THE AHA IN TEACHING & TUTORING

The Flash of Insight, Resolving Student Conceptual Confusion, and One-on-One Help Session Tutoring.  8 Nov 05  V10

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To my mentor and research colleague Fred Reines who said "Make it simple".

Abstract: This article describes an effective one-on-one tutoring technique that 1) systematically locates and resolves serious student learning difficulties, 2) illustrates how to put the technique into practice, and 3) tells why it works. Case histories and a summary from the author's experiences in university sophomore physics courses are given. From the examples given, the technique is easily generalized to any science/math based course beyond 9th grade. Through systematic use of the technique, the teacher will gain a new understanding of human perception and human learning. This new understanding, although quite general and very useful, is not easily obtained in other ways.

Introduction:

It happens to me repeatedly as a science teacher: A serious student asks a question or shows major confusion in a lab report, homework, or quiz. I give my clearest explanation. The student nods, "Yes, I understand", thanks me for my help, and departs. But I suspect that the student is just as confused as ever and the exams confirm it. As a teacher, I became tired of treating the symptoms rather than the cause. I wanted a better "trouble shooting" technique, so that I might understand the source of my student's difficulty and be of greater assistance in their efforts to learn.
SUMMARY OF DISCOVER AND RESOLVE TUTORING (DART).

I started listening very closely to my students when they came to me for help.

I stopped my practice of doing all the talking when, for example, a student came in for help on a homework problem(1). Seventy-three help sessions and five years later, I had evolved a helping technique that uncovers deep-seated student conceptual confusion and resolves stubborn debilitating hang-ups in science learning. The technique, which I call Discover and Resolve Tutoring (DART), accomplishes the following:  

1) DART successfully helps the student and in the process,

2) Reveals where and why student learning is blocked;

3) Shows how to improve formal class/lab instruction and;

4) Reveals why specific topics are so difficult for the student.
5) In addition, DART reveals a view of human perception and learning otherwise not readily observed in other ways.

*References at the end of this article will be indicated by (number in parentheses).

The DART technique can systematically locate and resolve serious student learning confusions and hang-ups, and can have significant long-term benefits: 1) The student himself* can see what has caused his* hang-up and, through direct experience, will learn what to do when similar problems arise again. 2) The student will realize that a learning problem which appears hopeless and stress-producing can, with proper assistance, be cleared up in a "flash of insight". ** AND, The flash of insight itself, is a pleasant experience for both teacher and the student.

3) Resolving a serious learning difficulty is a great relief to a worried student. It will boost the student's self confidence and increase his general ability to study effectively.

4) The teacher or tutor will gain an entirely new understanding of the general learning process: What works and what causes failure. The experience gained will provide reliable guides to needed improvements in science lecture or laboratory.

5) The technique is time-consuming, but (in the long run) will reduce overall expenditure of teacher effort by increasing overall efficiency and self-reliance of the student. This article builds on developments in psychology and perception. Relevant literature is cited.

** HOW I EVOLVED THE DISCOVER AND RESOLVE TUTORING TECHNIQUE **

Dr. Robert Fuller, a physicist-educator, described the educational techniques used in his undergraduate physics program at the University of Nebraska at Lincoln, called ADAPT (2). He said, "Listen to the students. Really, really, really, "LISTEN!" I wondered, "How do you listen? How do you know what to listen for?" In pondering these questions, I eventually stopped talking, and started listening. Here is the semi-clinical interview technique (3) I developed. When a student cannot solve an assigned problem, and appears confused or harboring major misconceptions, the student should be invited to a help session with the teacher (the "sooner the better" even if it is in the hallway). First, ask the student to show you what he has been doing, about the confusing topic. Have him perform concrete physical actions such as calculations, drawings, and/or demonstrations with props or make-do apparatus. Involve body motion as much as possible. (The numbers in (parenthesis), indicate literature references at the end of this article.)

Ask the student to:
1) "Show me what you have been doing to solve the problem that you are having difficulty with."

2) "Draw a picture of the lab apparatus used". The student should do as much of the work as possible for himself. If the student hesitates, give well-timed suggestions as follows:

3) "Read the problem aloud for me."

4) "Write down the equation or definition needed."

5) "Draw a diagram of the side view of the problem situation."

6) "You may look in the text for the equation or facts that you need."

Using the steps, given in this paper, the student will be able to complete a large portion of the help session work and the teacher will be able to identify the student's major point(s) of difficulty or "hang-up". The teacher should observe the characteristics of the student

The difficulty is usually:

1) Quite unpredictable.

2) Well beyond resolution by normal classroom methods.

3) Far beyond resolution by the student's own efforts.

4) The misconceptions (or confusions) will be quite obscure and debilitating to the student, but will, by the methods herein, be easy to clear up and resolve once identified. experience.

The following table summarizes the author's help session

(The reader may wish to first read the case histories given in the Appendixes at the end of this document.)

**TABLE - Summary of Author's Experience in student Help Sessions**
Available Records.

Student Lab Report books available** 47

Number of Written "Please see me" requests in lab books 138

Please see me sessions signed off in lab book 71

Documented "FLASH of Insight" Occurrences****.

