VISUAL COGNITION IN UNDERGRADUATE BIOLOGY LABS; CAN IT BE CONNECTED TO CONCEPTUAL CHANGE?

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Abstract: This paper describes a theoretical framework for the investigation of some specific types of visual learning difficulties commonly experienced by biology undergraduates. The framework was developed based on the findings of three simple qualitative pilot studies. A variety of neurological, cognitive and cultural mechanisms can influence what humans visually perceive, however, when an observer's perception of what they see changes, some interesting mental processes must occur. The author suggests that these mental processes are in some respects similar to Posner et al's (1982) theory of conceptual change. The author further suggests that special inherent properties of biological material (such as its structural complexity and hierarchical organization) are confounding factors that make visual interpretation especially problematic within this discipline. The author will offer some speculative suggestions for new research that might eventually connect this model with studies of conceptual change and visual cognition in a variety of other fields.

Introduction – some background information about visual cognition

Contrary to intuitive belief, the images that humans consciously perceive do not represent a perfectly full and accurate recreation of a positivist external reality. An in-depth analysis of visual cognitive science is beyond the scope of this article, however, for a general description of the major principles discussed in this section, see: Bruce et. al. (1996), Biederman (1995) & Edelman (1997). What humans "see" is actually a highly plastic mental representation, influenced by many complex cognitive and neurological phenomenon. When light falls onto the human retina it is processed into optical data that is sorted and directed along multiple data streams. These streams flow to several different parts of the brain and are processed separately. The results from many types of analysis are then combined with other sensory and cognitive information and somehow integrated into a representation or "percept" that the conscious mind perceives as a single image.

Within the field of psychology, it is well known that an observer's perception of what they see may be influenced by a number of factors including optical clues (such as visual context, perspective, occlusion, lighting gradients, texture maps, movement and many others) as well as the observer's past experiences and cultural background. Perception can also be affected by neurological and anatomical factors. For example, it is known that visual perception can be affected by brain injuries, or certain pharmaceuticals, and it is also known that different species of animal may have radically different perceptions of the same visual stimulus. Many aspects of this process present profound cognitive and philosophical problems for investigators and, in a world of infinite visual variety, there is still no good single model that describes how observers are able to consciously recognize and make sense of what they see. Nonetheless, although somewhat neglected by educational researchers, the mechanics of the human visual cognitive system have been extensively studied by neurologists and psychologists who now have a fair understanding of many of the *individual aspects* of image processing. Particularly noteworthy are recent studies that have yielded information about which parts of the brain are involved in which parts of the visual process, and how the brain responds to novel versus familiar images.

Gauthier et. al. (2000a, 2000b) has performed functional MRI studies with patients suffering from various forms of visual agnosia. These studies suggest that certain specialized parts of the brain may be involved with visually recognizing sets of very similar objects, (such as human faces), while other parts of the brain are concerned with the general recognition of objects and sorting them into crude categories. Gauthier et. al. (1996) have also shown that observers have the ability to improve their ability to distinguish between unique individuals within large sets of very similar objects by visually studying them for prolonged periods. As this learning process progresses, FMRI shows that different parts of the brain seem to be activated, with activity gradually moving from the part of the brain that deals with the general recognition of broad categories to the part of the brain that deals with closely related sets.
Studies such as these raise the possibility of actually observing the neurological changes that occur during the process of visual learning and have started to forge much needed and overdue links between the fields of neurology and education.

