valuable and meetings limited. The role should include the review of matters of curriculum content and appropriateness of a laboratory in terms of latest technology and practices. The committee also needs to be of assistance in funds development and gifts-in-kind.

Too often education is trailing and not leading. We must be constantly looking to the future, utilize the latest "State of the Art," computerize our academic curriculum, and move with dispatch. Enterprise laboratories offer a superb opportunity, but, faculty and administration must modernize and plan ahead because accountability is so visible.

Summary

Enterprise laboratories operating within the normal rigors of the market place offer an exciting educational tool that is in high demand by faculty for motivating and preparing students for occupational opportunities at the technical level. Considering the high potential for financial risks, student safety and other similar matters, it is extremely important that laboratories be legitimately in support of an academic program as documented by the faculty in terms of educational needs and objectives. Moreover, faculty must hold leadership responsibilities and authority in the formation and day-to-day operation of the laboratory. Faculty must also possess the experience and capabilities to handle operational decisions, and strict accounting of both financial and academic matters is an absolute factor. Today, for laboratories to be viable they must be forward looking and incorporate the latest technology and management style. Individuals who hold administrative authority and responsibilities for enterprise laboratories need to be educators first, but educators who can organize and manage.

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Helping Students Learn by Understanding How They Think

John E. Fulkrod

Have you noticed that certain topics in your courses never appear to be mastered by a significant portion of students? I am not referring to students who make no effort to learn. Some conscientious students who really make an honest effort just cannot seem to master certain topics and concepts.

According to Piagetan theory, intellectual development occurs in four stages (1,2,3,4,5). These are called: 1) sensory-motor; 2) pre-operational; 3) concrete operational and 4) formal operational.

Piagetan theory assumes that children enter the formal operational stage around 12 years of age and complete this stage at age 15 or so. This theory of intellectual development was widely accepted for a long time and considerable curriculum content was actually based on this theory. However, other studies suggest that as many as 50% or more of entering college freshmen may function entirely at the concrete operational stage (6,7).

Many topics as they are presently covered in the agricultural curriculum may require formal operational thought for the student to fully master them. Students functioning at the concrete operational level of thought require concete examples and observations and have difficulty in understanding concepts that depart from their concrete experiences. A student operating at the formal operational level begins to think in terms of what is possible and what variables must be controlled before drawing conclusions. A student at the concrete level of thought relies on past experiences.

As an instructor of chemistry at an agricultural college, I have observed many students entering my classes whom I think have not yet reached the formal operational level of thought. As an example of this let us consider the calculation of the percentage composition of a compound. This is one of the earliest topics in most chemistry courses. Practically all students can, after some practice, calculate the % composition of Fe_2O_3 as 70% iron and 30% oxygen when given the atomic weights of Fe = 56 and O = 16. However, if you tell the students that a hypothetical compound of formula X_2O_3 is 30% oxygen by weight, only those students who have reached the formal operational level of thought will calculate the atomic weight of X to be 56 without prior experience at solving this type of problem.

In discussion with faculty members at our college who teach courses in fields of agriculture such as agronomy, soils, animal science, horticulture and economics, I have found many topics that require students to think at the formal operational level. Practically any concept involving a ratio or proportion can give students who are not at the formal operational stage trouble if they are asked to apply the concept to a new problem or example or to explain the meaning in general terms. Suppose you tell your students that two different solutions of a herbicide are to be sprayed onto a field. If you tell the students that solution A is less concentrated than solution B, and ask which will cover the most area to produce a desired level of herbicide,

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how many of your students will be able to draw a diagram which explains how each solution spreads on the field? What type of situations in your class require the use of ratios or proportions? Are you really convinced that the student understands the process, or is the student simply able to follow your example and make a calculation correctly on an identical problem?

Suppose that in a crops course you give information that soybeans assimilate high amounts of protein and oil in the seed. Now suppose further that you state that they are called legumes. A week or two later you tell students that peanuts are legumes. Only students who have started to think in terms of what is possible will recognize immediately without prodding that peanuts would be expected to assimilate high amounts of protein and oil in the seed because they are legumes.

Students in soils courses who are at the concrete level can understand that liming a field will change the acidity or that adding a fertilizer containing potassium will increase the potassium available for plants. However, I feel that without concrete experiences, a true understanding of soil phenomena such as cation exchange capacity is only possible for students who are at the formal operational stage. If we accept the fact that a large share of our students are not at the formal operational level and that visualizing a process such as ion exchange on a soil colloid is not something that a student has a concrete example to fall back on, then how do we present the subject? I believe that we need to attempt to provide concrete examples for abstract concepts to aid our students who are not yet at the formal operational level. I'm sure most instructors do some of this. But, do we do enough? One of the methods that I have used to illustrate a concept such as cation exchange is to place large signs with -1 on them on a table. The table represents the soil colloid with negative charges. Then I give some students a single +1 sign and I give other students two +1 signs. The students with single +1 signs represent ions such as $Na+^{1}$, $K+^{1}$ and $H+^{1}$ and those with two +1 signs represent ions such as $Ca+^{2}$ and $Mg+^{2}$. Then I have the students "neutralize" the soil colloid until no negative charges are left uncovered. Then we have more students represent another ion such as NH_4+^{1} with one +1 sign. The second group of students are then directed to replace the first group that are "attached" to the soil colloid in a way to keep charge balance. This really stresses the fact that it takes two NH_4+^{1} ions to replace a single $Mg+^{2}$ or $Ca+^{2}$ ion. The possibility for the use of concrete examples to represent abstract concepts in all fields is practically limitless (assuming you are at the formal operational level), and I believe that it may well be worth our time as teachers to use these examples in classes.

Recently I visited with a friend of mine who happens to be our college football coach. He was lamenting the fact that his well designed playbook with X's and O's was as simple as you could make it, but that many of his players (our students) could not understand the diagrams and the related sequence of plays until they walked through the plays many times in practice. It is my opinion that only the players at the formal operational stage were capable of thinking in terms of what is possible and that many of the players needed the concrete experiences of practice to master the system at least to some extent. My advice to the coach was that he was not wasting his practice time by physically walking the players through the related plays to show one play sets up other plays for future success.

Conclusion

Is it possible for teachers to help their students improve their formal thought process? Certainly we can use props as I have mentioned earlier to aid in understanding abstract concepts by giving students concrete examples, but to truly improve formal thought processes the student must be encouraged to think about what is happening. I believe that exercises which encourage students to make lists of what is possible and then to weigh the merits of these possibilities should help. Another type of exercise which encourages use of formal thought processes is to have the student diagram a process described by data. Proportional reasoning and understanding of ratios can be increased by always starting with simple examples such as 2 times, 3 times, 10 times, 100 times, ½ of, ⅓ of, .1 of etc. Whenever using proportions and ratios, I attempt to stress the physical situation represented with diagrams, pictures and props. It is important to let students think of what is possible in certain situations without being too critical of what we might feel are far-fetched ideas. One question I like to ask of students is how some things will influence chemical reactions. For almost any answer they give me, I will give them a "yes" with a real example. I believe that one of the best ways to gain insight into the level of thinking students have reached is to talk with them individually in the office or at the lab bench. If we as instructors can gain insight into how our students think, perhaps it may help us to help them to improve their reasoning abilities.

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