As a result of my "Please See Me" requests to my students.*** 7

As a result of Student-Initiated Help Sessions. 8

Voluntary written or verbal reports from students.*** 9

Results should be taken as indicative. This was not a controlled study.

Footnotes:

** A student's bound lab report notebook for both semesters counted as one record.

*** See Appendix for a discussion of selected examples.

**** Equivalent names are AHA, Eureka, Illumination, Epiphany. See pages below for more discussion.

***** Throughout this paper male pronouns should be taken to refer to males & females equally.

The above table shows that approximately one-tenth of the help sessions culminated in specific behavior identifiable as a "Flash of Insight." From experience it will be seen that the Flash of Insight is the "tip of an iceberg". Just as the size, material, and general characteristics of an iceberg can be interpreted from its small tip, so important parts of human mental information processing, including perception learning and problem solving, can be interpreted from the Flash of Insight.
The discovery event, called Flash of Insight, occurs because the processes of human information decoding (i.e., perception) have been blocked for a period of time (minutes to hours) and then suddenly discovered a new (and hopefully correct) perception. It is important for the teacher to study its occurrence because, in retrospect it shows:

1) What circumstances have caused the perceptual failure in a student, causing the perception process to halt (i.e. blockage).

2) What disabilities (i.e. perceptual blindness) occur during the failure duration, and 3) what specific steps will get perception "back on track" and keep it there. Many, even most, learning difficulties result in rigidly held specific ideas that are much different from those intended by the learning material (4). The DART tutoring methods outlined herein (5) show how to find the student's learning problem and resolve it with net reduction in anxiety (6). At first the reader may find the rules mysterious, but through actual repeated usage, the truth and utility will become evident. It is suggested that readers keep informal records of their student help sessions for later study and course improvement. (7)

HUMAN PERCEPTION AND THE FLASH OF INSIGHT.

Perception may be considered as having two parts:

1) Analyzing: The nervous system breaks down incoming messages and data into components.

2) Synthesizing: The brain places the components back together in a holistic meaningful manner.

When synthesizing is complete we "realize" we have "perceived". Obviously, mistakes or misdirection can occur anywhere in this process. If anyone perception is contradictory, lacks coherence, or otherwise fails to have meaning, there will be a halt until a new "re-assembling" of the components is tried, usually spontaneously. Often the reorganization is accompanied by the "Flash of Insight". Watch for it! You will be amazed! (9)

Although there is as yet no single commonly accepted name for the "Flash of Insight", the phenomenon can be identified by exclamations such as:

Eureka!,
Aha!,
Flash of Insight!
OHHH... Now I see!

Epiphany
I had a Bright Idea!
The light (bulb) went on!
Light bulb (as in cartoons)!
It dawned on me!
The reality hit me!
Something went click in my brain!
Suddenly it occurred to me!
I realized!
I discovered!
I noticed for the first time!
I never saw it until it was pointed out to me.

These above responses, often called merely "Insight" (8) (9), have been listed above in order of intensity.
SPECIFIC RULES FOR DART TECHNIQUE WITH RATIONALE

STEP I. The student who comes to a help session should do as much drawing, calculating, and talking as possible.

My experience has shown that student confusion and "hang-ups" in learning, usually cannot be resolved by giving more information to the student (10,11). If the teacher is to help the student, he must know the student's specific problem (or idiosyncrasy). Then it is possible to help the student with that specific problem as quickly as possible. For this reason, encourage the student to explain, draw, calculate, look in text, point, etc., so as to maximize the information that comes out of the student. The teacher should, with paper and pencil supplied, ask the student: "Show me what you have been doing on the homework problem that you are having trouble with", or suggest: "I would like to have you do this similar but easier problem first. If the student is unable to start, ask him to
Draw a picture of the electric field near the charged wire, or

Write the definition of velocity, or

Calculate the density of iron from data given, or

Say, "I noticed a curved line here. Could you redraw it to be straight?"

Summary:

The teacher must have information about the student's problem(s). The more work the student does and the more concrete actions he takes, the more the teacher will be able to discern the student's existing knowledge and identify the student's learning hang-up. Therefore, it is necessary to maximize the information flow from the student to the teacher. The teacher must say as little as possible while doing everything possible to facilitate the student's own actions which the teacher can watch and interpret.
STEP II. As the student works, closely watch her eyes, face hands, body movements, and posture. Very often what the student does with his eyes, face, hands, breathing and body posture is more revealing (12) than what is said:

1) What was the student about to do when he pulled his hands

2) Where did his eyes go during that step?

3) Why was there a sudden shift of body posture or change in rate of breathing?

4) When did the student suddenly become motionless and a blank facial expression shown? In summary, pay very close attention to the student's eyes, face, hands, and body. Integrate this information with what is learned from his drawing, calculating and discussing.

STEP III. As the student works, watch for signs of his emotional state.
A panic session or a full outburst of anger or a prolonged crying session are very troubling circumstances. These reactions occur because it is stressful for a student to work while someone else is watching. Look for signs of emotion. Is he or she angry, sad, helpless, agitated, etc.? As the help session progresses, the teacher should watch for the precursors of these intense emotions and be able to avoid actions that will make them worse.

