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ABSTRACT

Most middle school science curriculum has been created to provide superficial treatment of the different subject areas (earth, life, and physical science), and in-depth coverage of very little. The Third International Mathematics and Science Study (TIMSS) criticism of the typical American school curriculum is that it is a "mile wide and an inch deep." In contrast, "Energy in the Human Body" is an in-depth investigation of cellular respiration that is based on the National Science Education Standards. It was designed using the latest research on how students learn and develop mental models. This information was used to develop methods for helping students learn material of fundamental importance to Biology. This paper attempts to demonstrate how "Energy in the Human Body" has maintained the use of an inquiry-based approach into its curriculum. (Contains 27 references.) (MVL)

Keeping the Inquiry in Curriculum Designed To Help Students' Conceptual Understanding of Cellular Respiration

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KEEPING THE INQUIRY IN CURRICULUM DESIGNED TO HELP STUDENTS' CONCEPTUAL UNDERSTANDING OF CELLULAR RESPIRATION

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The National Research Council (NRC) (1996, 2000) endorses science curricula that actively engage students in science using an inquiry-based approach. This approach has shifted the focus of science education from the traditional memorization of facts and concepts in separate specific disciplines to inquiry-based learning in which students seek answers to questions that are driven by the learners' own curiosity, wonder, interest, or passion to understand and/or solve a problem (National Science Foundation, 1999). The pedagogy advocated for is an inquiry approach, in which students are actively engaged using both science processes and critical thinking skills as they search for answers. The National Science Education Standards (NSES), developed by the NRC in 1996, define inquiry in education as: "Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other source of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations and communicating the results. Inquiry requires identification of assumptions, use of critical thinking, and consideration of alternative explanation." (p.23)

According to the NSES, there are five essential features of classroom inquiry: 1) learners are engaged by scientifically oriented questions, 2) learners give priority to evidence, which allows them to develop and evaluate explanations that address the questions, 3) learners formulate explanations from the evidence to address the scientifically oriented questions, 4) learners evaluate their explanations in light of alternative explanations, particularly those that reflect scientific understanding, and 5) learners communicate and justify their explanations (NRC, 2000). Science education reform calls for inquiry-based teaching methods that enable students to contribute their own ideas and to pursue their own investigations.

Inquiry begins when students are puzzled about some event or object, and then design and carry out an experiment to test their hypothesis. The process involves all the activities that a 'real scientist' uses to find information such as hypothesizing, conjecturing, reading, designing experiments, experimenting, collaborating with others, etc. Discourse is a means for inquiry, exploration, even activity, and expression of concepts. Using this approach requires that data be gathered, and interpreted. Students are required to draw conclusions based on the evidence they gather. The information learned through carrying out these investigations provides the opportunity for students to communicate their data and justify their conclusions. This in turn provides a means for students to get feedback from their peers, as well as the teacher, which can lead to students modifying their conclusions (this mimics the real scientific community). Research has shown that students, who carry out investigations to test their own ideas, or mental models, are much more likely to understand and retain the concepts learned.

Inquiry occurs when students are allowed to seek answers to questions for which they do not have answers. This does not mean that students have to discover everything on their own. As long as students are unaware of the relationships being investigated, students are carrying out inquiry-based science. Inquiry-based teaching begins with teachers who are willing to start with what students already know or "think they know" and to take the time needed to understand with what they are struggling. David Hawkins, philosopher of science has said that teachers must try to understand "the map" of children's minds (Hawkins, 1974). By carefully observing and listening, as students take part in investigations and discussions, teachers can come closer to knowing what students' conceptions or mental models are, as well as where they are struggling. Science is a social process, in which knowledge is constructed as students and teachers dialogue their understanding of science concepts with one other (Newton, Driver, & Osborne, 1999). The teachers' role is to drive the dialogue to the more scientific understanding.

Research has shown that alternative conceptions, or students' mental models, in science are often very difficult to overcome (Arnaudin, & Mintzes, 1985; Bishop, Roth, Anderson, 1986; Clement & Rea-Ramirez, 1997; Mintzes, 1984; Mintzes & Arnaudin, 1984; Sanders, 1993; Seymour & Longden, 1991; Songer & Mintzes, 1994, Rea-Ramirez & Clement, 1997; Rea-Ramirez, 1998). Learning is complex; it involves many changes in students' models as teachers and students work together to construct intermediate mental models (Buckley, 2000; Clement, 1989; Clement, 2000; Gobert, 2000; Gobert & Buckley, 2000; Harrison, 2000; Justi & Gilbert, 2000; Rea-Ramirez, 1999; Snyder, 2000; Steinberg & Clement, 1997). In the co-construction process, teachers guide students thinking through dialogue. Instead of presenting students with the scientific explanation, teachers build upon students' mental models. Teachers become a partner that guides the student in the co-construction of knowledge (Rea-Ramirez, 1998). In the process, teachers can use discrepant questioning to cause cognitive dissonance, which is required if students are going to modify their views (Clement & Rea-Ramirez, 1997).

