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WHAT VIEW OF SCIENCE DISCOVERY BEST FITS THE SCIENCE LEARNING GAME?

Abstract:

This paper presents a view of science discovery that has the potential to change the way we construct learning games in science. This view is based on the work of a nineteenth century philosopher and scientist whose work, supported by a new generation of historians of science, counters the traditional view of scientific discovery as induction--the notion that new ideas are built from the bottom up so to speak, from particular experience to general concept. The alternative to this view is one that insists that scientific discovery is an "ideas first" leap of creative understanding termed "abduction." It proceeds as follows: (1) A surprising fact, C, presents itself to an individual; (2) a big idea (H) is then suggested that, if true, would render C a matter of course; (3) this then leads the individual to conclude that there is reason to believe that H is true. This view of knowledge, we will argue, complements efforts to bolster the educative aspect of a game in a way that contributes to, rather than detracts from, the all important immersive aspect of that same game.

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With games being increasingly recognized as formats for legitimate curriculum in education, the desire to develop curriculum in the STEM content areas has kept pace with this view. There is a growing belief, in other words, that games can be both educative **and** engaging. The second characteristic, engagement, encompasses the two traits of being interactive and plain old fun. The trick in combining education with immersion, particularly as it relates to designing games that teach core concepts in science and mathematics is, it must be emphasized, no easy task. The purpose of this paper is to highlight one of the ways this task can be carried out. It draws heavily on the experience of the first author, who studies STEM related educational issues, and the second author, who is an independent game developer and a major consultant on a STEM related, federally funded game project.

What both authors bring to the discussion of educational games is a belief in the role that technology can play, even in an immersive game environment, in promoting understanding of powerful core content in all disciplines taught at the K-12 level and beyond—and especially in science and mathematics. Immersive technology, we believe, can create problematic opportunities that encourage children to want to know more about the particular situation—especially as it relates to the disciplinary big ideas that help explain the situation. In history, this may involve a brief portrayal of a well-known historical situation—like the fall of the Alamo—as viewed from an unfamiliar (i.e., Mexican) perspective. A disciplinary big idea that might emerge from immersive student interactions with this portrayal is the notion of "history as story—told from a particular perspective and with a unique set of heroes and villains. What makes the approach we advocate different then most that rely on technology to mediate teaching and learning in disciplinary areas is the unique perspective we bring to bear on the pedagogical process.

This view assigns top priority to the concept of pedagogical content knowledge. Pedagogical content knowledge (PCK) represents knowledge of content **for teaching** and thus is distinct from content knowledge per se, which is typically measured by performance on subject-matter tests (Shulman, 1986, p. 9). Lee Shulman, the person who originated this concept, insisted on one further stipulation which we have found extraordinarily helpful in thinking through our approach to games: This is the notion that PCK assumes that ideas are the unit of analysis. Teaching, Shulman wrote, is at its core the "exchange of ideas." Teachers who appreciate the role of big ideas in disciplinary knowledge, research demonstrates, bring a unique perspective to bear in thinking about the role of knowledge (Prawat, 1993). They appear to value knowledge as a transformative rather than what might be termed a merely **in**formative interaction with the world. The informative approach, in its most enlightened, constructivist form, still views knowledge as primarily instrumental in nature. Knowledge informs the individuals about situations they encounter that are potentially problematic in the sense that they block progress toward important goals. Knowledge thus helps people figure out and deal with problematic situations.

A problematic situation, by definition, is complex for the individual who is trying to make sense of it. This is especially the case in those problem situations that require disciplinary knowledge to unravel. The preferred approach in science education to the problem of making sense of this type of situation is the process known as "discovery learning;" this process is typically viewed as a "facts first, concepts later" boot strapping operation. The approach, which drives at lot of progressive alternatives to traditional text-based curricular material, places a special burden on the student—a large part of which is the fact that it views the role of knowledge as being essentially negative in nature. Knowledge is a tool that enables us to deal with obstacles or difficulties in life. Thus, students are told that they have to learn the valuable task of taking number apart and putting it back together in early elementary school so that they can avoid being in a real life problem situation like that of being cheated by the corner grocer.