Usually it is best (and productive) to interrupt the work of the help session and vaguely indicate to the student that you recognize his condition. (13) Be sure to follow up his lead in any discussion of what he feels and why. Often the student's emotions come from problems in home-life, or being generally overwhelmed with school, or attempting too many courses or courses too advanced. At this point, the tutoring concerning his specific course problem (why the student came to your office), should be forgotten, and the emotional problem should be the focus. The student's larger problems require the school counselor's attention, and you should suggest this and of course ask how you can help.

In some circumstances, it is advisable to guide the tutoring session so as to avoid the emotion, especially in the case of anxiety. Suggesting a moment to stop work, relax, share a joke or talk about something else, will produce much benefit.
STEP IV. The student should be allowed to proceed at his own speed and with his own chosen methods.

Allow student to work at their own speed and methods. Also allow every student action to run fully to completion. (15) The student is probably having a hard time keeping his thoughts together. It will not help to disrupt his thinking or try to change his chosen thinking course. Any suggestions or other interruptions from the teacher will reduce his ability to perform and must wait until the student comes to his own natural conclusion. The student's existing plans of action must be allowed to run fully to conclusion, before new ones may be formulated, especially for the confused student. Certainly in a help session, never offer negative criticism. Of course, if the student obviously needs or desires assistance on a particular equation or fact, it should be supplied. When the student does stop working and needs assistance, offer a well-timed brief suggestion: "Why don't you..."

1) Read the problem again, aloud. (So you, the teacher can discern any point of student uncertainty or peculiar word groupings.)
2) Express this problem in your own words.

3) Redraw the diagram, showing more realistic relationships.

4) Ask the student: "Tell me what you are thinking." (16) (Gently probe for why he thinks that way.).

5) Ask the student: "Tell me what you are feeling." (16) (Gradually coax out "why"). Give the student every possible occasion to show he actually can do something on her own terms. This will allow him to completely integrate and stabilize his own knowledge and provide a solid base for continued work in the help session. Such full complete actions will increase student's ability to function as he develops a full integration of the topics at hand and at the same time show the teacher his true abilities.
**STEP V. The help sessions should be pleasant and encouraging for the student.**

The session should increase confidence in the student's own ability. A help session may be a stressful experience. For this reason the teacher should facilitate and encourage and generally make the student feel at ease. Relaxed moments, humor, and a pleasant attitude will pay many dividends. (6) A student's confidence will be bolstered when he solves a problem before the teacher's eyes. He should be given extended time to successfully show what he can do. (17) Of course, some of the work can be done away from the teacher's immediate presence. As often as possible, offer hearty praise for genuine improvement or a good performance relative to the student's previous abilities.

**Summary:**

A one-on-one help session with the teacher may be fairly intimidating for some students. The student does not need interruptions or negative feedback. Give hearty praise for genuine improvement. Avoid putting the student on the spot or otherwise showing displeasure at his limited knowledge. This will only lower his confidence and/or erect barriers to further communication.
STEP VI. The student will receive sufficient compulsion to improve his study habits from his own observations of his own performance in the help session.

It is a curious fact that a weak student does not know how weak he is. He thinks his performance is not that bad and thus there is little reason for him to improve. The student's failure to perform with the teacher watching is a very persuasive way to make a resistant student very much aware of his own weakness! Unsolicited comments about need to improve from the teacher will be counterproductive, especially for the weaker student. Further urging is not needed and is likely to cause hurt feelings, plus resentment. Also, such exhortations often turn out to be a way for teachers to show off their "superior intelligence"! This is not the purpose of the help session! It is important for the student to develop his own "get up and go" and not acquire the habit of waiting for the teacher to do his thinking for him. Let the student figure out for himself what he needs to do. He'll need this habit for the rest of his life!!!
STEP VII. Any urge to SHOW the student how to do the problem or

Give a short lecture must be rigidly suppressed during the help session.

The teacher will, at first, be very frustrated, especially with the slow, faltering efforts of the weak student. The teacher must remember that the student has come in for help. This means that there are things the student cannot do. In this circumstance, it is almost automatic for the teacher to take over the discussion and show the student "how-to-do-it" or give a short lecture. All such urges, and they will be severe, must be rigorously suppressed. (14, 15) The teacher will gradually become more patient with the student's weak performance when he/she begins to see that the DART technique is actually superior to "showing".

Taking over the discussion will be seen to be counterproductive, because:
1) The very fact that the student is having difficulty or is confused on a topic means he does not have the "internal templates" to follow or understand, (further) discussion of that topic. More discussion will merely pile on words that have no place to go. "You can't teach faster than the student can learn."

2) "Showing how to do" or giving a brief lecture presumes in advance that the teacher knows what specific information or new insight is needed by the student. But this is impossible, since the ways in which the student's thinking can go astray are large in number and astonishingly unpredictable.

3) When the student is doing "all the work", he will control the work speed so that he can achieve stable understanding at each step. He will automatically stop or falter when he arrives at a confusing point, thus allowing identification of the problem. By contrast, when the teacher is leading the discussion there is no equivalent mechanism for establishing rate of progress and stopping at the necessary point(s). This is because the confused student cannot listen to an argument presented in new, unfamiliar terms and, at the same time, decide where his own concepts are faulty. More often the student will nod "yes I understand" just to keep the teacher going and thereby avoid the embarrassment of having the teacher find out he doesn't know what he is supposed to know!!