Limitations of and influences on the human visual system

The human eye is unfortunately not a perfect optical instrument. It is limited by a number of factors such as recovery speed, optical imperfections, light-sensing cell density and structural issues related to the needs and limitations of living material. In addition the human brain has only a finite computational capacity. To minimize these problems the human brain has developed ingenious algorithms for the rapid processing and correction of information. Unfortunately these algorithms are also imperfect and some types of visual information are prone to processing errors that lead to interesting cognitive dilemmas. Psychologists with an understanding of these shortcomings are able to demonstrate them using images that contain information specifically intended to be difficult for humans to visually process - we call these parlor tricks "optical illusions". Optical illusions are actually demonstrations of visual errors that all of us make frequently, but are typically unaware of, at least at any conscious level. Because of variations in the complexity, physical structure, optical properties and cognitive significance of different things we observe, some things are more likely to generate these errors than others. Also, because of variations in the optical and cognitive systems of different individuals, we should expect that some individuals are more likely experience these effects than others. When we observe novel material, material that is extremely optically complex or when we observe things under conditions that reduce our brain's ability to focus on optical computations (e.g. during times of physical stress (Ross, 1975)) we may further increase the probability of encountering optically problematic material or making visual errors that can negatively influence our interpretation of what we see. The fact that humans tend to assume primacy of visual data is a compounding issue because it makes observers somewhat reluctant to question or examine the image that the brain's visual centers present to them.

An easy illustration of the plasticity of human visual perception and the role of cultural and experiential influences is the use of so called ambiguous forms and reversible figures. In one well known example we see an image that could easily be perceived as either an old woman or a young lady:

Young/Old Lady

Note that the tendency to see either one or other of the two possible images is called "perceptual set". Overcoming perceptual set can be quite difficult. Just how difficult depends on many factors, but in most cases, once it has been overcome once, it then becomes fairly easy to flip between opposing perceptual sets, indicating that something in the brain has apparently changed. Psychologists have shown that in reversible figures like this, certain characteristics of the observer can be used to predict which image is more likely to be seen first. In this case, young men are more likely to initially see the young lady.

Another example of an optical illusion that can cause perceptual difficulties is shown on the next page. This example is a two-dimensional image characterized by high contrast organic shapes and the lack of information conveying a sense of depth. Images of this kind are often difficult for the human visual system to interpret. Look at the black and white image for a few moments and try to decide what it represents, then read on.

The image shows a cow, with its face looking out at the observer. Many observers experience difficulty seeing this image, but they are apparently somewhat more likely to see the cow if they live in a rural area where cows are common, and even more likely to see the cow if they have ever lived on a dairy farm.

When we look at ambiguous or "hidden" image illusions such as these, it is possible (with a little practice) to "flip" back and forth between two different perceptual sets. In some cases, one of these perceptual sets might be the tendency to see nothing meaningful at all. The visually complex world we live in presents us with many ambiguous or hidden images, and our cognitive system must sometimes "flip" to correct for the phenomenon of perceptual set. Sometimes this happens without us even noticing, but other times the change is more dramatic, as when we are startled by, say, a shadow in a room that we think might be an unwelcome intruder. Note that in these examples and others (such as the famous "Rorschach" or ink blot test) it is clear that our perception is influenced by what Posner might call our "conceptual ecology", that is, the sum of the influences of our experience, culture and cognitive process. As education specialists, we should probably expand the definition of "experience" and "culture" to include a number of more specific education-related issues that might influence perception, Hence, in the interest of disclosing the full complexity of the "can of worms" I have opened here, I present below a partial list of some of the various factors that might conceivably be involved in determining what people perceive when they look at a given visual stimulus:

Optical clues in the visual field and their low level processing (perspective, etc., too many to discuss in detail here, but extensively previously studied)

Biological / biomechanical / biochemical factors

Eyesight (resolution / acuity)

Innate visual cognitive abilities

Multiple intelligences (Gardener), assuming biological basis

Specific genes and genetic disorders

Neurological issues

Pharmaceutical issues

Developmental issues / age

Gender, assuming biological differences in brain structure / function

Other factors not yet considered

Cultural / experiential factors

Language and semantics

Direct and indirect content knowledge

Visual experience

Biologically useful visual literacy (BUVL)

Multiple intelligences, assuming strict Vygotsyan constructivist basis

Learning style (Kolb)

Teaching approach (constructivist, behaviorist etc)

Motivation

Lifestyle and previous visual environment

Metacognition

Other cognitive factors

Other socio-cultural factors

Other factors not yet considered

My point is that what we see is not a strict positivist reflection of some exterior reality. What we see is influenced in complex ways by many factors including our past experiences, just as Posner says that students' ideas about the world are affected by their existing conceptual ecology. Understanding the specifics of exactly how different factors affect what we see is an almost impossible task, just as fully understanding any given student's conceptual ecology is also impossible. For Posner et al, what is more important is trying to understand how students' conceptions might change over time as a result of specific cognitive events.

