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Analyzing Breadth and Depth of a Virtual Charter School's Science Curriculum

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This case study analyzes five science courses of a United States virtual charter school. Online quizzes and exams are provided by the corporate partner, while local teachers have selected report topics, virtual labs and at-home labs for students to complete. These assessments were coded for their correlation to the cognitive levels of the revised Bloom's taxonomy and the US NSES (National Science Education Standards). The remembering level was associated with the largest number of quiz and exam questions. However, analysis and application were also frequently assessed. Most of the standards were assessed at some point. The teacher selected projects address science inquiry standards but not additional content standards. The projects often required higher levels of thinking. Recommendations for teachers in virtual K-12 (kindergarten through 12th grade) schools are made to select additional content that focuses on key concepts and include more application, analysis, evaluation and creation.

Keywords: program evaluation, curriculum development, standards, virtual education

Introduction

Online education is a growing trend in K-12 (kindergarten through 12th grade) education. Virtual schools offer new modes of instruction to students in the 21st century. These schools deliver complete curricula online to students in their homes. In the US, federal law requires publicly funded virtual schools to employ certified teachers and administer state assessments for accountability purposes. These state assessments are correlated with the state's content standards. Virtual curricula in the sciences offer positive possibilities, such as diverse class offerings for students in remote locations. However, they also lead to questioning how science is being taught in these schools.

The US NSES (National Science Education Standards) affirm "a vision of science education that will make scientific literacy for all a reality in the 21st century" (NRC (National Research Council), 1996, p. ix). The NSES content standards emphasize scientific reasoning over factual recall. The introduction to the standards clearly states that the standards do not exist to prescribe a specific curriculum, but rather they are to serve as a guide for various stakeholders to determine whether particular actions will help develop a scientifically literate society. The state standards for the virtual school in this study are highly correlated to the NSES.

Bloom's taxonomy is a tool that can be used as a basis for determining the meaning of particular educational goals (Bloom, 1956). The revised taxonomy (Anderson & Krathwohl, 2001) has six levels of cognitive processes: remembering, understanding, applying, analyzing, evaluating and creating. They are

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arranged with the first three being lower level thinking skills and the latter three involving higher order thinking skills. Much of the formal assessment in the studied virtual science curriculum involved quizzes and exams with multiple choice and free response questions. What levels of knowledge these questions addressed was not previously known. This case study analyzed five online science courses for their correlation to the NSES and the cognitive levels of the revised taxonomy.

Bloom's Taxonomy

The original Bloom's taxonomy (Bloom, 1956) was devised as a method of classifying learning objectives and assessment of those objectives. Three domains of learning were postulated: the cognitive, affective and psychomotor. The cognitive domain related to knowledge and conceptual understanding. The affective domain related to attitudes. The psychomotor domain related to coordinated physical abilities and skills. The cognitive domain was further divided into six levels that formed a hierarchy from low to high levels of critical thinking: knowledge, understanding, application, analysis, synthesis and evaluation.

The taxonomy was revised by Anderson and Krathworthl (2001). Four knowledge dimensions have now been described: factual, conceptual, procedural and metacognitive knowledge. The six categories within the cognitive domain have been renamed in verb form and the order has slightly changed. The six levels are now remembering, understanding, applying, analyzing, evaluating and creating.

A critical analysis of the original and revised taxonomies was conducted by Amer (2006). The hierarchy found in the original taxonomy was described as being misleading and overly simplistic (Furst, 1994; Anderson & Krathwohl, 2001; Kreitzer & Madaus, 1994). For instance, knowledge tasks could be more intellectually involved than evaluation tasks. Also, the original taxonomy was grounded in behaviorist philosophy whereas educational research supporting constructivism has emerged.

Amer (2006) argued that the two dimensions of the revised taxonomy (the four knowledge dimensions and the six cognitive processes) have several advantages over the original taxonomy. Firstly, they help researchers and practitioners to more clearly analyze objectives. Secondly, they help practitioners not to confuse activities with objectives. Thirdly, the revised taxonomy clearly links activities with assessment. Finally, it allows for more clear alignment of instruction, assessment and objectives.

The Vision of the US NSES

Efforts at the reformation of science education in the US have focused upon an emphasis of teaching with inquiry methods and focusing on key concepts necessary for scientific literacy (AAAS (American Association for the Advancement of Science), 1993; NRC, 1996). The US NSES consist of sets of standards for science teaching, professional development, assessment, content, programs and systems. This case study focuses on the content standards. Five unifying standards exist for all K-12 science instruction. These standards involve: (1) systems, order and organization; (2) evidence, models and explanations; (3) constancy, change and measurement; (4) evolution and equilibrium; and (5) form and function.

The content standards are then divided into three grade level ranges: Kindergarten through the fourth grade, the fifth to eighth grade, and the ninth to 12th grade. In each grade level, there are seven content standards: (1) science as inquiry; (2) physical science; (3) life science; (4) earth and space science; (5) science and technology; (6) science in personal and social perspectives; and (7) history and nature of science. The NSES explicitly state that these content standards emphasize the following components less than in traditional classrooms: knowing facts and information, studying subject matter disciplines for their own sake, separating science knowledge and process, covering many science topics and implementing inquiry as a set scientific method. The NSES have a greater emphasis upon understanding of concepts and inquiry, learning about subject matter in context of inquiry, technology, history and the tentative nature of science, and a focusing on a few fundamental concepts rather than many disconnected topics (NRC, 1996, p. 113).

