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Teaching Hypothetical/Deductive Reasoning in Radiologic Technology: Explanation Games and Other Classroom Methods

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Abstract
Teaching strategies for radiologic technology education can be enhanced by the use of metacognitive techniques which promote real-world critical thinking. The aim of these techniques is to encourage students to develop an awareness of themselves as autonomous thinkers and, ultimately, practitioners. Through an examination of the contributions to this area of medical, scientific and philosophical educators, various approaches are presented and unified under the model of an "explanation game." Both the theoretical underpinnings of these approaches and their practical applications in the classroom are discussed.

Introduction
This paper will discuss various metacognitive (that is, advanced-level thinking) strategies applicable to teaching in radiologic technology. Such strategies are designed to increase the critical thinking skills of students by teaching them to postpone an immediate search for answers, and to pay attention first to the questions that must be asked to find the answers. This approach is transferable to a variety of settings. A number of strategies will be presented here, all conceptually similar to Black's method entitled the "Explanation Game."

Following a general description of explanation games and their metacognitive implications, the use of the concept in science education will be presented. A further analogy will be drawn with the McMaster system of medical education, followed by examples of direct relevance to classroom instruction in radiologic technology.

The General Use of Explanation Games
An explanation game is a game in which participants have to discover an explanation for a scenario or series of events supplied at the outset by the game leader. Black has described his use of these games in teaching philosophical critical thinking, a practice originally suggested by Dr. Lawrence Resnick of Simon Fraser University. [1] The aspect of critical thinking developed by the games is the ability to create defendable hypotheses and to subject them to systematic testing.

In the typical explanation game, participants ask questions which the leader may answer "yes", "no" or "irrelevant." Participants have, then, to formulate general hypotheses about the form of the hidden explanation and to reject or modify them in response to answers from the leader, until the correct hypothesis is reached. In the general use of the games, there is no guarantee that the correct hypothesis will be the most reasonable: the correct answer is simply the explanation which the game leader has in mind.
For example, a game might begin with the following three-sentence clue: Two people enter a bar and order drinks. One finishes the drink quickly and leaves, suffering no consequences. The other slowly nurses the drink and dies within a couple of hours.

The intended solution involves the bartender having placed poisoned ice-cubes in the drinks. Thus only the drinker who lets the ice-cubes melt dies. The leader can further articulate the explanation in whatever form s/he finds most useful. For example, this may have been a deliberate action on the part of the bartender, in which case questions about what the bartender knows will elicit clues to the solution. On the other hand, the leader may decide that the bartender is an unwitting instrument of somebody else, or that the whole thing was an accident.

A variety of factors make these games useful in teaching reasoning. First of all, they constitute active, student-centred and collaborative learning. Students are actively engaged in thinking in the classroom and must draw on previously-gained knowledge and understanding of the world, and work collaboratively, to maximize the efficiency of the solution process. As a result, the games are fun; and the affective responses of curiosity, puzzlement, success and realization can set the tone for other learning activities later in a class.

Second, the games promote the development of a number of important reasoning abilities, valuable in educational as well as ordinary life. The kinds of reasoning abilities these games require, and therefore develop, include: memory/recall; precision in choice of expression; attention to consistency and implication; awareness of assumptions behind questions (avoidance of the fallacy of "dubious assumption" or "loaded question"); attention to the generality and specificity of questions with respect to their efficiency in approaching a correct hypothesis; the use of metaquestions (e.g. "Would it help me if I asked ...?").

The games can be played with or without instructive comment on questioning strategies; this is very useful once the basic idea has been assimilated by the students. Also valuable is trying to reconstruct the reasoning processes at the end of the game. The assumption, supported by metacognition research, is that self-conscious understanding of the logical processes involved in the games enables students to develop the corresponding reasoning abilities.