Given that our conceptual ecology influences what we perceive, and that what we perceive can be resistant to change (for example, as a result of perceptual set) does this mean that the re-evaluation of a percept is an example of conceptual change? To answer this question we must revisit Posner et al's original idea.

Posner et al's basic idea

Conceptual change learning theory is based on a number of central tenets:

1) Students have preexisting ideas about phenomena.
2) When new concepts are encountered that are compatible with a students existing conceptual ecology *assimilation* occurs.
3) Sometimes a new idea is incompatible with a student's existing conceptual ecology, in which case a more radical phenomenon called *accommodation* must occur. This involves rearrangement or replacement of existing conceptual ecology.
4) Because of their epistemological commitments, most individuals are somewhat resistant to accommodation unless certain conditions are met and this is why some students hold on to old ideas that are incompatible with the "mainstream science" they are told in class.
5) For accommodation to occur there must be dissatisfaction with the existing idea (typically because of accumulating anomalies that do not seem to support the old idea) and the new idea must be intelligible, plausible and fruitful.
6) In order to bring about conceptual change it is necessary to actively engage learners so that they are able to discover for themselves anomalies that undermine their old ideas.

Simply telling students they are wrong is ineffective because accommodation cannot occur until the conditions in 5) are met.

7) Since Posner's original paper research has focused on issues such as:

a) Identifying common "misconceptions" in science.

b) Observing how students deal with anomalies and why they sometimes ignore them.

c) Studying the importance of "finding out what students know already", and then starting the instruction from there.

d) The use of metacognition as a tool to help students understand and anticipate their own learning stages, as well as their resistance to rearrangements of their existing conceptual ecology.

e) Clarification of what exactly a conception is, how, when and why they form, how they are connected to "conceptual ecology" and how, when, why, or even if conceptions can be changed.

What is, and is not conceptual change – more theoretical underpinnings

The key to understanding the relationship between visual perception and conceptual change seems to be an exploration of exactly what constitutes a "concept". Educational researchers and cognitive psychologists sometimes use the word "concept" in different ways: Cognitive psychologists consider that a "concept" is an arbitrarily constructed, human representation of some single, discrete, "real world" phenomenon. Things in the real world are referred to as "categories" and are assumed to have some "real" definition. "Family resemblance" categories are things like classes of similar objects, e.g. chairs. This type of concept is philosophically hard to understand because there appear to be no necessary and sufficient conditions that can adequately define them. We all know a chair when we see one, but it is hard to precisely define what a "chair" should look like. The slippery nature of this problem has confounded cognitive scientists in many fields, because without a good definition of how categories are defined and how they differ from their human-internalized counterpart (concepts) it is extremely hard to understand almost any cognitive function, ranging from language acquisition to object recognition. (See Pinker, 1984 for a general discussion of this issue). This fundamental problem is often overlooked and ignored in our culture because it is at odds with the positivist tradition that infuses every part of our culture. The common assumption is that all things can be logically categorized based on certain necessary or sufficient conditions that member items must meet. This belief is the origin of the infamous “dichotomous key”, a tool that is widely used by biology professors and widely despised by students. I would argue that in this case, the students are correct to be suspicious of this dubious tool because in reality, traditional biological taxa (excluding those defined by the newer technique of cladistic analysis) are actually family resemblance categories that cannot be logically defined by simple rules. The more logically defensible cladistic taxonomies also present a problem for novices because the characters that some cladistic trees are based on (e.g. “antennae”) are themselves family resemblance categories! This is one reason why cladistic trees based on DNA sequence data are more useful to scientists than previous approaches.