Online Student Assessment

Distance education has existed since the late 19th century. While it began with correspondence courses and eventually involved video delivery, online/virtual delivery has radically transformed the role of distance education in society (Majdalany & Guiney, 1999). A report from the Sloan Corporation (Picciano & Seaman, 2009) found that 70% of K-12 public school districts had at least one student enrolled in an online course during the 2007 to 2008 school year. The National Center for Educational Statistics found that 37% of school districts offered online courses in the 2004 to 2005 school year (Zandberg & Lewis, 2008).

Reasons for the increase in online education has been attributed to increasing the types of courses offered to small numbers of students (such as virtual AP (advanced placement) courses for students in rural districts), cost effectiveness of delivery and increasing the student to teacher ratio without lowering the quality of education. A meta-analysis found that on average, students in virtual education settings performed better than those in face-to-face settings. Hybrid or blended learning experiences that utilized both online and face-to-face components showed the most performance difference. The report did caution that it should not be interpreted that the online medium is superior, but that perhaps the element of extra time allowed online was an important factor (USDE (US Department of Education), 2009).

Online learning may be effective at transmitting explicit knowledge, such as facts, formulas and vocabulary. Özdeimir (2008) argued that online learning is not effective at transmitting tacit knowledge, described as "knowing how" rather than "knowing that". In terms of science education, explicit knowledge could include facts about anatomy, atomic structure or classification of landforms. Tacit knowledge could include the concepts related to the nature of science, such as understanding that science produces tentative knowledge based upon empirical evidence. The higher levels of the revised taxonomy (analysis, evaluation and creation) involve tacit knowledge, but the type of questioning will determine whether the student is required to question the sources of knowing and inquiry.

The use of quizzes in virtual education has not correlated to greater student achievement. Maag (2004) found no statistically significant difference when comparing a group of nursing students in a math course that took online quizzes and one that did not. Stanley (2006) found no statistically significant difference between students taking online quizzes and those who only completing homework at university level disease control and epidemiology virtual courses. Lewis (2002) compared two groups of university students in an online course. One group began a course taking online quizzes and a second group participated in online discussions. After half of the course modules were completed, the groups switched their formats. The first group did better than the second group when taking online quizzes, but the second group showed no difference when they took quizzes and the first group did discussions. Lewis interpreted this result as meaning that the quality of online discussions for the first group negated the advantage of taking online quizzes. Tselios, Avouris, Dimitracopoulou, and Daskalaki (2001) found that the software platform used to deliver a quiz affected university student test performance in their study. The two platforms they compared had similar functionality and content, but the interfaces differed. This study, thus, offers caution against generalizing studies of online quizzes.

One study of the distance learning courses from six colleges (Yang, Hsiao, Liu, & Lin, 2009) found that online course objectives emphasized application the most. Remembering was the second most emphasized level of the taxonomy. Evaluation was third. Faculty teaching online courses was significantly more satisfied than faculty teaching correspondence or television based courses. They found that all types of distance education focused on most of the application of knowledge. The application and evaluation components of these courses could show some emphasis on tacit knowledge, but it is not described whether the students were required to think about the nature of inquiry in the fields of study.

Science education also involves the use of laboratory experiments to teach about the processes and methods of science (NRC, 1996). The national level professional organization in the US for science teachers notes that "computers should enhance, but not replace essential 'hands on' laboratory activities" (NSTA (National Science Teachers Association), 1999). This statement, thus, does not support the role of labs in virtual settings. Nevertheless, virtual schools are conducting science courses with simulations.

Klahr, Triona, and Williams (2007) compared the effects of virtual and physical labs in terms of performance and achievement. The seventh and eighth grade students from two private urban middle schools crated and tested a series of mousetraps cars. Four groups of students were formed. One condition was whether the lab was physical or virtual. A second condition was whether the students were assigned to create six cars or they were assigned 20 minutes time to construct as many cars as they could. Students were given a pre- and post- assessment. Students were found to be able to construct more cars using the virtual lab. No significant effect on understanding was found in terms of whether a physical or virtual lab was used.

Finkelstein, Adams, Keller, Kohl, Perkins, Podolefsky, Reid, and LeMaster (2005) compared a virtual and physical electric circuit lab in a college level introductory physics course. Students who completed the virtual lab were able to later build physical circuits faster than those who had only had physical lab experience previously. The students who did the virtual lab scored higher on an assessment of conceptual understanding. Finkelstein, Adams, Keller, Perkins, Wieman, and the Physics Education Technology Project Team (2006) also indentified six key characteristics shown by the PhET (physics education technology) simulations used by his group (Retrieved from http://www.phet.colorado.edu) that correlate with quality science instruction. The PhET simulations support a provided dynamic feedback, follow a constructivist approach, provide for creativity, make explicit microscopic or invisible models, and constrain students "scientific play" constructively. These characteristics fit the model of science instruction promoted by the NSES (NRC, 1996).

Conceptual Framework

The conceptual framework for this study includes both the NSES and revised Bloom's taxonomy. The content standards of the NSES are used to inform this analysis of the science curriculum of a US virtual charter high school. Questions from quizzes and exams were matched with corresponding content standards. The revised taxonomy was also linked to each question. This analysis uses the six cognitive processes (remembering, understanding, applying, analyzing, evaluating and creating), but it does not include the four knowledge dimensions (factual, conceptual, procedural and metacognitive). Because students have access to textbooks, the Internet and other resources, while completing the quizzes and exams in these courses, it would be difficult to differentiate among the dimensions of knowledge assessed.