4) Teachers tend to take control, guide the student, and get it over with. After all, the teacher knows his topic very well and time is at a premium. He will imply by his mannerism and rapid, clear, logical, well organized presentation that the topic is simple and obvious. Of course, it is clear and obvious to the teacher, but not to the student who, for reasons given above, will still be confused but will not admit it. In addition, the "clear and obvious" will make the student feel all the more inadequate in the presence of an all-knowing, superior teacher. Thus the net result of "showing" is to further reduce the student's self confidence. (18) He has received demoralizing proof that he can't do what is expected, even on material that is implied to be simple. In summary, "showing" is counter productive.
STEP VIII. The teacher should seek to identify the student's foremost point of conceptual confusion or erroneous knowledge.

Properly supported, the student will be able to show many areas of competence and, despite weak knowledge plus confusion, the teacher will be able to follow and confirm the student's efforts. The teacher will be able to follow well enough to discover the student's major source of conceptual confusion. The teacher will realize that if the teacher had the same erroneous concepts, he would be just as confused! In my experience, there is usually only one major point of confusion and that it so dominates, that no other learning will take place until that confusion is located and resolved.

Examples of student confusion:
a) He is blending two related ideas, (Example: Force and Field).

b) She has reversed the meaning of two concepts (Example: Horizontal and Vertical).

c) She is confusing different physical circumstances because they have similarities when verbally described. (Examples: Hurricane and Tornado; Speed of Light and Speed of Sound; Longitude and Latitude.)

d) She has failed to differentiate a ratio concept as distinct from the two variables that make up the ratio concept (Example: Pressure is the same as Force).

e) He has failed to differentiate two similar but, never the less distinct, ideas (Example: mass vs. weight; acceleration vs. velocity; heat vs. temperature). Quantities that are proportional, are especially subject to this confusion. (20)

f) He has the definition backwards or insufficiently learned. (using sec/ft in place of ft/sec/sec).

g) When the student is trying to think about acceleration, she is really thinking of velocity. The teacher may need to help the student "see" the acceleration concept thru physical, concrete, body dynamic. To illustrate de-acceleration: say "walk across the room ..... now slow down".

h) Considering his experience, the student has made an interpretation (of the topic, data, etc.) that is correct and reasonable, but his conclusion is considerably different from the one intended by instructor. These points of confusion may appear simple and obvious to the teacher, but are very hard for the student to identify with his own efforts.

The examples mentioned above (and quoted in the Appendixes below), have actually occurred and caused serious learning difficulties for the student involved. See Appendix I through IX for additional examples and discussion. See also Hewitt Conceptual Physics for his mentioning of concepts where he says "it is easy to confuse". (21).
STEP IX. As soon as the student's confusion has been identified, the teacher should direct the student's attention to it by simple gestures or simple short one word sentences. Long explanation should avoided this time.

As soon as the cause of the student's confusion has been identified, the teacher should redirect the student's attention by gestures and simple short sentences. A long explanation should be avoided at this time. Often, merely identifying the student's difficulty is sufficient for him to know how to correct it. The teacher may simply pointing to it or use other verbal attention such as:

   a) Point to the student's paper and say "I believe you are treating heat and temperature as being the same" (21) or

   b) "You are thinking of the magnetic field vector as if it were a force."
Such statements may be sufficient for the student to see his error spontaneously. Very likely further discussion will not be needed. Other student hang-ups may be more resistant, and the teacher may need to propel a "mental shift" so the student will take a "different view". Sometimes the teacher may have to guess the locus of the student's problem, and then use a temporary detour to achieve confirmation:

c) He should use the simple to help understand the complex: "Let's greatly simplify this problem and find that result first".

d) The teacher may use the familiar to help to student understand the unfamiliar: "For the moment, let's work through a similar calculation but using an equation that is more familiar to you". The familiar will provide a "template", help the student to "decode the unfamiliar.

e) Providing an analogue (22) may give the student a new "handle" on the meaning. "First I would like you to calculate density of iron from its ratio. That will help you understand the concept of entropy defined as a ratio."

f) Often a student will resist a new idea because he is or has contradictory data in mind. An extreme or limiting case may be used to show the student that in fact he is wrong and thereby prompt him to re-examine his thinking:

"If your idea that all pieces of iron sink in water, then how does a battle ship float? or, If your thinking is correct, then think what would happen in outer space?"

or "What would be the result if we let this variable get larger and larger?"

g) In a few cases, the nature of the student's problem still will be perplexing to the teacher. In this case vague, open ended, oblique or tangential statements are often most productive:

1) What does this situation remind you of?

2) Is this result good or bad?

3) Tell me what seems to be the problem.

4) Restate the problem in your own words.

5) Think of energy as a kind of money deposited in the bank.

6) Look again, what would happen if...
Remember the US Navy KISS principle: Keep It Simple Stupid. When a student is having difficulty, reduce complexity. (23 & 24) Get back to the familiar. Provide simple examples and use analog situations familiar to the student. Provide simple cases as means for decoding the complex.