Metacognition may be characterized as the process of thinking about one's thinking processes. It might be defined as the application of problem-solving skills to cognitive tasks. [2] It involves solving the problem of what cognitive processes are required in order to complete some other problem-solving task. Thus, it includes the conscious creation of cognitive strategies for task-completion, based on an awareness of the nature of the overall task. It is known that metacognition is a developmental phenomenon, and that learning, especially active learning, can facilitate its development and hence its contribution to general problem-solving ability. [3],[4]

This somewhat theoretical description of metacognition can perhaps be made clearer through the use of an example. The metacognitive approach has been used to teach reading comprehension by focusing on the types of thinking involved in various types of reading. Poor readers fail to understand that reading tasks vary both in purpose and in difficulty, requiring different learning strategies. Thus, the reading required when a student is asked to critique a journal article is quite different from the reading needed to study for a test, but poor readers do
not understand this. Deficits in comprehension can be overcome by teaching thinking and question-asking, e.g. "How is this article like (or unlike) the one I read last week?" and "How closely do I need to understand the details of this text?"

In a similar manner, the explanation games technique can teach students the format needed to reason out logical solutions to various problems of a certain general type. It avoids the traditional "drill-and-review" approach in which the student is passive even when trying to answer the instructor's questions; instead, the instructor provides the end answer, and students must learn to ask appropriate questions. In this way it more closely mirrors the real-life solving of problems, and is thus a more fitting preparation for real-life problem-solving activities, notably those encountered in the workplace.

The third factor which makes explanation games useful in teaching reasoning is that the process of the game models the hypothetico-deductive picture of science described by, among others, Karl Popper. [5],[6] The central insight of that picture is that science is much more than the accumulation of lawlike generalizations based on inductive inference. Scientific theories are hypotheses generated to explain observed regularities. They are tested one against another through crucial experiments, in which differing predictions are validly deduced from differing theories conjoined with background assumptions and a description of the experimental conditions. When the experiment is carried out (at least) one of the predictions will be found to be false - the corresponding theory is then falsified, since a false claim (the prediction) cannot be validly deduced from all true premisses (the theory, background assumptions and experimental conditions). A theory which survives many tests of this type is then taken to be verified, although provisionally - it is impossible to prove a theory deductively, no matter how many experiments one carries out. (See Giere [7] for a fuller, though modified, account.)

While the details of the process are a little more complicated than this brief account allows, it is sufficient for our purposes in that it allows us to develop in outline an important analogy between explanation games and scientific reasoning.

The Scientific Use of Explanation Games

The analogy between scientific reasoning and explanation games is as follows: in science, hypotheses are tested by developing the logical consequences of one hypothesis which are not identical to those of competing hypotheses in the field, and finding out by experiment whether these logical consequences are true. If not, the hypothesis is refuted, unless one has made an incorrect background assumption or wrongly described the experimental conditions. If the consequences are borne out by experiment, then the hypothesis receives a degree of confirmation. In teaching philosophy of science or critical thinking it is essential to bring the students to understand that what is now accepted as fact (say, the existence of the atom) was at one time just a series of best guesses that led to a construct of reality. This can be seen too in the profession of radiology, where Bushong devotes three pages in his radiologic physics text to a historical description of the various theories of the atom. [8] Why waste precious instructional time on "outmoded" theories? The answer is clear - if students can understand the historical basis
of a theory, including the thought-processes that went into its development, they will understand the current model better.

The games provide a way of bringing students to such an understanding of theoretical explanation, for in them players test their hypothetical explanations by thinking of a logical consequence of a hypothesis they have in mind and asking if it's true. The instructor, who plays the role of "Nature," gives more definite answers than she, perhaps, but the confirmation of the final hypothesis is still a gradual process involving the rejection of alternative explanations.

The analogy between scientific reasoning and explanation games is a very fruitful one. For a start, it enables us to see the degree of commonality between scientific theory-confirmation and other more day-to-day forms of problem-solving. Exactly the same kind of procedure is followed by an auto-mechanic attempting to diagnose the problem with your car's electrical system. The application of the games to technical/vocational education is immediately apparent. The analogy also raises the possibility of modelling scientific reasoning in a parallel sort of game, in which both scenario and explanation are part of course content, whether pure or applied science. For example, students could "work out" a theory by designing experiments and asking the instructor what the results would be (or, rather, whether they would be such-and-such). Other possible applications might be to the standardized analysis of salts (by flame-testing and other reactions), to biological classification by anatomical features and to the naming of organic compounds.

In this kind of game, direct attempts to guess the answer would have to be refused, perhaps by distinguishing between "experimental," "hypothetical" and "metahypothetical" questions. Experimental questions ask about the result of a certain experiment, manipulation or observation. Hypothetical questions are attempts to guess the answer. Metahypothetical questions are about not entirely relevant features of the correct hypothesis (e.g. "Does it begin with the letter A?").