For instance, a question that would assess conceptual understanding in a proctored classroom environment may rather assess factual understanding, because of the access to materials that will turn the exercise into one of finding information rather than conceptualizing it. Similarly, a creating question (synthesis under the original taxonomy) that may be designed to assess procedural understanding of combining several methods may also become a factual question due to the ability of students to find a direct answer to the synthesis from their other resources. Therefore, this study does not minimize the importance of this dimension of the revised taxonomy, but it would not be adequately addressed due to the mode of delivery of these assessments.

Research papers, at-home labs (labs physically performed by the student) and virtual labs were also coded, but not at the question level, because students had vast amounts of freedom to choose one of the suggested projects. This study analyzed the types of content and skills valued by the lab choices and compared this to the quizzes and exams.

Methodology

This case study analyzed the virtual earth science, physical science, chemistry, physics and biology courses used by a virtual charter school in the US. The charter school was authorized by a local school district that contracted with a provider of distance education curricula. The school uses state licensed science teachers. The provider supplies a curriculum on blackboard course management software that includes roughly weekly quizzes, unit exams and a semester exam. Each semester consists of three lessons that are subdivided into weekly quiz blocks.

The local teachers working for this virtual school elected to add application assignments. These assignments were in the form of research papers, at-home labs (labs physically performed by the student) and virtual labs. Many of these activities redirected students to Websites with simulations or directions for conducting the lab at home. Students were given a menu of choices for each of the six lessons in a course. There was also a required project for each lesson of each course. These focused on items, such as research skills, evaluating sources and using a spreadsheet. The required projects are not included in this study.

A weekly pace chart is supplied to students telling them which chapters in their physical text book to read and which quiz or test to take. Projects and labs are also noted on the pace chart. A lesson viewer is supplied by the distance education provider: It is a Web-based version of the text book. Individual teachers have also created PowerPoint presentations that teach the content in a different manner. A weekly class discussion/lecture is also available via Web conferencing software.

Each question on the quizzes and exams was coded for the cognitive level of the revised taxonomy that corresponded to it. Items coded for remembering focused upon specific pieces of knowledge or facts. Items coded for understanding asked students to explain a concept, as multiple choice questions allow students only to select answers rather than construct their own answers; they were not coded in the category. Items coded for applying had students using content knowledge in a new situation. This typically was the code for problems that asked students to identify how a term applied to a given situation rather than just defining it. Items coded for analyzing involved questions that had students differentiating among different concepts, and many of these questions were matching, since students had to differentiate between terms. Items coded for evaluating required students to defend a position. None of the multiple choice questions were coded for evaluating, but several constructed response questions had students defending a position. Finally, items coded for creating involved students combining several concepts and either describing similarities or developing new knowledge from the given information. This level of thinking was only coded in constructed response questions.

The NSES content standards consist of five unifying concepts and processes for all grade levels and seven standards for grades kindergaren through grade four, grades five to eight and grades nine to12. Each content standard is further broken down into categories of student knowledge or abilities. Then, each of these categories is further broken down into fundamental concepts and principles that underlie the standard. For instance, content standard A states that as a result of activities in grades nine to 12, all students should develop: (1) abilities necessary to do scientific inquiry; and (2) understandings about scientific inquiry.

Further, under "understandings about scientific inquiry" are six fundamental abilities and concepts. To code for not only the overall standard, but also the fundamental concept, principle or ability, the associated standard for a question was in the form of A.2a where "A" refers to content standard A for grades nine to 12, the "2" represents the second bullet of standard A as listed in the NSES, and "a" refers to the first of the six concepts, principles and abilities. Some of the contents focused on material which fit better with the grades five to eight standards. To indicate this, a 5-8 was placed in front of the standard, for instance, 5-8.C.3a refers to the grades five to eight content standard C, bullet 3, first principle/concept.

The application projects were coded for association with the NSES and revised taxonomy, but only at the overall level of the lab. Individual questions were coded for their level on the taxonomy, but since students had such a wide choice of activities, the researcher focused on analyzing the overall possibilities that students were exposed to. The lab procedure itself was not coded, if it was merely a list of steps for students to follow. Labs that required students to develop their own procedure and synthesize their own results were coded with parts of standard A that relates to science as inquiry. Labs that required students to physically make a model or substance were coded as creating.

The coding was done by the author of this paper based upon his experience with the standards as a past high school science teacher and college methods professor. After an initial coding, the researcher reviewed the categories looking for discrepancies and contradictions. Questions using the same verbs were analyzed to ensure consistent coding. Finally, member checking was used by sharing the results with the administrator and lead science teacher of the school.

Results

This section details the analysis of each of the virtual science courses. A review of the coverage of related content standards is given. This is followed by a report of the levels of the revised taxonomy used in the assessments. A final section reports the results of analyzing the teacher selected application projects.

Earth Science

The NSES content standard for earth and space science in grades nine to 12 emphasizes geochemical cycles driven by sunlight and the earth's internal energy, evidence for change and dynamic equilibrium in the earth's systems over geological time, and the scale and nature of cosmic bodies. This is in contrast to the earth and space science content standard for grades five to eight which emphasizes an understanding of the earth and solar systems in terms of their changes, but not integrating those themes with energy.