Sometimes after the student is able to identify his problem, he or she will often say: "Is that all there is!" "It can't be that easy!" "I guess I have been expecting physics, chemistry, etc. to be hard and I couldn't believe my simple idea could be correct!"

STEP X. A Successful Help Session May Achieve a "Flash of Insight".

In a successful help session, the student may spontaneously resolve his problem, and the new proper view will "click into place". In this event, the teacher will see the specific behavior patterns (25) of a "Flash of Insight" (8) (9). The student's previously blank, expressionless face
and rigid body posture will vanish. The student may blink and smile with sparkling eyes, tip his head back, laugh, make generally free body movements, and may express relief such as Ahhhhh ...., now I see!. The student's previous uncertain thinking will now change to certainty. He will be able to tell clearly what was causing him so much difficulty and often will give additional appropriate explanations of the topic that had previously produced confusion! Of course, the above-mentioned behavior patterns may not always accompany new and equally significant student insight. Often the student is abruptly silent and appears to be engaged in thought. After a moment (for his thoughts to go to completion) the teacher can find out what happened by an open-ended non-directive statement to the student such as "You are thinking something ....".

Although not all help sessions will occasion a "Flash of Insight", the flash occurrence and the exact nature of the previous confusion and/or lock-up deserve very close attention. The teacher and the student both will learn much about the ways in which learning (and understanding) can go astray and understand the methods (often simple and pleasurable), that will bring perception back on track. The above discussion gives no hint as to why the flash of insight occurs or what is happening in the student's mind. Normally perception is automatic, quick, accurate and reliable and we really never see "inside" the process. A moment's reflection reveals that "perception" is solving a vast intricate code to tell us "what is out there" and "what should we do next." It should be no surprise that once in a while it is falsely diverted or faced with conflicts that bring the perception process to a halt. This is when the insight occurrence is needed. And when the AHA happens, we often can identify the exact hang-up or confusion which had blocked the normal processes of perception. The longer the state of hang-up persists, the more the distress. A Flash of Insight occurs simply in cases where (spontaneously and in a very short time) a different solution to the same data is suddenly successful. This is an amazing "general problem solving" ability intrinsic to human and animal brains. The characteristic posture reflex actions indicate there has been an internal mental change. The pleasure derives from the removal of the distress and the renewed sense of power and control we feel when we gain a new understanding of relationships and events. The larger the posture shifts and larger are the person's expression of pleasure, the larger was the blockage and the larger was the internal mental shift to a new perspective.

It should be evident that the Flash of Insight and Perception are one and the same mental processes. The Flash of Insight is what happens when the normal processes of perception have been blocked and suddenly allowed to go forward. Perception usually is so swift an sure, we do not see into it's steps(25). However, the flash of insight, and its previous hang up, gives us a chance to see why and how perception goes wrong (or gets stalled) and allows study how to get it back on track.

When the learning hang-up occurs, the needed mental re arrangement is verbally inaccessible to either the student or the teacher. This is why long, extended, logical, discussions are not usually
of any help. The student needs to "let go" of the present decoding and "try a new one" What does help is to get the proper facts before the student, and with gestures plus open-ended suggestions gently "bump and nudge" the student until something "clicks". Educators (9) (26) and psychologists (3) (8) have been intensely interested in insight. The conditions for scientific discovery, creativity, invention, problem solving and for insight in learning all appear to be similar (8) (27).

SUMMARY AND CONCLUSION

By its very nature, confusion blocks a person's ability to see what is wrong. Only after the confusion has been resolved is it possible to look back and see the nature of the conceptual difficulty. The fact that the student has problems or is confused should be a clear indication that the previous lecture/text approach for that topic is unsuccessful for that student. More lecture or text input will cause further confusion since this will probably add new or different information to a situation where the student cannot make sense of what he already has. In addition, lecturing/explaining requires the student to find or realize the source of his own confusion at a time when he is least able to do it. This is probably a time when the concepts and terms are all very new and poorly learned. He has no way of knowing he has mis-learned key ideas, or has certain terms conflated, scrambled, or backwards in his mind. Also the student doesn't have any of the BIG PICTURE to keep him oriented. Because of his confusion, he cannot use what he is being told, to resolve his confusion or even see the point at which his thinking departs from that which he is being shown. The teacher does have the big picture. The teacher is very familiar with the material and presumably is not confused. He is in a much better position to help resolve the confusion. But to help the student, the teacher needs maximum information about what is going on in the student's brain. The only way to do this is to listen and not to show! The steps of the DART helping technique are chosen to maximize student information transfer to the teacher, and thereby guide the teacher in his attempts to help the student. The experience gained should be beneficial to both student and teacher. Both will gain a new understanding of perception, memory, insight, and problem solving.

APPENDIX I to APPENDIX IX.

REPORTS OF SELECTED DART SESSIONS AND STUDENT AHA FLASH OF INSIGHT.

The following reports give the reader concrete examples of student confusion and how the cause of the problem was discovered. The student's body response at the moment of insight is indicated.