Most middle school science curriculum has been created to provide superficial treatment of the different subject areas (earth, life and physical science), and in-depth coverage of very little. The Third International Mathematics and Science Study (TIMMS) criticism of the typical American school curriculum is that it is a "mile wide and an inch deep" (Schmidt, McKnight, and Raizen, 1997, p. 122). In contrast, "Energy in the Human Body" is an in-depth investigation of cellular respiration that is based on the National Science Education Standards. In this paper I will attempt to demonstrate how "Energy in the Human Body" has maintained the use of an inquiry-based approach into its curriculum.

Background

"Energy and the Human Body" is based on the NSES and many State Curriculum Frameworks in the area of middle school life science. It was designed using the latest research on how students learn and develop mental models. This information was used to develop methods for helping students learn material of fundamental importance to Biology. A cohort of dedicated classroom teachers and researchers who had many years of classroom teaching experience created the curriculum, which is based on sound theory and practical application that takes into account the developmental abilities of a variety of students.

In this curriculum, students learn about how their own body uses the energy they get from food. They learn why we breathe in oxygen, and breathe out carbon dioxide. They learn fundamental information about how their body works. Most importantly, they learn why their bodies are designed the way they are. Instead of memorizing vocabulary, students learn concepts of fundamental importance in later learning. Students have the chance to relate structure and function to help them understand how the way a part of the body is structured relates to the way it works.

Students are taught for deep conceptual understanding, through active involvement, using the knowledge they already have to construct new understandings. Teachers provide help in the form of questions that provoke thinking, as well as using analogies, demonstrations, hands-on science experiences, videos, computer animations, discussions, and student drawings to promote model construction. Teachers use the following series of steps to help students construct deeper understanding:

- Ask students what they already know
- Pose an open-ended question
- Have students think about the question, than share and compare the results of their thinking with others
- Have students discuss their ideas and come to consensus
- Challenge students' conceptual understanding using discrepant explanations
- Have students complete and articulate/draw their models
- Present the scientific model
- Have students complete their model revision by articulating/drawing their final understanding
- Have students compare their initial models with their final models
- Have students apply their knowledge to new situations

Throughout the curriculum students are engaged in small group work/cooperative learning. When students work in small groups/ cooperative groups they have the opportunity to present their ideas to each other and discuss them together. This helps students clarify their own understanding as they learn from one another. In addition, students are asked to draw their "mental models", this helps students clarify their thinking and it helps them create an image that can be revised. At times teachers' present misconceptions (wrong ideas) and through the use of discrepant questioning help students see the flaws in the misconception. At other times, teacher may use analogies to help students' ideas about difficult or unfamiliar concepts. This allows students to use ideas they already have to understand new ideas. In addition, teachers and students discuss the relevance of what students are learning to "personal life", this helps students see the usefulness of this curriculum to their real lives. Lastly, teachers use videos, animations, and other graphics to help students see the scientific model.

Inquiry in the Curriculum

Some of the ways "Energy in the Human Body" fosters an inquiry or 'active learning' approach:

- Students generate and improve initial models before the teacher presents the scientific model
- Discrepant questioning leads to student criticism and modification of models
- Learning through analogies, where students help flesh out the mapping or correspondence within an analogy
- Small and large group discussions

All of the above activities go far beyond a rote learning approach in their emphasis on student thinking as a means to learning science. "Energy in the Human Body" was designed to build upon students' prior knowledge. Students are constantly required to state their own mental models about how the human body works. As new information is presented it is interpreted through students' existing mental models.

At times students need to be made aware of discrepant information. It is possible for students to have simultaneous ideas that are contradictory. Only through reflection upon one's own thinking can change occur. With this in mind, this curriculum was designed to help students develop deeper understanding of cellular respiration through continually reflecting on their own mental models. In addition, students who use this curriculum are taught to value open-mindedness (a willingness to change ideas in light of contradictory evidence). This habit of mind is taught to students as they use this curriculum. As students use "Energy in the Human Body" they take on some of the attributes (values, attitudes and ways of thinking) associated with our scientific community. Through repeated occasions of social interaction with others (their peers, as well as the teacher) students collectively come to understand a phenomena or event as they explore cellular respiration.