The grades five to eight content standards correlated with 35% of the assessment questions. In fact, the three standards correlated with the most questions were all from grades five to eight. The most questions addressed the concept of landforms being the result of constructive and destructive forces (5-8.D.1c). The assessments had questions about plate movements, earthquakes, volcanism and weathering, but mostly, in terms of defining these terms of identifying examples, such as the cause of the Hawaiian Islands. The components of the atmosphere (5-8.D.1h) were assessed by 15 questions, mostly about constituent gases and names of layers. The water cycle (5-8.D.1f) had 13 questions associated with it. Many questions about ground water, cloud types and cloud formation were asked.

Two of the grades nine to 12 standards had more than 10 questions associated with them. Geologic time and the use of radioactive isotope decay in terms of determining age of rocks (D.3b) were related to 11 questions. The questions related to age of rocks and names of geological eras. The questions did not focus on understanding the methodology, but rather upon remembering names of eras as established facts. Ten questions addressed global climate and its relation to cloud cover, the earth's rotation and geological features (D.1d). The questions mostly related to air temperature and cloud/front movement.

The scientific method (unifying standard 2) did receive the attention of 11 questions. However, the questions presented the nature of science in a very positivist light rather than emphasizing its tentative, revisionary nature. The hypothesis was matched only with the term "educated guess". A question asked for a definition of a control group. This leads to the conclusion that science only studies problems that can be tested experimentally. This is problematic in an earth science course, since many theories are developed upon observational data. Use of experiments is not a realistic method of studying plate tectonics, climate or the history of earth and the universe.

Three earth and space science standards only had one question associated with them. The first related to movement of matter in cycles being driven by the earth's internal and external energy sources (D.2b). The single question was about whether a rise in global temperature would cause sea level rise, so this association is not strong. The second relates to the big bang theory (D.4a). A single definitional matching question is asked on one quiz. Finally, how stars use nuclear reactions which leads to formation of elements heavier than hydrogen and helium (D.4c) had one question that asked about the two most abundant elements in the universe; thus, it did not even address theories of the source of all other elements.

One question asked how old people living in the 19th century thought the earth was. This question is probably assuming a North America/European answer. It was classified as G.3d, since it emphasized how scientific explanations have changed. One limit is that this belief of the age of the world was not really scientific, but it relied on biblical revelation. Another question asked students to identify the steady-state theory. This gives historical perspective; however, it could also lead students to think that all theories have opposing theories (steady state versus big bang). This complicates discussions of how evolution is not an opposing scientific theory of intelligent design; rather, they are different ways of knowing (evolution being based in empiricism and intelligent design based in revelation).

Other standards were completely unaddressed by the questions in the assessments: How atoms flow between different reservoirs as parts of geochemical cycles (D.2a); how changes in the physical earth systems relate to the evolution of the earth's features and geological time(D.3c); and theories of formation of galaxies and stars (D.4b). Astronomy questions were of a descriptive nature about different phenomena.

In terms of the revised taxonomy, 61% were remembering, 29% were analyzing, 5% were understanding, 2% were applying and 1% were evaluating. All of the matching questions were classified as analyzing. The 51 free response question parts emphasized understanding (35%) and analyzing (20%) the most. The 191 multiple choice questions by far emphasized remembering (97%) with the rest categorized as analyzing. Finally, all 24 true/false questions were classified as remembering questions. The data for earth science are reported in Table 1.

Table 1

Percentage of Earth Science Assessment Questions Classified by the Revised Taxonomy

	Remember	Understand	Analyze	Evaluate	Create
Free response	3.2	100.0	9.7	100.0	100.0
Matching	0.0	0.0	84.5	0.0	0.0
Multiple choice	85.6	0.0	5.8	0.0	0.0
True/false	11.1	0.0	0.0	0.0	0.0

Physical Science

The NSES content standard for physical science in grades nine to 12 emphasizes that students should develop understandings between the macroscopic, microscopic and symbolic domains. While grades five to eight call for studies in changes of state, solutions and simple chemical reactions, the grades nine to 12 standards call for connections to be made from physical lab experiences, microscopic knowledge of atoms, ions electrons and chemical formulas. The structure of the atom is mentioned as an area where students can learn "how scientists know".

Nine content standards were assessed by 10 or more questions. The largest numbers of questions (42) were related to laws of motion, calculations related to an objects motion and equilibrium (B.4a). Both analyzing and remembering classifications were associated with 31% of the questions related to this standard. Standard B.2b (24 questions) addresses the nature of elements and the periodic table. Another 24 questions on the assessments were about factual knowledge about elements which did not relate to conceptual understanding of the periodic law. The chemical reactions standard (B.3c) related to 17 questions, but it classifies reactions as involving hydrogen ions (acid/base), electron transfer (oxidation/reduction) and radical reactions. Six other questions related to chemical reactions classified reactions as single displacement, double displacement, combustion, synthesis or decomposition. The electromagnetic force (B.4e) was correlated with 15 questions mostly related to the properties of magnets, but connections were also made to electromagnets, motors and generators. Standard B.1d (15 questions) and B.1c (12 questions) both relate to nuclear reactions: the former to radioactive decay and the latter to fission and fusion. Chemical bonding (B.2c) was assessed by 13 questions. The formation of molecules and association of salts with ionic bonds were made, but the difference between the two was not fully analyzed. Standard 5-8.B.3d relates to circuits (11 questions), and another eight questions were asked that involved calculations of voltage, current or resistance in a circuit. Finally, standard B.2a (10 questions) relates to the properties of electrons in atoms and how they are transferred or shared. Sixty percent of these questions used analyzing as students decided what type of ion an atom would form or how many covalent bonds could form.