APPENDIX I. IT IS EASY TO CONFUSE FORCE AND FIELD.
Ned W., an engineering student with a B+ average, came to my office for help on the vector cross product idea as applied to magnetic fields. He did not understand why his answers on this topic were marked wrong on his physics examination. Before I attempted to assist Ned on this advanced topic, I wanted to be sure he had a good overall comprehension of basic magnetic field phenomena. I asked him to draw magnetic field lines surrounding a bar magnet as he remembered them from his lab experiences during the previous week. He drew adequate field line diagrams, but when asked to discuss the relative field strength at two positions within the "Field", Ned would give inappropriate "Force" type answers. Also, in applying the vector cross product, he substituted the field value (B) where the force value (F) should have been placed. I said to him, "A magnetic field is not a force." He replied OH...REALLY! !!! .... and simultaneously shifted to a straight-up and motionless posture. In our subsequent discussion he stated that he had been making this misidentification, even though other facts that he himself was then aware of, clearly should have told him otherwise. He stated that he had been considering all vectors to be forces for nearly two semesters. Apparently he never realized he was making a serious mistake all this time. He then mentioned several additional examples where his former assumption (e.g. Velocity is a Force) was clearly not true. Only then did he experience the overt realization of his conflicting assumptions. Subsequent examination of his previous lab report revealed the statement "Force comes out of the paper" where it should have stated "Magnetic Field comes out of the paper". The reader should well note the following recipe for student confusion. The words force and field each begin with "f", have five letters, and have to do with pushing and pulling. Words which are similar in appearance and sound invite (cause?) confusion.

APPENDIX II. A SIMPLE MEASUREMENT PROBLEM MAKES STUDENT BELIEVE SHE CAN NEVER UNDERSTAND THE CONCEPT OF INTERFERENCE OF LIGHT WAVES.

Anxious and distraught, Elisabeth B. came in for assistance in calculating the wave length of light using a simple given equation. Her answers were much different from the values consisted of five equally spaced pencil lines that she had traced directly from observed light interference pattern, obtained during a standard introductory physics lab called "Young's Double slit Experiment". She showed me her result which was clearly wrong by more than a factor of 2 despite the fact that her tracing was correct. I asked her to repeat the measurement and calculation while I watched. She proceeded to get the correct answers! I was deeply mystified. What had she been doing wrong previously? As I was pondering over the possible solutions to this dilemma, I noted Elisabeth's posture and face go static. Before I could react in any way, I was surprised by her sudden completely unexpected change in manner. She leaned back and burst out laughing "OHHH I know what happened! I used my father's multi-scaled triangular drafting ruler. I must have turned it the wrong way!" Except for this single mistake, she did have the correct answer. However Elisabeth was nevertheless convinced she had no ability to handle the topic of wave interference. Although she normally completed all her assigned work, at the B+ level, she made no attempt to write up this lab report! A simple measurement error had prevented any progress in her understanding of wave interference.
APPENDIX III. EXPERIMENTAL DATA CONFLICTS WITH STUDENT EXPECTATION.

In a physics lab, students were to measure and graph the electrical current (I) as a function of voltage (V) applied to a lab resistor, and show that the resistor produced a straight line graph (current proportional to volts) and thus obeyed Ohm's law where resistance is constant. They were to then repeat this procedure on two different electrical incandescent light bulbs and from this data they were to discover that the light bulbs did not produce a straight line graph and hence deduce that not all conductors obey Ohm's law. Most of the students accomplished the required discovery and in addition accurately reported that the resistance of the light bulbs increases as the filament gets hot, as discussed in their lab manual and physics textbook. Student Katy R., a B+ student, had very accurate complete data and graphs for all assigned measurements. However, she was absolutely convinced that she was supposed to get a straight line on all graphs and actually drew straight lines on her light bulb graphs contrary to her data. Her lines greatly missed many of her data points. She recognized the discrepancy in her report saying: "The result (of the resistor) is the finding that (I) was proportional to (V). The second graph shows the findings of the lamp. The same result was found, (I) proportional to (V). There are two points that are somewhat off the general flow of the line. These two points may have resulted from an error in reading the voltmeter or in keeping the current constant." Kathy makes a similar conclusion about the second light bulb graph WHICH also clearly shows a smooth curved behavior much failed to make additional required graphs of the resistance vs. voltage for each of the three devices. When Katy came in for a help session, she continued to believe that her data were erroneous despite my hints to the contrary. I drew a nice curved line through the data points for both light bulb graphs and asked "Do you really think you made reading errors on both light bulbs, especially since you did such a nice job on the resistor. In an instant she tipped her head back 30 degrees, smiled and said "OHHHHHH !!!" She subsequently finished drawing the resistance as a function of voltage graphs. Subsequent discussion showed she now understood how and why the resistance was not a constant.

I might here add that this lab is purposely structured to catch (and identify) those students who are too prone to assume that all data will produce a straight line. When the straight line does not appear, they will receive practice adjusting their mental habits to be alert for new meaning!!

APPENDIX IV. A STUDENT DAWN D. REPORTS HER "LIGHT BULB" INSIGHT AFTER AN ILLNESS.

After writing her Ohm's Law and electrical resistance lab. report, Dawn D. adds the following comment: My own analogy of resistance came to me when I was sick. I made the statement that I had to increase my resistance to keep from getting so many bugs (germs). A light bulb went off and it came to me that the lower the resistance the more the current can go through a circuit. Current follows the path of least
APPENDIX V. FAILURE TO SEE A SIMPLE ALGEBRAIC DERIVATION, BLOCKS LEARNING FROM TEXTBOOK.

