A Pedagogical Model for Nurturing Curiosity

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Abstract

Curiosity is widely regarded as a precursor to much investigation and learning. From science, where the first step of the scientific method is questioning, to successful business models, where Google's CEO Eric Schmidt says, "We run this company on questions, not answers," curiosity seems essential. Although the ability to ask meaningful and productive questions is often nurtured in early childhood and elementary STEM education, too often in the classrooms in higher education it is only the instructor who poses questions, leaving students little practice in developing their curiosity.

This paper presents an instructional strategy that nurtures student curiosity and improves their fluency in meaningful questioning over time. The intervention includes:

- *Classroom discussion of categories of questioning based on how we model the world around us;*
- *Intermittently inverting the questioning roles of instructor and student by requiring students to generate questions, not answers; and*
- *Subsequent demonstration of various categories of questioning using exemplars from peers and experts.*

This strategy has been used successfully with a wide range of topics and diverse learning situations, including an introductory physics lecture (500 students), an intermediate electricity and magnetism class for physics majors (60 students), an advanced engineering physics laboratory class (70 students), and a seminar series for graduate-level physics students (50 students). Although our application is in university science courses, the use of models to predict is ubiquitous and the technique may be applicable in other fields.

Beyond the discipline-specific advantages of gaining fluency and depth in questioning in science, we observe that such an emphasis on questioning also enhances student motivation about the content being discussed in class, it very likely increases metacognition, and it serves as a rich springboard from which to introduce content and/or address misconceptions.

1. Introduction

Curiosity is widely regarded as desirable in a learning environment. It is at the interface between cognitive and motivational psychology [1] and recent neuroscience evidence highlights the role of curiosity in preparing the brain for more effecitve learning [2]. Although the ability to ask meaningful questions is often nurtured in early childhood and elementary STEM education, too often in the classrooms of higher education it is only the instructor who poses questions, leaving students little practice in developing their curiosity.

A procedure for nurturing students' curiosity by increasing their abilities to ask productive questions was recently introduced [3]. This instructional strategy is expanded here with a more complete description, followed by two examples and a discussion of other considerations in effective implementation.

2. Description of Procedure

Learning relies on using models, heuristics, or schema, either formally or informally, to explain past observations and make sense of new ones. Based on a rich body of literature in educational psychology and learning theory, authors of the seminal book "How People Learn" conclude that "modeling practices can and should be fostered at every age and grade level" [4]. Such models are typically the content delivered in our courses, with the instructor presenting the best model that explains all observations up to that point.

The procedure to nurture curiosity is based on these models. Students are given a prompt that illustrates the consequences of a model they are studying, and practice asking questions about how their understanding relates to the model. The procedure is also founded on the principles that we learn both by watching others and by being given a procedure to follow, a combination often associated with

that of apprenticeship. Therefore, this procedure also provides an opportunity for students to ponder exemplar questions produced by experts and by their peers.
In overview, the iterative procedure includes:

- Classroom discussion of 6 categories of questioning based on how we model the world (Table 1);
- Provide students with a prompt (a demonstration, a video, a problem, an experiment, a photo, etc.) related to the model being studied;
- Students generate questions (not answers), which can be collected electronically or by paper and pencil;
- Subsequent demonstration of various categories of questioning using exemplars from peers and experts. This often helps students think about both the prompt and the questioning process in new ways and allows them to refine how they model the world.

CATEGORY	Purpose of question	Examples
INCONGRUOUS	To clarify seeming violations of a model or heuristic rule of how the world functions	Doesn't this violate a fundamental principle? Why does this happen?
CONGRUOUS	To further one's understanding of a model, or to gather information about how a model is applied	How do I calculate this effect using Newton's laws?
MODIFYING	To probe what happens when the assumptions, parts, applications, or parameters of the model or rule are changed	What happens if the temperature is not assumed to be constant? What if . . . ?
GENERALIZING/ ANALOGY	To see how one model relates to another	During an earthquake, do the plates slip when pressure generates melting at an interface, like a skate on ice? Is this like . . . ?
CAUSAL/ CREATIVE	To attempt to generate a new model, improve on an existing one, or search for novel patterns	If we model the moon as a viscous liquid, could that explain why the shape of its craters change with time?
INFORMATIONAL	To find information simply for its intrinsic interest or diagnostic purposes	When was the leaning tower of Pisa constructed?

Table 1. *Categories of Questions*

The categories of questions help students diversify their curiosity. Unlike Bloom's taxonomy of educational objectives, there is no hierarchy among the categories. The goal is to increase fluency in a given category and diversify the number of different categories about which a student becomes curious. Although there may be some overlap among these categories, where one could argue that a given question could be categorized differently, that should not be a distraction in the process.
This instructional strategy to nurture student curiosity has been used successfully with a wide range of topics and diverse learning situations. Following are two examples of implementation that differ dramatically in the audience targeted and in the models about which the students are to exhibit their curiosity.

3. Implementation in a Graduate Student Seminar

An editor from an academic publishing company presented a talk about the publishing process to approximately 50 graduate-level physics students, with the goal of improving the future publication success rate of attendees. The prompt, in this case, was the presentation by the speaker.
The model here is that research is completed, a manuscript is prepared, a prestigious journal is selected, the manuscript is submitted, the editor filters submitted manuscripts, referees evaluate manuscripts, a dialogue occurs between the referees and authors, either the reader or the author pays for publication, and quality assessment is determined via subsequent citations of the paper.
The following are some of the responses submitted by the graduate students:
INCONGRUOUS: "What would cause you to choose to submit to a journal whose prestige is high but is not as well related to your research?"