Four of the grades nine to 12 physical science standards were assessed by only one question: connecting the macroscopic states of matter to the microscopic properties of molecules (B.2e), evidence that chemical reactions occur in a variety of daily situations (B.3a), the variable reaction rates of chemical reactions (B.3d), and the gravitational (B.4b) and electrical (B.4c) forces. No questions compared the strength of the electrical force to the gravitational force (B.4d). Also, there was no emphasis on how the electrical force related to most observable forces (also B.4d). Fifty-five percent of the questions were not correlated to a national standard.

In terms of Bloom's taxonomy, 37% were remembering, 48% were analyzing, 7% were understanding, 8% were applying and less than 1% were creating. All of the matching questions were classified as analyzing. The 142 free response question parts emphasized understanding (33%), analyzing (36%) and applying (25%). The

288 multiple choice questions by far emphasized remembering (87%) with the rest categorized as analyzing (6%) and applying (7%). Frequency data for physical science are reported in Table 2.

Table 2

Percentage of Physical Science Assessment Questions Classified by the Revised Taxonomy

	Remember	Understand	Apply	Analyze	Create
Free response	3.8	100.0	62.5	14.2	100.0
Matching	0.0	0.0	0.0	80.5	0.0
Multiple choice	95.8	0.0	37.5	5.0	0.0
True/false	0.4	0.0	0.0	0.3	0.0

Chemistry

The chemistry course essentially focused on standards B.1, B.2, B.3 and B.5. The structure of atoms (B.1) had all parts partially covered. The structure and properties of matter (B.2) also had all parts touched upon. States of matter was a common topic for questions, but they did not delve into the molecular nature. The chemical reactions standard (B.3) had four of five parts covered in part. No questions addressed the concept of a catalyst. Chemical reactions were classified as single displacement, double displacement, combustion, synthesis and decomposition rather than in terms of transferring electrons, hydrogen ions or radical reactions. Questions about thermal energy were asked (B.5c) and calorimetry problems were given.

The three standards that had at least 10 questions associated with them were standards B.3c, B.2c and B.1c. Chemical reactions (B.3c) were the topic of 32 questions. As with the physical science course, this course emphasized identification and classification of chemical reactions rather than connecting the microscopic, macroscopic and symbolic domains. Also, as with the physical science course, this course focused on classification of chemical reactions by single displacement, double displacement, combustion, synthesis and decomposition rather than the emphasis found in the standards. Fourteen questions related to ionic and covalent chemical bonding (B.2c), while 13 questions related to fission and fusion (B.1c). Questions also related to the binding energy of nuclei and nuclear power plants.

Three physical science standards only had one question associated with them: the ubiquitous nature of chemical reactions (B.3a), the relationship among the macroscopic and microscopic properties of solids, liquids and gases (B.2e) and the motion of objects (B.4a). Standard B.4a is better addressed in the physics course. Standards B.2e and B.3a were both also found to be minimally covered in the physical science course.

The majority (64%) of questions were not correlated with one of the NSES. Many of these topics focused on calculations mainly relating to gas laws (16 questions), conservation of mass and balancing equations (18 questions) and stoichiometry (13 questions). Quantum chemistry (13 questions) focused on information about electron orbital, which are not included in the national standards. Solutions, mixtures, colloids and suspensions (27 questions) were mostly assessed through knowledge about definitions.

An overall analysis of the curriculum in terms of the revised taxonomy showed that 47% of the question were related to remembering, 30% related to applying, 17% related to analyzing, 5% related to understanding and less than 1% related to either creating or evaluating. The 55 free response question parts focused most on applying (36%), understanding (29%) and analyzing (20%). The matching questions involved both analyzing (38%) and applying (62%). Multiple choice questions only related to remembering information 54% of the time, while applying (29%) and analyzing (16%) were also utilized. The true/false questions were mostly (92%)

remembering information. The frequency data for chemistry are reported in Table 3.

Table 3

Percentage of Chemistry Assessment Questions Classified by the Revised Taxonomy

	Remember	Understand	Apply	Analyze	Evaluate	Create
Free response	2.4	100.0	18.7	18.6	100.0	100.0
Matching	0.0	0.0	7.5	8.5	0.0	0.0
Multiple choice	84.5	0.0	72.0	72.9	0.0	0.0
True/false	13.1	0.0	1.9	0.0	0.0	0.0

Physics

The physics course focused on the physical science standards B.4, B.5 and B.6. Much of the early course focused on motion, forces and calculations associated with those concepts, which explains the reason why standard B.4A was associated with 76 questions. Electromagnetism (B.4e) was correlated to 35 questions. Both conceptual and analytical questions were asked about kinetic and potential energy (B.5b). Energy transfer from hot to cold objects (B.5d) was associated with 21 questions. This standard also refers to entropy, which was not a topic in the course. The electrical force (B.4c) was the topic of 17 questions. Standard B.5c (14 questions) is associated with the differences between heat and temperature. The conservation of energy (B.5a) was covered by 11 questions.

Standard B.6 deals with waves and quantized energy. Standard B.6a was the only part not associated with any questions, but it was a general standard related to how waves transfer energy through an interaction with matter. Twenty-nine questions did assess student knowledge about wave properties and the use of basic wave equations, but they did not address this foundational concept. Optics was a topic of 37 questions, but they did not relate to the wave properties of light.

As with chemistry, the majority (51%) of questions were not correlated with a national standard. Other than topics already mentioned, the questions asked about the following concepts. In terms of sound, beats, the Doppler effects and resonance were assessed. Vectors, units and significant figures were also assessed.