Dawn D. came to my office with a number of prepared questions, one of which indicated she was confused by the text discussion of light waves as applied to the optics of the thin lens. She pointed to the equation in her textbook:

\[-\frac{1}{p} + \frac{1}{f} = \frac{1}{q}\]  (Equation A)

and asked "this equation .... is it...?" She did not finish the question, but switched to asking about the curved wave fronts in a nearby diagram that illustrated a lens which brought light waves to a focus. (For you the reader to understand the student's flash of insight herein described, it is not necessary to understand the meaning of this equation. simply notice that Equation B is a simple algebraic re-arrangement of Equation A.

\[-\frac{1}{p} + \frac{1}{q} = \frac{1}{f}\]  (Equation B)

This simple result is what the student did not at first see! I felt it would be best to delay her question concerning her understanding of wave curvature. And instead appeal to her prior knowledge. So I pointed to both of the above equations and asked, "Are these equations the same or different?" As I asked this question I should have mentioned that I was not asking a trick question. For more than 10 seconds she was very still almost rigid, and expressionless. Then she slightly dropped her head, blinked, and shifted her body posture. But she did not smile. After a long silent wait, I asked again "Are these the same equation?" She said "yes, just rearranged", and motioned how terms could be shifted to the other side. At this point, she readily could follow that Equation A and Equation B were describing the same idea, and were algebraically "the same". Her subsequent discussion indicated good comprehension. She was visibly more relaxed and at ease when we finished the help session. In retrospect, I do not think that Dawn's understanding of wave curvature was at all faulty, or the source of her difficulty.

APPENDIX VI. MISCONCEPTION BLOCKS PROBLEM SOLUTION.

Student Don K. requested assistance on the following electrical potential energy problem: A proton initially at rest, moves from point x to point y and gains 9.6 x 10 joules of energy in the process. What is the electrical potential between the points and what is the velocity? He asked, "How could kinetic energy of a moving object be obtained from a static non-moving potential energy?" I sensed that the concept of force was missing from his thinking. Rather than a theoretical discourse, I simply posed to him an indirect question approximately as follows: "If an electrical potential exists, are there any electrical charges present?" After a pause, I received a sudden smile and observed an obvious relaxation of the previous tense posture. Don then clearly specified the needed kinetic energy equation and how he would use it to get the answer. I asked Don to finish his problem solution and then write a report of his "AHA". He did so immediately after his correct solution. He not only was able to achieve the correct problem solution, but also wrote up a clear understanding of the incident as follows: "At first, I was thinking that PE
meant the charge was not in motion, so that difficulty and confusion arose in how to obtain the velocity from the KE equation. But I realized by talking to Dr. Gurr and seeing a "flash" that the PE it gains by the potential difference will be used as KE and thus giving the proton a velocity." Clearly Don was in complete control after his "Flash". Be sure to notice that I did not mention 1) potential energy, 2) kinetic energy or even 3) forces, but nevertheless the correct needed information arrived and Don's problem was resolved thru his own efforts!

APPENDIX VII. STEVE A. REPORTS HIS OWN EXPERIENCE WHY "REVERSE" CURRENT AND REVERSE VOLTAGE DO NOT MAKE NEGATIVE RESISTANCE.

In his lab report Steve mentioned his data tables where he showed resistance as having negative value. He. stated "It is a mistake I made when I was plotting the graph of resistance vs. voltage. I didn't realize the mistake until I was writing up the lab, and it hit me. Ha! ! Resistance can't be negative because the signs cancel out. I realized this and corrected my mistake." Notice that the words "HIT ME", "AHA" and "REALIZE" are equivalent, and refer to the necessary recognition, then mental reorganization required for productive learning. Without it, there would be a missing "brick" in this student's structure of knowledge.

APPENDIX VIII. A SERIES OF VOLUNTARY WRITTEN REPORTS WRITTEN BY A STUDENT STAN W.

"The other day when I was waiting to get into the physics lab, I noticed a picture pinned to the bulletin board. At first, I couldn't make any sense about what was going on. Then slowly, I began to put the pieces together. The first thing I noticed was two balloons hanging from a string and then I noticed there was another balloon present, but almost completely disintegrated. Shortly thereafter, I realized that the three balloons were being popped in succession, but I couldn't figure out why they were popping. So I started with the balloon that had almost completely blown up and traced the apparent path of whatever was causing the balloons to pop. I came to the last balloon but still didn't see what was causing the popping. Then I saw a bullet way over on the right side of the picture. I suddenly realized that the bullet had caused the popping of the balloons. The picture had to be a high speed photograph of the event." Before Steve took the time to study the photograph it had no special meaning. The picture was just a scramble, until the relation between the balloons was noticed and the bullet finally discovered. Steve is a hunter and has a great interest in guns and bullets. But the photograph had been on the door for two weeks prior to his discovery. During that time he was blind to its meaning. During the school year 1987-88, I was pleased at the number of students who experienced and reported their own "AHA's"! For example, I have received seven voluntary written reports that year, whereas such reports have averaged less than one per year over the previous few years. I have reviewed my steps, as a catalyst, to bring this about, and now have the conviction that student Flashes of Insight are an essential (and trainable) component to learning (25). As a consequence my increasing skills, I am able to point out the student's AHA discovery events, quickly and
convincingly, and thus encourage more of the same. It is clear to me that this interaction among the students also generated more "AHA's" as follows.