The way that "conceptual change" educational researchers use the word "concept" is a little different to the way it is used by psychologists. What Posner (1982) and his ilk are really talking about when they speak of "conceptual change" is a change in some or all of a student's "conceptual ecology", that is, the student's ideas about the way that different concepts are related to each other and arranged into some coherent mental model of reality. Typically, this is a conscious change involving high-level reasoning and /or conscious mental imaging. Changes in this constructed model of reality are what Posner calls conceptual change. Posner et. al. were aware of this potentially confusing semantic issue (i.e. the meaning of the word “concept”), and that is why they chose to use the word “conception” to denote the singular form of “the thing that changes” during conceptual change. (Strike, 1992). A conception can be considered to be a single concept and the sum of its relationships to an individual’s conceptual ecology, or a specific set of concepts and their relationship to each other or an individual’s entire conceptual ecology.

It may seem counter-intuitive to suggest that an observer’s “concept” (used in the psychological sense) for any given object (such as a chair) can change while they are observing it, but in fact, sometimes it does. Sometimes an observer may encounter a new type of chair that allows their visual definition of “chair” to be modified. Equivalently one might say that the image of the new chair has been assimilated, creating an updated concept of the family resemblance category known as “chair”. In other situations, a perceptual error may occur where part of the brain responsible for object recognition briefly misidentifies an object. Almost everyone can recall an example of when they visually mistook one object for another, perhaps briefly thinking that a branch was a snake. Internal perceptual representations corresponding to some external entity are called percepts. When a percept is re-evaluated by the brain’s object recognition centers and re-categorized as an entirely new percept, it might at first appear that a Posnerian process of change has occurred. After all, didn’t some part of the brain become dissatisfied? Surely this must have been in response to anomalies that prompted the dissatisfaction? The reality is that so little is known about the low-level, subconscious process of object recognition that these are not valid assumptions. Since perceptual changes such as the “flip” from one perceptual set to another are low-level, subconscious phenomena, they are not necessarily governed by the same cognitive rules as processes that occur in the higher-level reasoning centers and therefore, although they may appear formerly similar to that described by Posner, it is probably not quite the same thing. The actual act of the “flip” is primarily a perceptual phenomenon and involves little or no immediate *conscious* restructuring of the observer’s conceptual ecology. However, once this perceptual change has occurred, it may force a radical re-evaluation of the relationship between the observed object and the schemas within which the concept of the object is embedded. When an individual re-categorizes a single entity (for example when they decide that an animal is not the species that they initially visually perceived it to be), this is not necessarily Posnerian "conceptual change", but it seems likely that the re-categorization will *lead to* Posnerian conceptual change because any schema that included the changed entity must now be adjusted to take account of the new definition of one of its components. Thus, when a percept is modified by the subconscious vision centers it can become an example of what Posner calls an anomaly; something that the conscious brain must now deal with by either assimilation or accommodation.

Example of visual percept error and conceptual change

This image can be seen as a seal or a donkey. The human visual system can flip interpretation back and forth between the two perceptual sets, although it is hard to see both simultaneously. The exact cognitive process that allows this to occur is unknown but it does not seem to involve any conscious reasoning or rearrangement of a conceptual ecology, therefore it is probably not conceptual change, although it does seem to resemble it. Since the image is presented without much context here, the act of "flipping" from one perceptual set to another seems to have few cognitive consequences since the correct identification of the object is not really critical to other cognitive issues.