Large amounts of this course were assessed at the application (28%) and analysis (17%) levels, but remembering still was the level of the majority of the assessment questions (51%). Understanding was the focus of 3% of the questions. The free response questions emphasized understanding and application equally (36% each). However, remembering was involved with 26% of the 50 question parts. All matching questions were classified as analysis. The multiple choice questions consisted of 55% remembering, 29% applying and 16% analyzing. The 18 true/false questions were 78% remembering. The data for physics are reported in Table 4.

Table 4

Percentage of Physics Assessment Questions Classified by the Revised Taxonomy

	Remember	Understand	Apply	Analyze
Free response	4.9	100.0	12.2	1.1
Matching	0.0	0.0	0.0	18.9
Multiple choice	89.8	0.0	85.7	78.9
True/false	5.3	0.0	2.0	1.1

Biology

The individual standards with the most questions were the content standards for grades five to eight, not the standards for grades nine to 12. Standards 5-8.C.1d (12%), 5-8.C.1e (13%) and 5-8.C.2a (4%) showed the highest involvement. One of the course's six lessons' quizzes and exams focused on the various animal phyla, thus, correlating mostly with standard 5-8.C.1d about specialized cells, tissues and organs cooperating for the organism's functioning. Another lesson focused on human body systems structure and function (5-8.C.1e). Standard 5-8.C.2a referred to reproduction in living things and how it can be both asexual and sexual. Of the 24 questions asked, many related to the forms of asexual reproduction found in several species and to information about mating practices of organisms, such as fish. An understanding of meiosis was assessed earlier in the course. Standard 8.C.3a noted that organisms need resources to grow, reproduce and maintain stable internal conditions. This standard was mostly addressed through an understanding of the difference between endothermic and exothermic animals.

All six grades 9-12 life science standards were addressed at least partially. The six standards address the cell, the molecular basis of heredity, biological evolution, the interdependence of organisms, the organization of matter and energy in living systems, and the behavior of organisms.

Nine of the standards were addressed by at 15 questions. In terms of cells, structures and functions (C.1a), the processes of transcription and translation (C.1c), cell regulation and expression as well differentiation and organization (C.1d, C.1f) were covered substantially. The role of chromosomes and gamete cells (C.2b) was emphasized, especially in regards to the process of meiosis. The role of natural selection and adaptation to different niches (C.3a) was covered by different questions. Biological classification was assessed (C.3e) mainly in terms of characteristics of different phyla of organisms. Students often had to use analyzing skills to differentiate between phyla. The only ecological standard assessed by a large number of questions was the flow of energy through ecosystems (C.4b). The NSES choose the nervous system as the body system for high school students to analyze at a deep level of understanding. This curriculum spent a lot of time on other human systems that are recommended for grades five to eight, so the nervous system did not stand out. Nevertheless, several questions on assessments did address the functions at the cellular level of the nervous system (C.6a).

Items not covered by many questions included genetic regulation of the expression of cellular functions (C.1f), how cell functions involve chemical reactions (C.1b, C.5a and C.5b) and the role of photosynthesis beyond knowledge of reactants, products and conditions (C.1e). The concept of descent from a common ancestor was not specifically noted in the curriculum (C.3d). Energy loss among trophic levels, cycles and environmental limits on species growth were also not addressed. The in depth knowledge about the nervous system in terms of evolutionary and human implications were not addressed.

Table 5

Percentage of Biology Assessment Questions Classified by the Revised Taxonomy

	Remember	Understand	Apply	Analyze	Create	Evaluate
Free response	0.6	100.0	14.3	6.1	100.0	100.0
Matching	6.3	0.0	0.0	53.4	0.0	0.0
Multiple choice	71.5	0.0	71.4	38.7	0.0	0.0
True/false	21.6	0.0	14.3	1.8	0.0	0.0

The 58 free response questions mostly assessed understanding (52%), followed up by creating (19%) and analyzing (17%). The multiple choice questions mostly assessed remembering (85%) with some analysis (14%) and only a few application questions. The true/false questions were almost all remembering (97%). The data for biology are presented in Table 5.

Teacher Selected Labs and Projects

The applications projects designated by the local teachers overall did not address content standards missing from the quizzes and exams. One notable exception was that chemistry labs did connect to examples of chemical reactions in daily life (B.3a), which was not evident in the quizzes and exams. The projects did address most of the parts of standard A.1 on abilities to do science as inquiry. These skills included students' ability to indentify questions for exploration (A.1a), design the experimental procedure (A.1b), use of technology and math to investigate (A.1c), formulate and revise scientific explanations (A.1d), analyze alternative models (A.1e), and communicate and defend conclusions (A.1f).

The number of projects addressing each of these standards is reported by course is reported in Table 6. All of the courses offer some labs that require students to design their own procedure, while only a few require students to identify and ask their own research questions. Creating explanations and communicating results were found in all courses to some extent, but the analysis of alternative explanations was only found in a few places. The lead science teacher at the school stated that the labs in middle school (not studied) and physics are mostly inquiry. The ones in biology and chemistry are more content and analysis, since proper procedure is needed. In all cases, the analysis of the data and reflection back on the hypothesis or purpose is a must. Biology and chemistry did show less correlation with the inquiry standard and more correlation with content standards.