In the initial stages of the game, only experimental questions would be allowed; hypothetical questions would be considered only after a wealth of "experimentation" has been carried out. Metahypothetical questions might be disallowed entirely, except in one circumstance: if one is impressed by the significance of analogy in scientific discovery, one might accept such metahypothetical questions as "Is this case similar to the one we had in the section on circuits last week?"

Dreyfus and colleagues have used a strategy similar to that of explanation games to teach scientific concepts not previously understood by students. [9] As they formulate their "cognitive conflict" approach, it involves three stages of conceptual change: 1) Awareness; 2) Disequilibrium; 3) Reformulating. Thus, first a concept is presented, with the student being asked to develop a theory to explain it (Stage 1); then the instructor challenges the theory (Stage 2); finally, the student must look for new explanations (Stage 3).

When presented with the concept of selective permeability, for example, students theorize a variety of explanations for the phenomenon. Thus, some view the cell wall as a "sieve," or as having its own "brain," for example. The instructor must skilfully challenge the student until a logical, defendable theory is constructed.
Deductive Reasoning in Medical Education

Barrows and Tamblyn use a method of simulation similar to the explanation game. [10] They call it problem-based learning; it is also called the "McMaster System", as it was developed at McMaster University. They define problem-based learning as learning resulting from the process of working towards the understanding or resolution of a problem. To teach this, they have defined the steps involved in the reasoning processes used by experienced clinicians. Physicians must know how to build on the usually small amount of information given them when a patient first presents. In this first step, initial clues influence the direction and scope of the subsequent reasoning process. In Step 2, experienced physicians develop from two to five possible hypotheses. Students rarely realize that multiple hunches are actually preferred at this stage, feeling that the search for "one right answer" involves a narrow approach. Step 3 involves further data collection.

In Step 4 the broad variety of data must be encapsulated into a brief description of the patient's condition. Formal closure occurs in the final step, where this brief description is formalized - into a consultation note, progress note, problem-oriented record and so on.

Teaching Hypothetical/Deductive Reasoning in Radiologic Technology: Explanation Games and Other Classroom Methods

Roner and Ganiel use the conceptual equivalent of the explanation game in a class activity on the biologic effects of ionizing radiation. [11] It is designed to move the student from an "assumption of knowledge to knowledgeable considerations", that is, to render them able to ask the right questions about the topic. Based on a game they developed called "Beware - Radiation!", it is of direct relevance to radiologic technology education and will be described in some detail here.

Stage one of the activity takes about five minutes. The students fill out a game sheet/questionnaire asking them to rank the biologic effects of various activities (e.g. one chest x-ray a year; living next to a nuclear power plant). Stage two is a thirty minute lecture on radiation bioeffects.

In stage three, students must now attempt to quantify the exposures they ranked on the game sheet. This takes about ten minutes and is followed by another ten minute session (stage four) in which class discussion focuses on the "game results." In step five, another half-hour lecture focuses on problems of estimating biologic effects of radiation. The final step is a short class discussion of the "human" side of such issues.

In addition to forcing students to see the value side of science, this activity makes them see the need to ask, before forming or in modifying an opinion on scientific knowledge: What basic information do I need to help me form an informed judgement? Is my knowledge at that level? Where can I find the information I need?

The use of questionnaires in education to begin units of instruction is not a new concept, and has been described in the radiologic technology literature. Patient-care topics are also sometimes "difficult" to teach as science, technical issues, and values must be presented almost in the same
breath. Though this may be simply a prejudice of the authors, we do not see effective patient care as simply mechanistic in nature. Though teaching tasks is an important component of teaching patient care, it is difficult to believe that training students to do a right thing at a right time is the sole function of education in the profession. I (S.D.) used Palmore's facts on aging quiz (FAQ), which contains a variety of factual and attitudinal questions on the topic of aging, to begin instruction on the topic of aging. [12] Previously, I had found that both technologists and students tended to view the elderly either in terms of personal experiences (eg., grandparents) or early clinical experiences. The subsequent method of teaching used is similar to that of Ronen and Ganiel - 1) Appraisal; 2) Class discussion of results; 3) Lecture; 4) More class discussion; and 5) Reassessment. This method can also be viewed as a fusion of value clarification with factual presentation.