Now imagine something like this same image transferred to the following hypothetical situation: You are on a beach. You look out to sea. You see something in the water. You can't quite make out what it is. Your visual system struggles to identify it. At first your object recognition centers are unsuccessful and the object either remains invisible or is classified as "unknown". Your object recognition centers may somehow call for more information from your past experiences:

- *in ocean*
- *moving*
- *splashing*
- *making a noise (bark? growl?)*
- *therefore alive?*

When seen out of context, the image might be interpreted as either a seal or a donkey, however, in this new scenario it is more likely that the additional context will allow your object recognition centers to identify it as seal because of the conceptual ecology within which it is embedded. Furthermore, once this conclusion has been reached, this interpretation becomes resistant to change; anchored in place by the connections to other information. The easy perceptual flip you performed on the isolated image becomes much harder or impossible. The knowledge that the object is a seal has been *assimilated*. If, after returning home, someone informs you that what you saw was actually a donkey, you would be unlikely to believe them.

Let us now imagine that the object is not a seal, but really *is* the head of a donkey. It might be that you may depart the scene without ever realizing your mistake. However, suppose that you walk closer. Eventually you may start to notice some anomalies:

- *Not swimming gracefully*
- *Appears to rising out of water > illogical*
- *Noise not like a seal*
- *Rear fins out of water – illogical*
- *Eyes seem to be releasing steam*

At first you ignore these anomalies, but finally, at some point you begin to feel *dissatisfaction* with your initial conclusion. At this point, you may feel that what you are seeing is not *intelligible* and you cannot identify it. For a moment you think what you see is a donkey.... but resist drawing that conclusion because that idea is not *plausible* to you

You stare hard and (presumably) send requests to your sub-conscious object recognition center for a re-evaluation. At the instant your conscious mind finally receives the conclusion "donkey", and provided that you consider this possibility to be plausible, it is necessary for you to perform a radical rearrangement of your conceptual ecology; this rearrangement is what Posner et. al. have called accommodation:

- *fins > ears > must be concave not flat*
- *swimming > drowning*
- *barking > braying*
- *natural event > unusual*
- *happy animal > animal in distress*
- *no further action necessary > action may be required to save drowning donkey*

The sub-conscious (or largely subconscious) change of your percept from seal to donkey forced a conscious rearrangement of your conceptual ecology. In addition, the conscious re-arrangements may feed back new or additional influence to the way you apply subconscious visual cognitive algorithms so that details that you previously did not consciously see at all become re-classified from "noise" to "significant". You therefore, are quite suddenly able to see new details that were invisible seconds earlier. (e.g. the concavity of the donkeys ears). In this example the re-evaluation of a percept is not only critical to it's immediate cognitive dependants, but it may also trigger a cascade of events that can lead to additional subconscious re-evaluations of other closely related percepts and *their* cognitive dependants. The end result can be an accommodation event that can be quite striking to the observer.

It is my belief that this type of scenario is played out many times (and with many variations) in learning situations where learners are asked to look at complex material that they are not familiar with. It is easy to see how the interplay between misperception of unfamiliar objects and the incomplete conceptual ecology of a novice in a new field can generate mutually stabilizing misconceptions that have both a conscious and a sub-conscious component, both of which may need to be addressed if learning is to occur.

Special issues of visual perception in biology classes

The study of biology is a highly visual activity. Many of the various sub-disciplines explicitly assess visual skills including, for example, the recognition and categorization of animal taxa in zoology, the recognition of complex anatomical structures and their 3-dimensional arrangement in pre-med classes and the interpretation of the precise meaning of slight variations from the visual norm when studying complex prepared microscope slides in histology classes. Most biology instructors can describe instances of novice biology students encountering learning difficulties related to their inappropriate visual perception of target material during lab or field exercises. A few published articles have hinted at this phenomenon (e.g. Wandersee, 1999), but no single theory has emerged to explain what it might mean for education. Although psychologists have extensively studied perceptual phenomena and the reasons why visual perception can mislead us, virtually nothing has been written about the relationship between visual perception and student misconceptions in classroom settings. I suggest that novice students' visual difficulties are the result of their inability to visually perceive or appropriately interpret the meaning of biological materials. Sometimes this can involve the perception of non-existent order or meaning within random visual data (a phenomenon called pareidolia). In other cases misperception can be the result of an apparent failure of the object recognition centers to find the meaning that *does* exist. These visual difficulties are nicely illustrated by a quote from "My life and Hard Times" by Ohio State University alumnus James Thurber:

> "*I passed all the other courses that I took at my university, but I could never pass botany. This was because all botany students had to spend several hours a week in a laboratory looking through a microscope at plant cells, and I could never see through the microscope. I never once saw a cell through a microscope.*"

The apparent prevalence of perceptual optical illusions featuring biological material (such as donkeys and seals) and the tendency of humans to find images of biological material such as human faces and figures within random patterns suggests that there might be some special issues connecting biology and vision. It could be that there are certain intrinsic properties of biological material that make correct visual interpretation a particularly persistent problem. For example, biological material is structurally complicated, organized at multiple size levels and arranged into hierarchical categories whose definitions are subtle at best and entirely arbitrary and irrational at worst. It could also be that the human visual system has evolved or otherwise acquired a strange obsession with, or particular subsystems dedicated to, the visual identification of biological material and these systems are imperfect. The visual observation of biological material in classrooms settings may be further complicated by the use of optical instruments such as microscopes, and by the fact that the material often occurs in complex or unfamiliar visual contexts such as surrounded by tangled vegetation, submerged in mud or water or moving rapidly through the environment. In addition, many organisms have been strongly evolutionarily selected specifically for their ability to avoid visual detection by other living things. Collectively, it is easy to imagine that these factors might deny the visual system access to vital optical clues and overcome its ability to filter noise from the visual field. Just as with all visual perception, there is also presumably a cultural or experiential influence on what biology students see in the lab. Here too, novice biologists or non-biology majors (especially those raised in urban areas) may be at a disadvantage because they may not have seen a lot of biological material in the past and are thus less likely to recognize new material. Their visual systems may also be somehow subdued by negative attitudes such as the belief that "bugs are gross" and that "science is boring". Finally, since the visual perception of living things seems like it might have some adaptive value, we should not rule out the possibility that there is some innate mechanism that causes some individuals to be better at it than others. Howard Gardner (1998) has hinted at this through the addition of what he calls "naturalistic intelligence" to his inventory of multiple intelligences. Naturalistic intelligence is defined as the ability to see natural patterns and relationships within and among living things. If such a quantity does it exist, it seems likely that professional biologists are quite likely to be drawn to the field specifically because of their innate ability. Undergraduates who may be talented in other areas must therefore contend with finding themselves frustrated and disheartened by the fact that their instructor seems to perpetually see things that to them are utterly invisible. The combined total effect of an observer's biological training, experience, eyesight and innate ability (if any) presumably all contribute to their ability to see, recognize and interpret biological material appropriately. For want of a better term, I have dubbed this quantity "biologically useful visual literacy" or BUVL.

Pilot study design and procedure

Three separate pilot studies were conducted. All three used a convenience sample of non-science major undergraduate students from a large Midwestern University. The first and second studies also included a small number of experienced professional biologists. All three investigations were essentially qualitative, grounded studies that consist of video data collected as the participants attempted visually demanding tasks. The first two studies also attempted to quantify certain phenomena in an attempt to answer specific questions that the author later deemed to be of less interest than the overall emerging themes.

Pilot study 1 - "observation of ecosystem in a jar"

In the first study, nine participants observed a miniature aquatic ecosystem in a two-gallon jar and described what they saw. A count of the total number of species correctly indicated by each participant was recorded. This was presumed to be an approximate indication of their overall BUVL. Each participant filled in a short, open ended question survey designed to reveal details of the observer's educational background, biological experience and attitudes towards living things. Qualitative analysis of the video data was used to try to identify patterns in the students' observational and cognitive processes. The data from the survey was coded and ranked in an attempt to quantify each participant's biological background and attitudes towards living things. Hardly surprisingly, the results appeared to indicate a correlation between the extent of the participants' past exposure to biological observation exercises and their BUVL. In particular, the two professional biologists appeared to spectacularly outperform the novices, but note that the sample size was small and the methodology was not particularly stringent. (Day, 2001) At that time my objective was to look for connections between BUVL and past exposure to specific educational approaches such as constructivism. As the study progressed I began to notice that some participants seemed to change their minds about what they reported seeing, while others steadfastly "refused" to see things that, to me, appeared perfectly obvious. I eventually realized that this pattern of "change" or "resistance to change" appeared to fit

Posner's model, and after discussions with others in the field (Beeth, 2001), I decided that this was this was the direction my investigation should take.

