. Facts and principles by themselves are static entities. But to investigate them involves asking questions. Questions are the dynamic mechanism by which inquiry-based learning moves ever forward.

OK, having written and examined our definition of inquiry-based learning, let's repeat it one more time for completion:

- *Inquiry-based learning is the act of acquiring knowledge or skills based on a systematic investigation into facts or principles*.

Anecdotes

When I was a small boy, I was given an astronomy field guide. The little book utterly captivated me, and I spent hours going through its beautiful pages. There were many things that I did not understand; but I felt a deep appreciation for the treasure that had been put into my hands.

Much later in time, when I was in my early 20's and beginning my career at NASA, I received the Time-Life book *The Universe* as a gift. I read it voraciously and committed to memory many of its more technical words and phrases. About the same time, I happened onto a *Dictionary of Astronomy and Astronautics* in the NASA library.

The dictionary was fun because it contained all of the technical words that I had learned from my other two books, and it contained cross-references. HERE was a book that I could use to pull everything together.

I became an archaeologist in the world of astronomical ideas, so to speak, finding beautiful gems, pursuing lines of investigation, and writing it all down into a notebook. I had never had such fun! And I was learning a great deal.

Some time later, a colleague of mine, who had become a professor of beginning astronomy at a local university, asked whether I would mind being a test subject for a new set of astronomy exams he had written. I hesitated.

"I don't run very deep," I confessed.

"No problem," he said. "You know enough."

I took a complete semester's worth of astronomy tests and scored an average grade of 96%! I was amazed at this result. He and I have since kept close contact and have had many wonderful discussions on astronomy and astrophysics.

The experience was my first in-depth experience in inquiry-based learning. I felt deeply motivated, very interested in the subject I was studying, and challenged by the possibilities of making discoveries, even though my resource was “no more than” a simple dictionary.

The key to learning was the desire and motivation to look further into things, to inquire.

About the same time, I also had a mentor who explained the operation of many different types of machines to me. One day we began a discussion of the television, and he repeated the advice that he had already given me many times before.

“Joseph,” he said, as I tried, ineffectively, to plunge in with both feet, “you’ll never understand the television by starting with the whole thing. You have to break it down into simple parts. When you understand the parts, you will understand how they fit together.”

Of course, this lesson was simply the astronomy dictionary lesson in another form. The difference was that the dictionary had already done the job of breaking its subject down into digestible parts and providing the cross references through which they were linked together.

There is a moral to all of this: If you take the time to break things down into simple parts, there is no reason why you can’t learn anything! All that is required is patience and tenacity.

I later did the same thing with a branch of advanced mathematics called tensor analysis. I played in dictionaries and math books on and off for 13 years before finally becoming comfortable with the subject. But, afterwards, when I took a university course in the subject, I scored higher in cumulative examination points than anyone else had ever previously done. And the professor actually requested a copy of my notes and homework, “because,” he said, “there is an interesting, original twist to the way you do things.”

Again, looking back, inquiry-based learning had done the trick. Inquiry-based learning is, most definitely, a powerful approach to learning.

Linear Reasoning

I’ve coined a term that I would now like to discuss briefly: Linear Reasoning. We have been discussing breaking things down and seeing how the parts fit. In essence, this is the process that I call linear reasoning.

Let’s look at yet another example.

I know that $2+3 = 5$. But does $2^2+3^2 = 5^2$?

Consider:

- $2^2 = 4$, $3^2 = 9$, $5^2 = 25$.
- But $2^2+3^2 = 4+9 = 13 \neq 25$.

The relation $2+3 = 5$ is a linear relation. What you see is what you get!

The relation $2^2+3^2 = 13$ is a non-linear relation. There is something hidden that needs to be drawn out before a correct solution can be achieved.

If all the people in the world were placed into two camps based on the way they think, then the difference between them would be similar to the difference between these two mathematical relations.

Many people think non-linearly. They feel, implicitly, that there is always more to any given situation than meets the eye. They say things like:

"If I could just see around [this or that]."

"What're we missing here?"

"They're always hiding something from us!"

"Yeh, but you've got to read between the lines!"

And so on.

But sometimes, almost all the times in fact, there is nothing to see around! Nothing missing. Nothing hidden. Nothing at all between the lines.