Table 6

Number of Application Projects per Science as Inquiry Standard

		A.1a Identify questions	A.1b Design procedure	A.1c Use math	A.1d Make and revise explanations	A.1e Analyze alternatives	A.1f Communicate results
Earth science	At home	2	6	-	7	-	2
	Virtual	-	-	1	-	2	1
Physical science	At home	3	8	1	10	-	5
	Virtual	2	6	4	6	1	4
Biology	At home	1	2	1	3	-	1
	Virtual	-	-	-	-	-	-
Chemistry	At home	4	6	-	6	1	4
	Virtual	1	-	-	-	-	-
Physics	At home	-	-	1	-	-	-
	Virtual	-	9	11	11	-	10

In terms of correlation between the projects and the revised taxonomy, the projects showed the use of higher levels of thinking than found in many of the quizzes and exams. This indicates that the teachers did attempt to select projects that would allow students to apply, analyze, evaluate and create. The earth science quizzes and exams were heavily focused on remembering while the projects emphasized applying, understanding and creating. The physical science projects highly emphasized analysis and creation. Analysis had also been emphasized in the quizzes and exams for that course. Biology emphasized analyzing and remembering; and remembering had been emphasized in the assessments as well. Chemistry emphasized analyzing and applying, whereas many of the assessment questions were about remembering. Physics emphasized applying, as did most of the questions on the quizzes and exams. The number of projects at each level of the revised taxonomy is reported in Table 7.

Table 7

Number of Application Projects at the Levels of the Revised Taxonomy

		Remember	Understand	Apply	Analyze	Evaluate	Create	Total
Earth science	At home	-	1	8	6	-	7	22
	Research paper	-	5	-	-	-	-	5
	Virtual	3	5	5	1	2	3	19
	Total	3	11	13	7	2	10	46
Physical science	At home	-	5	10	23	1	19	58
	Research paper	-	11	-	-	-	-	11
	Virtual	-	1	5	14	1	13	34
	Total	-	17	15	37	2	32	103
Biology	At home	3	3	3	9	-	8	26
	Video	2	-	-	-	-	-	2
	Virtual	2	-	-	2	-	3	7
	Total	7	3	3	11	-	11	35
Chemistry	At home	-	6	12	10	3	16	47
	Research paper	1	-	-	1	1	2	5
	Virtual	-	-	1	-	-	4	5
	Worksheet	-	3	1	4	-	2	10
	Total	1	9	14	15	4	24	67
Physics	At home	-	-	2	-	-	-	2
	Virtual	-	3	34	-	-	20	57
	Total	-	3	36	-	-	20	59

Discussion

The teacher selected application projects extend the virtual students' learning about science as inquiry and require them to use higher levels of the revised taxonomy. These projects do not, however, extend the actual curriculum itself into the areas of the content standards for earth and space, physical and life sciences. Students had control over whether they chose to do at home or virtual labs as well as the level of thinking required for the project they chose to complete for each of the six lessons in a course.

In the future, it is recommended that the virtual school science teachers continue to have the flexibility to add projects to standardized quiz and exam assessments. To improve the quality of these projects, the following additional recommendations are made:

(1) To design or choose more projects that require students to ask their own research questions (A.1a);

(2) To incorporate the recognition and analysis of alternative explanations into the procedures and expectations of projects (A.1e);

(3) To explicitly introduce students to key concepts of understanding scientific inquiry as found in standard A.2. This would involve students learning about the process of science separate of applying it. Students could then compare their own methods with those used by practicing scientists;

(4) To evaluate the method of giving students complete choice of projects to complete. Students could continue to pick projects for each lesson that did not challenge them to move beyond the remembering or understanding levels;

(5) Select labs and other projects that address content standards not addressed by quizzes and exams.

Examples of teacher selected projects that would address content standards not covered by quizzes and exams as follow. One example is given for each course as follows:

(1) Earth science: Emphasize understanding and analysis of the driving forces behind the flow of matter and energy in geochemical cycles using a virtual simulation or student created model;

(2) Physical science: Emphasize what occurs during reactions more than classifying them. Have students describe the relationship between a formula and a video clip, photograph or at-home lab;

(3) Chemistry: The calculation problems seem appropriate, but include follow up questions that require students to connect the results to the macroscopic world in conceptual terms. Have students apply calculations about stoichiometry, molarity or gas laws in virtual or at-home labs;

(4) Physics: Quantitative reasoning is valued in many parts of this course. This value could be maintained, but some concepts, such as circular motion, work, capacitors or electric potential could be evaluated at the understanding level rather than requiring students to apply formulas to quantities, such as voltage which they may not have a meaningful understanding of.

While knowledge about the human body may be of high interest to students, this course should pick only a few body systems to study in depth. Students then focus on understanding how the interconnected parts of the system operate rather than remembering part names. They could also use simulations or Internet pictures to compare the adaptations of various animals' anatomy to also connect to the evolution standards.

Conclusions

The methodology used in this case study can be applied to other virtual curricula. Since the assessment in a virtual course is much more explicit than much of the informal assessment in a face-to-face classroom, these courses allow for more direct measures of cognitive thinking levels addressed and the correlation with standards. This case study also provides evidence that much of the current assessment found in this school emphasizes remembering. As these assessments are "open book" and "open Web", developers and curriculum writers may consider shifting more of the emphasis towards application and analysis. Teachers in virtual settings should consider incorporating projects that require Özdeimir's (2008) tacit "knowing how" knowledge rather than focusing on factual content. In terms of national standard coverage, there were some gaps, but overall, the call from the NSES for deeper understanding of a few topics of shallow understanding of many topics is of higher importance. Designing a curriculum around fewer concepts may also allow for higher order cognitive questions to be asked. While Yang et al. (2009) found application to be emphasized in higher education online courses, the courses in this school tended to have large remembering components. Teachers in virtual K-12 settings may thus need to add additional material to include other levels of the revised taxonomy. As teachers select labs and other projects, they will also need to consider the balance between addressing different content standards with the projects than quizzes and exams versus concentrating on depth of knowledge over breadth by focusing on the same standards emphasized in quizzes and exams.