CONGRUOUS: “Peer review presumes that the best way to assess new knowledge/research is to have it validated by experts in the field. How does this handle revolutionary knowledge or knowledge which may be well performed but not popular?”
MODIFYING: “Are there journals that use a double-blind/blind way of reviewing articles to try to avoid reviewer bias or name bias?”
GENERALIZING/ANALOGY: No questions submitted from this category.
CAUSAL/CREATIVE: “Is there still an importance in using a journal as a claim to originality in the time of arXiv?”
INFORMATIONAL: “How is prestige/reputation different from impact factor?”
Expert questions generated by faculty in the audience included:
INCONGRUOUS: “Why would anyone publish this way rather than in a free open access journal?”
CONGRUOUS: “How do you form a cadre of good referees if they are not paid?”
MODIFYING: “Why aren’t the identities of both reviewer and author anonymous?”
GENERALIZING/ANALOGY: “Do large companies disseminate information in a similar manner?”
CAUSAL/CREATIVE: “Why can’t each department review and publish work from its own faculty rather than use a journal?”
INFORMATIONAL: “Does the number of reviewers vary with the field?”

4. Implementation in an Introductory Physics Class

Another illustration is from an introductory physics class studying pendulum motion. There were 454 students responding to the prompt: a video showing the motion of multiple pendulums, each of different lengths, which were released at the same angle and at the same time (https://www.youtube.com/watch?v=yVkdfJ9PkRQ). The model in this case is Newton's laws.
Some questions submitted by the students are:
INCONGRUOUS: “Why does this happen?” “How did they fake this video?”
CONGRUOUS: “How do I write Newton's laws for a pendulum?”
MODIFYING: “What would happen if the balls started at a greater angle?”
GENERALIZING/ANALOGY: No questions submitted from this category.
CAUSAL/CREATIVE: “How would air friction change the motion?”
INFORMATIONAL: “Are all the balls identical?”
Students’ questions provide insights into their thinking. For example, the incongruous category questions above indicate that students either don't understand the model (Newton's laws), can't apply the model to anything other than a homework problem, or suspect the model doesn't match reality.
Expert questions (generated by faculty) include:
INCONGRUOUS: “Why do they come in synchrony, since large amplitude motion is not harmonic?”
CONGRUOUS: “How do you calculate the effect of the string stretching?”
MODIFYING: “Would the same effect occur with masses suspended from springs?”
GENERALIZING/ANALOGY: “Is this similar to the alignment of the planets?”
CAUSAL/CREATIVE: “How is the motion affected by special relativity?”
INFORMATIONAL: “To what accuracy are the pendulum lengths known?”
In both of these examples, a synopsis of student and expert questions, along with a discussion of the questions, was sent to the students via email after class. This is an effective mechanism for implementing this instructional strategy in situations limited by time constraints.

5. Successful Implementation

This instructional strategy has advantages beyond increased fluency in curiosity. The process likely increases student metacognition. Once curiosity is aroused, students are more motivated to learn. The questions students generate often provide rich springboards for class discussions, or reveal misconceptions in student understanding that can be addressed during the learning process. The process also provides an opportunity for students to become more aware of and practice higher-level thinking skills, which leads to questions of greater depth.
Care should be taken to ensure that content is explicitly presented in the context of models. Otherwise, students tend to see the subject as a menu of equations from which the “right one” must be chosen.
Answering the questions generated by the students is not necessarily part of this procedure; instructor discretion may be used regarding further discussion of selected questions to improve student understanding of the model. Because of the expert/apprentice nature of this strategy, students will benefit from observing the instructor sort through the questions generated to glean those of greatest interest to an expert.

Students are more receptive to this strategy if they know why they are doing it. Possible learning goals include to improve fluency in asking productive questions, to become more aware of the model being taught, to understand its limitations, to challenge its assumptions, and/or to increase student motivation to learn. A low-stakes environment, perhaps with participation credit awarded, also makes students more receptive.

In STEM, asking productive questions is an important workplace skill. Students exposed to this instructional strategy have returned to campus, enthusiastic about its usefulness in their employment or graduate school research. Rather than a brief exposure, this instructional strategy will have a longer-lasting impact if it is implemented periodically throughout a course, providing time to nurture curiosity in a variety of contexts and demonstrate to students the value of curiosity. With practice, students increase both the number of questions they ask in a given category and the diversity of categories of questions. Even when students become fluent, however, time must be provided for them to generate questions. Some students may benefit from the use of random input or concept maps.

To help students learn to generate productive questions that can help them solve a problem or invent a new product, it is important to create a safe environment for them during this instructional strategy. Negative criticism should be minimized when the questions are being shared. Instead, the instructor can practice positive criticism by asking what is good about a question, or how the question makes one think in new ways.

6. Summary

Student curiosity can be nurtured in the classroom. The procedure described is based on how we explain past observations and make sense of new ones with models. It involves students asking (rather than answering) questions and encourages fluency and diversity in questioning. Two examples, from graduate and undergraduate courses, illustrate the technique. Considerations for implementation are also discussed. Although our application is in university science courses, the use of models to predict and understand is ubiquitous and the technique may be applicable in other fields. This instructional strategy is appropriate for both content delivery (*i.e.,* in “lecture” courses) and for ideation (*i.e.,* in design courses).

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