APPENDIX IX. STAN W. THEN TELLS A "THEN-IT-HIT-ME" REPORT.

"I do some shooting and a lot of target practicing. One of my major goals is maximum accuracy. I reload my own ammunition, each designed for a different purpose, but all designed for maximum accuracy. When doing one of the homework problems you had assigned, I was asked to calculate the wave properties of a bullet. I thought, whoa, wait a minute! Of all the technical data I had read, I had never come across any information of that sort. And yet with an "off the shelf" rifle I was able to shoot an inch and one half group at 200 yards with my 308 Winchester. Then it hit me - the wave property might apply technically but turn out to be so small that its effects would be minor. After working out the problem, it did in fact turn out to be an extremely small number." Stan's story is one example of an "AHA" I have been trying to get the students to report to me. Stan continues with another story. "We were working in class on a problem and I was unable to grasp the meat of the situation when all at once it hit me. AHA!!!! A fellow classmate noticed that I suddenly understood and told me to "Put it into a lab report appendix". So here it is. After it hit me I found myself smiling and feeling happy. Therefore, it could be said that Ahab's are pleasurable. It also helps to build your own self-confidence knowing that you figured it out instead of having to be "spoon fed". All in all it is an overall good feeling." Stan has other thoughts, apparently propelled by the above discussion. He continues. "I have come to the conclusion that no matter how much you play with numbers and can prove your theories on paper, until you actually do the physical work you won't know for sure. Its kinda like the (puzzle) two metal horseshoes connected via a chain that you gave to me. I looked at it for a while and told (my classmate) Donald "All you have to do is turn them sideways and slip off the ring over both at the same time". He looked at me and said, "Sounds good but I need to see it". After I worked on it for a bit, I showed him that, in fact, it did work. I think that when we are given a simple physics equation we really fail to understand the large amounts of work time and thinking that went into making the equation a usable tool."

REFERENCES


2) In October 1979, Dr. Fuller and members of the University of Nebraska at Lincoln ADAPT team conducted a workshop on our campus titled: "Logical Thought & Reasoning: A Piaget Model."

4) There is a considerable literature describing serious and extensive student science misconceptions that are not resolved by traditional physics instruction. The reader should study the authors and references given in L.C. Mc Dermott Physics Today July 1984, p. 24. See also several valuable articles in D. Gentner & A. Steven's Ed. Mental Models, Erlbaum, Hillsdale, NY 1983.

5) The DART technique is similar to widely used practices in counseling or medical interviews where the goal is to maximize the information obtained from the interviewee and do so in a non-threatening manner. See a Handbook of Counseling or a Handbook of Interviewing.

6) There is a considerable literature on anxiety in Math and Science instruction. See S. Tobias Physics Today, June 1985, p. 61.

7) Persons who send to the author, a report of their experiences with the DART technique will receive a copy of a compilation of all such reports. A science or mathematics class, is a good environment to observe human processes, as is discussed in the chapter "Teaching and Research" in Ellinor. Duckworth, Having Wonderful Ideas, Teachers College Press, NY and London (1987). Entire book is recommended for teachers of all ages.


10) D. Herron, Private communication. In many public lectures, Dr. Herron gave graphic demonstration that more information and/or formal arguments did not clarify a confusing topic.

11) Additional Rules for understanding human development are given by Wilder, Mathematics As Cultural System. Pergamon, NY (pp. 126-148).


13) Helping the student to become aware and express his feelings may give him the courage to reveal other concealed problems.

14) "How vain to try to teach youth or anybody truths. They can only learn them after their own fashion and when ready. I do not mean by this to condemn our system of education, but to show what it amounts to, A man thinks as well through his legs and arms as his brain." Henry Thoreau, Journal entry for December 31, 1859.
15) "(The student) must have sufficient time to grapple mentally with the new situation, possibly with appropriate hints, but without being told the answer - people must be allowed to put their ideas together for themselves." R. Fuller Physics Today Feb. 1977. Page 28. See also pp. 62-69 of Ellinor Duckworth, Reference (7).


18) The effect of "showing" can be clearly demonstrated in young children. When a young child comes to you with crayon and paper and asks for help in drawing a picture of a cow, for example, ask him questions such as, "Is the cow big or small? How many legs?" You must not take the crayon in your own hand and show the child. If you do, the child will not draw any picture form many weeks thereafter. Apparently he desires to draw as expertly as you did but will know that he can't, so he will forego the attempt altogether! (Author's sad experience and private communication, Esther Collyer, Supervisor of Music and Art, Fort Wayne, Indiana.


23) "Keep it simple. Make your theory, your experiment, your explanation just as simple as possible". Fred Reines Private communication.

24) When a complex organism (human being) meets a complex circumstance (our world) there is only one thing simple: What will happen next! That is what this paper is about.

25) The reader may request a copy of the author's paper Memory Perception and AHA Problem Solving.


************ END ************