There is a second, nontraditional way of thinking about the role of disciplinary knowledge in a person's life. Big ideas developed in the disciplines can open up new elements or facets of the world to the novice learner. They make life more interesting. Shulman writes that a trait shared by teachers who value pedagogical content knowledge is that of turning ideas around in their heads. Not only do these teachers examine

ideas, they take them for a ride so to speak. An example might be reflecting on the notion in biology that structure dictates function, and then seeing how many specific things in and outside the domain of biology can be viewed through the lens provided by this idea. It is big ideas developed within disciplines, according to Goodwin (1994, p. 608), that allow those in different professions to transform the world into what he calls the "phenomenal categories" that make up their work environment. Disciplinary ideas can thus open one up to the power of possibility.

This view of knowledge insists that scientific discovery is an "ideas first" leap of creative understanding termed "abduction." This notion is now widely accepted by science historians who discard the notion that great minds like Darwin or Einstein discovered their groundbreaking new ideas as a result of a fact and pattern finding process. (On his voyage to the Galapagos, Darwin failed to note which islands the particular finches came from [Weiner, 1995, p. 25].) Science historians, drawing on the unofficial record, now understand that theories like Darwin's emerged from an act of creative intelligence so dramatic that it represented, according to Jacob Bronowski, an "explosion" of thought (R. Root-Bernstein & M. Root-Bernstein, 1999, p. 145). One of Darwin's notions, that of nature selecting, developed in his mind as a metaphor. Being an English countryman, Darwin was well acquainted with the notion that man can create new species (i.e., of dogs and sheep) through selective breeding. This metaphor, he realized, was the perfect lens for viewing a process that created species.

Teachers who appreciate the power of disciplinary ideas must, at least implicitly, share this second view of knowledge discovery: That is, that it represents a creative insight

that points to an important regularity in the world. We have contrasted the approach to teaching and learning that best fits this view of knowledge as a hybrid of the two divergent roles, the "guide on the side" and the "sage on the stage." The teacher who

fully appreciates the eye-opening role that ideas play in a student's life would be less likely to see the value in either extreme—passive guidance or frontal presentation—as

it relates to the presentation of powerful concepts in the classroom. The teacher's inclination would be to use big ideas to foster a transactive relationship between students

and world. This notion fits well with Shulman's concept of pedagogical content knowledge (PCK).

The teacher's role in the above scenario is more like that of a tour guide, a "sage on the side" in other words (or, more properly, "a sage *along*side"). This sort of PCK-oriented

teacher is excited about the specifics of what his or her professional vision reveals about important aspects of the world. As a result, he or she is eager to equip students with a similar set of lens. These disciplinary lenses connect students, and teachers, to important regularities in the world. Once this "transaction" occurs it allows the non-professional to experience phenomena in a way akin to how professionals in the discipline experience it. The sense of excitement that results can be similar, if not identical, to that experienced by those who achieve an important objective in an immersive game.

Two Examples of the Use of PCK in the Development of Educative Games

As indicated, Theodore, one of co-authors of this paper, worked as a game consultant on a large NIH game development project. One of the early steps in this process involved the development of math and science guides for teachers and students. Theodore urged the project managers to entertain the possibility of using a "big ideas" approach in this regard. This process began with identifying the core aspects of subject matter knowledge that are vital to an expert (i.e., a scientist) who, it is recognized, makes use of this knowledge in their field everyday. One example presented in the guides was, not surprisingly, also a focal area in one of the games that was developed--environmental science: This was the idea that our everyday air is full of particulate matter. This was an eye opening big idea for most middle school level students, who may have never before realized that our air, every minute of every hour, contains thousands upon thousands of airborne particles.

A second powerful idea, closely related to the notion that air is full of particulate matter, is also a common core standard at the middle school level: This is the notion that quantities of air, like quantities of water, differ in the amount of particulate matter they contain. This idea, it was decided after some discussion, might give rise to a number of questions in students' minds about how scientists go about measuring air quality. One obvious one relates to the kinds of containers scientists use for this purpose. Are circular containers, for instance, more useful for storing or moving air than square ones? Students are likely to have noticed that pipes used to move fluids are circular rather than square. are circircular types of containers like pipes are used more often than square pipes for moving air—and other fluid substances like water or oil? There is less friction—more "room to move"—for the particles that make up fluids in round pipes. In scientific terms, the particles spread out in an "asymmetrical" way in square pipes.