Throughout this curriculum students are engaged in the process of inquiry (like real scientist) as they make predictions, classify, formulate models, make inferences, observe and measure, and interpret data. Lastly, the curriculum gives suggestions for individual and small group work that can give students experience with independent investigations.

Images of Inquiry Throughout the Curriculum

Chapter 1: Students start off by discussing different sources of energy that are used in everyday life to run things such as cars, lights, and household appliances. From there they move on to discuss the source of energy for their own bodies. They are asked to draw a model of what happens in their bodies as they exercise. They discover through classroom discourse that the body needs energy for all body processes. The teacher uses questioning strategies to provide scaffolding for students to build their own understanding. In addition, students working in groups also ask each other questions as they try to make sense out of each other ideas. The teacher acts as a facilitator, as students are actively involved and responsible for their own learning. Classroom discourse is an important component in the development of metacognition; students vocalizing their ideas may cause them to see the need to change their mental models.

Chapter 2: Students are asked to draw a model of what happens to food in their bodies. Drawing helps students clarify their thinking and helps them create an image or mental model. Working in small groups they discuss their models and come to consensus. Sharing with others causes students to reflect on their own model (metacognition) and others' models, which can result in restructuring their models. They discuss what food is made of and how it is broken down in the body. They learn that glucose is the source of energy for the human body. They are presented computer animations of the digestive system, which shows the path that food takes through our bodies as well as what happens at each site. One can consider the information presented in the animation as a type of alternative explanation (as some scientific explanations change over time as new information is uncovered). Students evaluate their models in light of the current scientific explanation. Working in small groups students discuss and justify their current model to their peers.

Chapter 3: Students are given a mystery box to find out how scientists learn about things that cannot be seen directly. The hands-on activity gets students interested in the topic and introduces some concepts that will be useful later. Students are asked to draw models that represent different kinds of cells (heart, muscle and skin) in the body. This gives students a chance to get their ideas on paper, and it allows teachers to find out what students already know. As students share their models with one another they are required to justify their ideas. Throughout the curriculum teachers are encouraged to use "what if" questions to help students construct new mental models. An example of a "what if" question that might be used by the teacher is: *"What if I could take a very thin section of the heart tissue – what would you see?"* Through the use of analogies (ear of corn and block wall) students discover that cells are found in patterned configurations in tissue. Analogies help give students ideas about difficult or unfamiliar concepts. Students learn they can use ideas they already have to help them understand new ideas. Analogies may help students generate new understandings of their ideas or mental models. They use a microscope to discover that cells are microscopic. The analogies used prior to using the microscope help students make sense of what they are looking at.

Chapter 4: Students are shown pictures of different kinds of cells (muscle, nerve, and skin). They are asked to compare and contrast these cells. They discover that cells have many common internal structures. Through the use of the "school analogy" students learn that structures inside cells have specific functions. The following "what if" question was used with a class of students to encourage model development through mapping and analogy and the cell: *"Look back at your drawing of the cell as if it were a school. In that model you said there would be chaos if you only had one big room where all the classes and gym and band took place. What if you and only had one big open space in the cell where everything took place?"* Questions like this make students think about their models and help them develop a deeper understanding. Questions in this curriculum rarely ask for factual information in the form of simple recall or memorized facts but rather encourage students to think deeper, to apply what they are envisioning. Students are asked to develop their own analogy for a cell and describe its similarities to a cell while giving the function of each major organelle. Students share their analogies with others. To assess their current understanding students are asked to create a three-dimensional model of a cell found in the human body, and write a story about being small enough to travel inside their cell. Students are given a rubric that shows how they will be graded on their projects.

Chapter 5: Through classroom discourse and small group work students discuss what cells need energy for. The exchange of ideas among students makes students' thinking available for inspection, and allows students to use their talk as a tool for thinking and communicating. Questions are used to help students recall prior experiences about what is needed for a fire to burn. Through the use of a "fire analogy" students discover that glucose if fuel for cells. The "popper simulation" helps students understand that when glucose is broken down in cells that energy is released which the cell can use for its needs. An animation is used that introduces the scientific model of how energy is released in the mitochondria. Students revisit their earlier model of mitochondria and revise it to incorporate newly presented information. Next, students construct a model of the structure of the mitochondria, to help them understand the importance of surface area of the inner membrane. This unit is culminated when students create a travel brochure about travel to the center of a cell. This activity allows students to demonstrate their understanding of cells in a variety of ways including writing, an important tool of communication in science.