Quite literally, in this majority of cases, what you see is what you get! (The real exception occurs when dealing with lawyers or insurance companies!) BUT, you must be able to SEE, or you will get little or nothing!

Think of the questions that appear in the introduction. They are interesting because they are unexpected. Yet, there is nothing tricky or hidden about them. Each refers to an obvious reality that our society has learned and practiced not-to-notice until it is pointed out.

As I say, you have to SEE.

Let's go back to our definition:

- *Inquiry-based learning is the act of acquiring knowledge or skills based on a systematic investigation into facts or principles*.

Let's look again at the words "...*systematic investigation*..." We've already examined these words. But let's examine them again: *To be systematic is to be methodical.*

Methodical: Doesn't this word refer explicitly to the way in which we have been breaking things down?

Let's do it again. Let's break down the relation $2^2+3^2 = 13$. To the non-initiated in algebra, this statement can look quite formidable. First of all, we notice that there are a couple of weird looking symbols: 2^2 and 3^2. What do these mean?

Let's consult a math book. We discover, upon so doing, that 2^2 is read "two-squared" and simply means 2×2. That's not so bad. We know that $2\times2 = 4$.

We might further reason that if 2^2 means 2×2, then 3^2 means 3×3. And, checking the math book, we find that we are correct!

That's not so bad, either: $3\times3 = 9$.

OK. Now let's put it all together: $2^2+3^2 = 4+9$ and $4+9 = 13$.

The relation $2^2+3^2 = 13$ is a non-linear relation. It is complicated, like the television. But it is made up of little linear pieces/parts! In order to understand the whole, we have to look at the pieces/parts, understand them first, and then fit them together.

That's the essence of linear reasoning.

AND HEY! We're back to the jigsaw puzzle again, aren't we?

Unexpected Connections

Sometimes we pursue a strange new word or idea and find that it leads us far from our starting point. Such a chase can be both fun and informative.

Consider the word, *Uintatherium*. This word is the name of a large mammal that lived some tens of thousands of years ago. Let's play with this word and discover where it leads.

First of all, a brief study of the names of some of these ancient creatures shows that we can break the word into the pieces: "Uinta" and "therium." The suffix "therium" comes from a Greek stem meaning "beast." So the Uintatherium is really the Uinta Beast.

OK, we have a beast on our hands.

What about Uinta? Well...a dictionary search shows that the word Uinta names a mountain range in N.E. Utah. In fact, it was in these mountains that fossils of the Uintatherium were first found.

Geography, geology, and paleontology!

And the Uinta Mountains got their name from the Uinta Indians, a Pueblo tribe that once lived in the area.

American Anthropology!!

So, we make a leap from the prehistoric Age of Mammals to a tribe of American Indians. From here, the sky's the limit!

Conclusion

I hope that, after having read this article, you might really consider stopping to admire a beautiful plant and turning over one of the leaves to see the underside; or holding a blue jay's feather to the light and observing that it appears brown in transmitted light even though it appears blue in reflected light; or reading a dictionary on some favorite subject.

Everybody is curious about something. Somehow, that curiosity seems to lose its edge as we go through school and prepare for professional life. Maybe some real introspection is necessary to discover just why this is so.

We often ask our youth, "What do you want to be when you grow up?"

Is this really what we should be asking our youth? Doesn't this question imply a present *inadequacy* that must be remedied before growing up—or else!?

In Lewis Carroll's "*Alice in Wonderland*," the caterpillar asks Alice the question, "Who are you?"

Isn’t this by far the better question? We are now who we have been and who we always will be, as long as life continues. And that personal someone is enough: a valid, inquiring, thinking being, full of life and creativity.

Like an unpolished gem, we can work at refining and polishing our personal someone, improving on all that is already there. This refinement is the true role of education

But perhaps we’ve become so busy teaching to Proficiency Exams, that we’ve truly lost sight of the marvel that each individual young person represents! And because we have lost sight, so have they!

Perhaps we should first inquire of ourselves, “Who am I?” If we have never done so, then perhaps we should. There is a vast field of discovery inside each and every one of us!!

And if we *have* already done so, we should continue to ask again and again, because THE question “Who am I?” takes an entire lifetime to answer!

And while we’re at it, let’s ask our children and students as well. After all, if inquiry-based learning is to take hold in our lives, this may be the question with which we need to begin.