AIDS education is another topic that must focus on attitudinal and knowledge components, or science and values and their interconnection. Again, most students enter a classroom with AIDS "knowledge" which is really a combination of media (mis)information, personal prejudices, and folklore. [13],[14] The above approach has also been described as working well with this topic - first assessing knowledge and attitudes through a pre-test, then asking students to think about the reality they have constructed, followed by presenting facts, and then making them re-evaluate their viewpoints based on the facts presented. [15]

This is similar to Strauss's concept of two main categorizations of knowledge - Experience-bound or common-sense knowledge and Cultural knowledge.(16) Experience-bound knowledge is that which has come from living and is not reflective or analytical. Cultural knowledge seeks to go beyond the immediacy of personal experience, and is self-conscious, having been constructed from lab experiments or through reflection on theories.

To return to strictly "scientific" or "technical" topics, a final, perhaps radical, use of this concept will be presented here. The active nature of this approach has been described earlier, as well as the possibility of having students design their own experiments. In radiologic technology education, it is common to have students carry out "pre-packaged" experiments designed by the instructor or from a commercial lab workbook. These experiments "prove" topics covered in lecture such as the effects of Kvp on contrast. However, the question must be posed: If we do not give students any kind of autonomy in the educational setting, what does this mean for their own future autonomy, and indeed, the autonomy of the profession? True learning will come from experience and this entails risk-taking and learning from mistakes.

In my own program (S.D.), I have "thrown out" the lab workbooks. Students in courses such as physics and technique must develop their own labs. The format used corresponds to the reporting format used in scientific journals. In step one, students must read the relevant text material on the subject (Literature Review) and develop a research hypothesis (Methods). This, along with expected results, is submitted to the instructor for approval.

Step three involves actual lab performance, with students writing the Results and Conclusion section. This step, along with instructor review, involves peer review, a step implemented very hesitantly. Despite natural misgivings about peer review, it has proven to be of great value, with
students developing fair, professional critiques that strengthen the labs and show they know how to ask the right questions. Close parallels may be drawn between this method and the McMaster system, for obvious reasons; Table 1 shows this as well as a summary of the methods presented here.

Conclusion

Using the explanation game as a model, various metacognitive strategies were presented here for the radiologic technology instructor interested in promoting the "real-world" thinking skills of students. Topics such as "metacognition" and "critical thinking" will continue to be an important issue in higher education. The profession of radiologic technology, interested in graduating practitioners able to function autonomously in a variety of settings, will find attention to the strategies presented here of value.

References


### Table 1 - Summary of Metacognitive Strategies

<table>
<thead>
<tr>
<th>Explanation Game</th>
<th>Cognitive Conflict</th>
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<tbody>
<tr>
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<td>1. Awareness</td>
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<tr>
<td>2. Experimental questions</td>
<td>(uncovering</td>
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<tr>
<td>3. Hypothetical questions</td>
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<td>4. Results</td>
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<tr>
<td>McMaster Method</td>
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<tr>
<td>1. Clues to reasoning</td>
<td>1. Appraisal</td>
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<tr>
<td>2. Hypothesis Formulation</td>
<td>2. Presentation</td>
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<tr>
<td>3. Further data collection</td>
<td>3. Activity</td>
</tr>
<tr>
<td>4. Data synthesis (Patient condition)</td>
<td>4. Class discussion</td>
</tr>
<tr>
<td>5. Closure/formalization (e.g. consultation note)</td>
<td>5. Lecture</td>
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<tr>
<td>Patient Care Explanation Game</td>
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<tr>
<td>1. Appraisal</td>
<td>Lab Development Explanation Game</td>
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<tr>
<td>2. Class discussion of appraisal</td>
<td>1. Literature Review</td>
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<td>3. Lecture</td>
<td>2. Hypothesis formulation*</td>
</tr>
<tr>
<td>4. Class discussion</td>
<td>3. Instructor input</td>
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<tr>
<td>5. Reassessment</td>
<td>4. Lab performance</td>
</tr>
<tr>
<td></td>
<td>5. Results/Conclusion (peer review)</td>
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</table>

* Steps 1 and 2 may be preceded or followed by a presentation of relevant material.*