Chapter 6: Students draw models that depict their understanding of how oxygen and glucose are delivered to cells, and how carbon dioxide (a waste product) is removed from cells. Drawing models allows students to contribute their own ideas. Working in small groups they come up with a consensus model. The teacher shows them an animation about how blood circulates in the body. The animation is a springboard for classroom discourse. If students cling to the misconception that the circulatory system is an open system, teachers are encouraged to use discrepant questions and more analogies to help students understand that it is a closed system. Students revise their models to incorporate new information that may have been presented. Next, the "river delta" and "water pipe" analogies are used to help students understand the function and structure of different types of blood vessels. Analogies are a way for teachers to humanize science. Teachers use analogies to help clarify an idea, or develop a concept, which may lead students to revising their mental models. An animation of blood vessels is used to present the scientific model. Classroom discourse and small group work allows students to criticize and revise their own models. The scientific model is not introduced until students have had the opportunity to work through their own ideas about how this model might work. Students conduct hands-on investigations to learn about diffusion, which helps them understand how glucose moves from the blood into cells.

Chapter 7: Students draw models that show how oxygen gets from the air they breathe into their cells. Drawing helps students make their models more accessible. Working in small groups they come to consensus. All students in the group are required to be able to defend their model. Next, they draw models of their understanding of the structure and function of the lungs. Through discussions with others students learn that others may have different models, this may lead some to revise their own models. They conduct hands-on activities to measure the volume of air in their lungs and use this information to revise their models. Mathematics is used to calculate surface area. The "grape analogy" is used to help students think about the structure of the lungs. After students examine pig's lungs they criticize and revise their own models. An animation is used to present respiration. It is important to note that students do not give up their models just because they have been presented with the scientific model. In order for students to revise their models they must see that their model cannot be used to explain certain situations.

Chapter 8: Students draw models of how the heart and lungs work together to deliver oxygen, and glucose to cells and carbon dioxide away from cells. Students are encouraged to challenge each other's models to see if they have flaws in them. Working in small groups they come to consensus. Students are asked to design a heart that transports oxygenated blood to cells and carbon dioxide rich blood away from cells. They share their models and revise their own mental models. It is important that the scientific model not be presented until all suggested models have been discussed and criticized. Next, they watch an animation about the structure and function of the heart, and revise their models one last time based on which model seems best.

Conclusion

Overall, "Energy in the Human Body" uses an approach designed to help teachers find out what students already know (this engages students), and to identify what questions students have (inquiry should involve students looking for answers to their own questions). The curriculum uses students' prior knowledge and questions to direct its implementation in classrooms. This is in sharp contrast to most middle school science curriculum material, which often does not start with students' current understanding of concepts nor does it take the time to find out what questions students would like to seek answers to.

Inquiry in the middle school science classroom can take many forms. Some activities in "Energy in the Human Body" are highly structured while others are more open-ended. Both have value in middle school science classrooms. Overall, an attempt was made to develop students' natural curiosity throughout the curriculum. Classroom discourse was an important component. As students work in small groups the teacher listens to students and learns about students' knowledge deficiencies and misconceptions. Lessons are exciting and motivating as students engage in conversations about science that is relevant to their lives. Allowing students to share their knowledge with one another creates a student-centered environment that empowers them to learn more about a given topic. Because students themselves explained what they knew about respiration, they are more likely to retain that information.

This curriculum identifies, builds on, and when necessary, consciously challenges students existing mental models. It provides opportunities for students to learn that are built upon their interest, questions, curiosity and existing knowledge. Students are constantly engaged in making sense out of situations. Students are required to be reflective and revise their thinking; self-assessment is used to help students reflect upon their own thinking. Students are given opportunities to apply their skills and understanding in new situations. Students spend a great deal of time collaborating with others to come to consensus. Students learn from one another, as they learn content in a positive environment that values all learners' opinions.

Middle school science teachers need more high quality instructional materials like "Energy in the Human Body" that were developed based on research about how students learn. This curriculum helps teachers understand how particular conceptions typically develop, as well as confusions that may arise. "Energy in the Human Body" gives students multiple opportunities to change their thinking and develop deeper conceptual understanding. In addition, the teachers' manual is designed to help teachers understand the pedagogical approach required to make this an effective curriculum.

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