Pilot study 2 - "observation of video segments"

In the second study, a total of eight participants observed about twenty minutes of custom-made video footage showing microscopic biological phenomena. Working with the microscope is one of the tasks that novice biologists seem to find consistently visually difficult, so I thought it was important to examine this. The video consisted of 30 short segments displayed on a large TV. The segments were specifically chosen for their visually challenging content. Participants were asked to use a pointer to indicate on the TV what they saw and were asked to describe what they thought the images meant. Occasionally I would ask for clarifications or ask the participants whether or not they could see certain details. Again, the sessions were videotaped and analyzed to look for emerging patterns in the students' observational and cognitive processes. The second study also considered the effect of showing participants still images or line art of selected organisms (known to appear in the videotape by the researcher) before the sessions began. Participants were then asked to indicate whenever they saw anything that they thought might be the same species as the one in the previewed still image. My objective was mainly to look for general trends but I also thought that exposure to the line art might make the students more likely to misidentify vaguely similar organisms that appeared in the videotape. In reality, all participants were equally likely to misidentify vaguely similar organisms, regardless of whether they were "primed" with photographic images or line art. Virtually all of the participants reported false positives (i.e they said that something on the video was the same as the organism in the previously viewed still images when in reality, they were unrelated.) Only one reported a false negative (apparently did not see the organism in the video that matched the previously viewed still image.) This study was somewhat useful but I thought that it did not really reflect classroom events because I had specifically edited the videos to make sure they included close up views of *something.* For the most part, participants in this study were apparently able to see things in the videotape fairly easily, even though they clearly did not know what most of them were. In the biology classroom, a common theme seems to be that a number of students cannot find anything at all when left to their own devices. I decided that I might need to modify the design a little in order to more realistically recreate the difficulties that some students have when they are asked to locate specimens for themselves. Potentially useful observations from this study included the fact that students appeared to require several seconds of silent observation of each scene before they would attempt to describe it and that it was fairly easy to find subtle details that I could see, but the participants apparently could not:

Investigator: “is the filament moving?”
Participant: “No”
Investigator: “Are you sure?”
Participant “yes”

(The filament was a cyanobacterial colony, gliding slowly across the screen.)

Pilot study 3 - “observation of student microscopy in lab”
The third pilot consisted of a grounded study where students were simply videotaped as they performed a lab exercise that was part of their regularly scheduled plant biology class. I felt that previous studies were perhaps too structured and relied too heavily on scripted surveys or pre-prepared images that failed to capture the unpredictable subtleties of real laboratory situations. Students tend to reveal their visual difficulties most strikingly when they are asked to perform authentic tasks using randomly selected material. I also learned from the first two studies that opportunities to specifically ask the students about interesting cognitive events tend to present themselves in unpredictable ways. I found that by keeping the sessions unscripted and allowing myself to ask questions and guide the students according to their individual difficulties I was able to reveal much more meaningful data than having move through a planned sequence of tasks.

Significance of this research

The author suggests that this research is significant for several reasons. It attempts to forge new theoretical links between educational and cognitive research so that future instructional strategies may be more closely tied to known cognitive and neurological principles. The neurology of vision has proven an ideal model of brain function because the retina is an easily accessible part of the CNS. Similarly, psychologists have found vision to be a good perceptual system to study because they have been able to devise ingenious tests that allow the relationship between stimulus and perception to be objectively recorded. Thus, the human visual system seems like a good place to start when trying to connect learning theories to brain function because vision has been intensively studied and some connections between visual neurology, cognition and mental representation have already been made.