References

AAAS (American Association for the Advancement of Science). (1993). *Benchmarks for science literacy*. Oxford: Oxford University Press.

Amer, A. (2006). Reflections on Bloom's revised taxonomy. *Electronic Journal of Research in Educational Psychology, 8*(4), 213-230.

Anderson, L. W., & Krathwohl, D. R. (Eds.) (2001). *A taxonomy for learning, teaching, and assisting: A revision of Bloom's taxonomy of education objectives.* New York: Longman.

Bloom, B. S. (1956). *Taxonomy of educational objectives, handbook 1: Cognitive domain.* New York: Longman.

Finkelstein, N. D., Adams, W. K., Keller, C. J., Kohl, P. B., Perkins, K. K., Podolefsky, N. S., Reid, S., & LeMaster, R. (2005). When learning about the real world is better done virtually: A study of substituting computer simulations for laboratory equipment. *Phys. Rev. ST Phys. Educ. Res. 1*(1), 010103(1)-010103(8).

Finkelstein, N. D., Adams, W. K., Keller, C. J., Perkins, K. K., Wieman, C., & the Physics Education Technology Project Team. (2006). *High-tech tools for teaching physics: The physics education technology project.* Retrieved January 23, 2010, from http://www.colorado.edu/physics/EducationIssues/papers/PhET_JOLT.pdf

Furst, E. (1994). Bloom's taxonomy: Philosophical and educational issues. In L. Anderson, & L. Sosniak (Eds.), *Bloom's taxonomy: A 40-year retrospective* (pp. 28-40). Chicago: The National Society for the Study of Education.

Klahr, D., Triona, L. M., & Williams, C. (2007). Hands on what? The relative effectiveness of physical versus virtual materials in an engineering design project by middle school children. *Journal of Research in Science Teaching, 44*(1), 183-203.

Kreitzer, A., & Madaus, G. (1994). Empirical investigations of the hierarchical structure of the taxonomy. In L. Anderson, & L. Sosniak (Eds.), *Bloom's taxonomy: A 40-year retrospective* (pp. 64-81). Chicago: The National Society for the Study of Education.

Lewis, B. A. (2002). The effectiveness of discussion forums in online learning. *Brazilian Review of Open and Distance Learning, 1*(1). Retrieved January 23, 2010, from http://www.abed.org.br/revistacientifica/Revista_PDF_Doc/2002_The_Effectiveness_Discussion_Barbara_Lewis.pdf

Majdalany, G., & Guiney, S. (1999). *Implementing distance learning in urban schools* (Report No. 150). New York: ERIC Clearing House on Urban Education Digest (ERIC Document Reproduction Service No. ED438338).

Maag, M. (2004). The effectiveness of an interactive multimedia learning tool on nursing students' math knowledge and self-efficacy. *Computers, Informatics, Nursing, 22*(1), 26-33.

McComas, W. F. (1997). Fifteen myths of science: Lessons of misconceptions and misunderstandings from a science educator. *Skeptic, 5*(2), 88-95.

NRC (National Research Council). (1996). *National science education standards.* Washington, D. C.: National Academy Press.

NSTA (National Science Teachers Association). (1999). *NSTA position statement: The use of computers in science education.* Retrieved January 23, 2010, from http://www.nsta.org/about/positions/computers.aspx

Özdeimir, S. (2008). E-learning's effect on knowledge: Can you download tacit knowledge? *British Journal of Educational Technology, 39*(3), 552-554.

Picciano, A. G., & Seaman, J. (2009). *K-12 online learning: A follow-up of the survey of US school district administrators.* US: Sloan-C. Retrieved October 17, 2009, from http://www.sloanconsortium.org/publications/survey/pdf/k-12_online_learning_2008.pdf

Stanley, O. L. (2006). A comparison of learning outcomes by "in-course" evaluation techniques for an online course in a controlled environment. *The Journal of Educators Online, 3*(2), 1-16.

Tselios, N. K., Avouris, N. M., Dimitracopoulou, A., & Daskalaki, S. (2001). Evaluation of distance-learning environments: Impact of usability on student performance. *International Journal of Educational Telecommunications, 7*(4), 355-78.

USED (US Department of Education), Office of Planning, Evaluation, and Policy Development. (2009). *Evaluation of evidence-based practices in online learning: A meta-analysis and review of online learning studies.* Washington, D. C. Retrieved October 10, 2009, from http://www.ed.gov/rschstat/eval/tech/evidence-based-practices/finalreport.pdf

Yang, J. F., Hsiao, C., Liu, H., & Lin, N. C. (2009). Modes of delivery and learning objectives in distance education. *International Journal of Instructional Media, 36*(1), 55-71.

Zandberg, I., & Lewis, L. (2008). *Technology-based distance education courses for public elementary and secondary school students: 2002-03 and 2004-05* (NCES 2008-08). Washington, D. C.: National Center for Education Statistics, Institute of Education Sciences, US Department of Education.