The issue of how one measures air quality is part of a complex overall problem situation, as our analysis of the big ideas involved in understanding the situation indicates. One test of the extent of the complexity of the problem is the breadth of the disciplinary knowledge that might be brought to bear on it. The people in charge of the NIH project wanted to push this notion in their game: They suggested that Archimedes great discovery about circles could be added to the mix. Two thousand years ago, this ancient Greek mathematician developed a geometric principle that explains the relationship between circles and squares (or other non-circular shapes). Archimedes' big idea, states that, "Among all two-dimensional geometrical shapes with the same perimeter (i.e., same size outer boundary) the circle has the largest area." It is a circular shape, in other words--as opposed to a non-circular shape with the same perimeter--that provides the most "room to move" (i.e., area). Archimedes proved that this was the case by bringing logic to bear: First, he estimated the area of a circle by creating different size polygons which consisted of a series of identically shaped triangles arrayed around a common point.

By measuring and comparing the perimeters of polygons just inside and just outside a circle, Archimedes was able to estimate the size of the circle by comparing figures where the circles encompassed the polygons with those where the obverse was true—that is, the polygon encompassed the circle. Comparing formulas for the two "encompassing" variables allowed him to derive the formula for measuring the area of a circle—which was the first step in computing the area for a cylinder or balloon. Knowing how to compute the area of circles and cylinders was a godsend for engineers faced, with, for example, solving a number of area versus boundary issues (e.g., constructing strong pillars to support a building).

This test of the depth of knowledge issue as it relates to the problem of air quality is relevant to a second pragmatic question that those who seek to develop games that are both educative and engaging must confront. How do game developers hold students' attention in a context that must, by definition, be immersive (i.e., interactive and goal oriented) while, at the same time focusing their attention on hard to learn common core science and mathematics standards? This is the sixty-four thousand dollar question. There are two possible responses to the question: First, game developers, assuming they take care in the selection of the problem situations they present to students, must rely on the power of those situations to evoke interest. The two criteria that most relate to the power of the situation, in our opinion, are aspects of the graphic interface that are often seen as disparate: They should be real but also, in as far as possible, imaginative as well. If gamers are looking for a classic example of what this means, at least as it relates to the characters in a game, they need go no further than Maurice Sendak' monsters with human feet in his fifty year old award winning children's book, *Where the Wild Things Are* (2012, Harper & Collins).

A second response to the sixty-four thousand dollar question is that the game developers must also trust in the power of each problem situation to evoke ideas that reveal new insights about the nature of the situation. The problem here is that presentation of ideas, and the students ability to interact with those ideas through quick responses to verbal or visual stimuli should not interfere with the students progression through the game. In other words, the educative and immersive aspects of the game should go hand in hand. Hopefully, the air quality example shows that complex problem situations can be used as an occasion to bring to the fore a number of big ideas in science, math, or other disciplines, all of which shed light on aspects of the particular problems and thus provide the knowledge necessary to suggest possible courses of action—possible solutions—in response to those problems. In a game context, it is the connections between ideas that allow one to connect the diverse responses of students.

A second, brief example will be presented. The idea presented in this example is one of the core science standards presented on page 188 of a document published by the National Academies Press (i.e., *A Framework for K-12 Science Education: Practices, Cross-Cutting Concepts, and Core Ideas* [2012]). The standard is described this way: "The foundation for Earth's global climate system is the electromagnetic radiation from the sun as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems and this energy's re-radiation into space. **The earth absorbs and stores large amounts of energy from the sun during the day and releases it very slowly over the nighttime hours."** This standard, somewhat surprisingly, is listed as one that the students were expected to master at the end of grade 12. In focus group testing, we have been able to demonstrate that students are able to grasp this concept at the end of fifth grade. We will describe the game approach we used in a brief prototype example of the larger game we plan to develop.