This research attempts to connect visual cognition with an established learning theory, specifically, it expands and modifies Posner's model of learning through conceptual change such that it can begin to make useful predictions about the role of perception in learning.

The research also has immediate practical pedagogic implications for biology instructors, who currently tend to underestimate both their own visual abilities and the full extent of the visual difficulties experienced by their students. If the author's assertion is correct, then existing theoretical principles of teaching for conceptual change (Hewson, 1998) could be used to suggest specific visual learning strategies as well as predict possible cognitive pitfalls for biology students and instructors. Ultimately, these strategies may be important not only for the instruction of biology, but for addressing cognitive difficulties associated with *any* visually demanding task.

Suggestions for pedagogy

- Have students describe and discuss in detail what they see, so that the instructor becomes aware of their visual misconceptions or omissions.
- Find ways for students to display, share or distribute what they see so that they can share their observations with others and allow peers to offer alternative interpretations. Modern digital video equipment can make this a relatively simple task
- Instructor should customize instruction to facilitate student dissatisfaction with visual misperceptions and associated misconceptions.
- Instructors should schedule time to work one-on-one with students in order to identify any unique visual problems that individual students may not even know they have.
- Instructors should emphasize metacognition so that students are more likely to understand there own learning and anticipate changes in their conceptual ecology.
- Students should receive some explicit training in conceptual change theory and visual errors they are likely to experience.
- Allow students to compare what they describe seeing before and after instruction so that they can be aware of, and empowered by their own cognitive changes.
- Instructors should make maximum use of authentic visual aids such as video, photography, multimedia and web graphics in order to maximize students' exposure to visual materials.
- Instructors should use explicit, authentic assessment of students' visual skills and make it clear that these skills are an important part of the curriculum.
- Instructors should carefully police themselves and try to avoid counter-productive assumptions about what they think the students *should* have seen versus what they actually did see.
- There is no substitute for actually seeing the material. Instructors should be careful to avoid simply talking about images and allow ample time to actually show them.
- Instructors should indicate important features by guiding student's eyes where they need to go using physical pointers of some kind.

- Instructors should always try to include as much contextual information as possible with images. Contextual clues help can significantly help interpretation. An example might be using a sequence of pictures at progressively higher magnification to allow the students to orient themselves to the correct scale of an image and its surroundings.

Suggestions for further work

- Perform in-depth studies of the role played by influencing factors on visual perception. How do these factors affect perception and what might this mean for educators?
- Evaluate the effectiveness of different teaching methods on the visual ability of biology students. Initially this might be done using a traditional (non-brain-image-based) approach.
- Use FMRI studies to compare brain activity of novice versus expert biologists when they observe biological material.
- Use this data to evaluate the effectiveness of different teaching strategies: Which strategy most effectively promotes the transformation of brain activity from that which is typical in novices to that which is typical in experts?
- Extend the studies to include other perceptual phenomena such as sound, particularly speech comprehension.
- Find a way to test for an innate component of visual ability. This might be accomplished by having different individuals study custom-made visually complex material that has no known cultural significance or meaning.
- How does visual ability affect the general public's beliefs and attitudes about biodiversity and conservation?
- Extend the study to look at visual cognition in biological researchers. How do researchers learn to make meaning of images that nobody has ever seen before? How might this affect the validity and reliability of visual research data?

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Some Related Web Links

http://www.siggraph.org/education/vl/vl.htm
http://www.rybak-et-al.net/vnc.html
http://www.15degreelab.com/education.html
http://www.sciencenews.org/20030517/fob4.asp
http://www.botany.org/bsa/psb/2001/psb47-1.html#Toward%20a%20Theory%20of%20Plant
http://psyche.cs.monash.edu.au/v4/psyche-4-12-milner.html
http://white.stanford.edu/
http://www-users.york.ac.uk/~awy1/delusion.html
http://www.cs.colorado.edu/~crader/Vl-poster.html
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