In the first step in the process of teaching this particular big idea, following the abductive process outlined in the abstract, students are presented with a doubtful situation—one that involves an event they think they understand but that they soon discover is more complicated than originally thought. To achieve this goal he began the segment of the game that deals with this standard with a question--**When is it coldest during the 24-hour cycle of day and night?--**followed by a three item multiple-choice question: "It is coldest during the 24-hour cycle in (A) midnight; (B) sunset; (C) sunrise**.** Almost all of our fifth grade students in the focus group testing chose choice "A" (midnight) first, followed by, when that choice exploded into nothingness in the prototype game segment, choice "B." These students apparently did not understand the fact that the earth, during the day, absorbs and stores energy from the sun and then through slowly releases it during the nighttime hours.

Students may understand the first part of this problem situation—the slow build-up of energy during the day. The second part is harder for them to grasp: The notion that the earth, once the sun goes down, then slowly releases this energy. It may be that they rely on their own personal experience and it can get in the way of understanding. Students know that, when the sun is shining, THEY feel the warmest at noon. It is logical for many students to assume, therefore, that they would then feel the coldest at midnight. Putting these two ideas together appears to explain why many students respond "midnight" to the question, "When is it coldest during the twenty-hour cycle?"

Following the "abductive" model described in the abstract, posing the question relating to the coldest part of the 24-hour cycle and then providing students with the correct answer, "just before sunrise," creates a perfect learning situation- Students often ask themselves how this can be. Why is it coldest just before dawn? Three relatively uninteresting events—sunset, midnight, and sunrise—suddenly become interesting, even confusing, aspects of a situation. Given the fact that the self-evident response, "midnight," is incorrect creates the "teachable moment" that opens students' eyes to a new, even exciting regularity in the world: The fact that, during the nighttime hours, the earth slowly releases the energy obtained during the day from the sun.

In the example presented here, a context is provided for the metaphor (a boiling pot of water with the fire turned off) that, based on focus group results, almost immediately enlightens students about the process of energy absorption in a way that allows them to reconcile their confusion about the reason that "sunrise" is the correct answer. It sets the stage for this sudden realization (abduction) by presenting them with a brief written and oral statement: "Now look at these two images—A on the right and B on the left. Pick the one that best explains the answer to the question you were just asked." Two possible instantiations, one of which points the way to the correct solution, next appear on the video game's screenshot: The first, a light switch being turned off, suggests a simple relationship between the sun going down (the light being "turned off") and the earth getting cold. The second suggests a more complex relationship. This is the depiction of a pot of water on a stove that contains a large thermometer. When they turn the fire beneath the pot off, the students notice that the amount of heat shown on the thermometer slowly dissipates. Image B, most decide, is a better illustration of what is happening when energy from the sun is slowly released from the earth at night.

This second brief example is an attempt to illustrate how sudden metaphoric insight can create an understanding that transforms how a student (or a scientist) views an important phenomenon like weather in a relatively short amount of time. In a sense, this example highlights the fact that ideas originate as iconic or perceptual metaphors. Archimedes, to cite another example, had a sudden realization that the volume of irregular shaped objects could be measured by immersion in water, an insight that came to him in the midst of a bath, with his own body serving as a physical metaphor for the new idea. The suggestion here is that "idea tools" like the one used in the second example (i.e., the boiling pot of water) could be used to plant the seeds of an idea about a problem situation.

Metaphor or analogy is the mothers' milk of pedagogical content knowledge. Representations of big ideas in the content areas (PCK), and the kind of quick responses to those representations used in the second example, could provide the answer to the question of how game teach and students move on within goal oriented, interactive and educative games. In a sense, the second example augments the first: The first highlights the importance of carefully thinking through the network of scientific (or other disciplinary related) ideas that identify regularities in the problem situations (e.g., particulate matter in "bad air"); the second highlights the role of abduction, defined in the classroom as the leap of understanding made possible by teachers skillful use of representations. Together, we believe, the two examples provide valuable lessons for game developers who recognize the difficulties, as we have emphasized in this paper, of trying to effect a balance between education and engagement in game design.

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