Invited Research Article

Science Curriculum for the Gifted: Innovations for Meeting Student Needs

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Abstract

It is the purpose of this paper to describe some of the curricular innovations that have been developed, particularly those created at the Center for Gifted Education at the College of William and Mary in Virginia. Science curriculum for gifted students provides a foundation for them to become knowledge producers. It is important for the student to internalize scientific skills such as observation, experimentation, and measurement, as well as to adopt an attitudinal mindset that views the world through the lens of a scientist which can be used as a framework for research in all fields. The science curriculum materials discussed in this paper represent an important step forward for the field of gifted education in crafting systematic science interventions that provide multiple opportunities for learners to practice scientific habits of mind yet also serve the gifted learner effectively in the areas of concept development, content attainment, and scientific investigation skills. Much of the work that has been done in science in gifted education has focused on the development of curriculum materials. By utilizing specific teaching and learning models, along with advanced content, achievement gains relative to science content and processes have been realized for gifted students.

Key words: Gifted learners, science curriculum, PBL (problem-based learning), Project Clarion

Introduction

Much of the work that has been done in science in gifted education has focused on the development of curriculum materials. By utilizing specific teaching and learning models, along with advanced content, achievement gains relative to science content and processes have been realized for gifted students. It is the purpose of this paper to describe some of the curricular innovations that have been developed, specifically those created at the Center for Gifted Education at the College of William and Mary in Virginia.

Science curriculum for gifted students provides a foundation for them to become knowledge producers instead of simply knowledge consumers. It is important for the student to master scientific skills such as observation, experimentation, and measurement, as well as to adopt an attitudinal mindset that views the world through the lens of a scientist. To ensure gifted students have these skills, it is essential to include five key components in a science K-12 science program:

1. Opportunities for laboratory experimentation and original research work;
2. High-level content-based curriculum;
3. Opportunities for interactions with practicing scientists;
4. A strong emphasis on inquiry processes; and the
5. Inclusion of science topics that focus on technological applications of science in the context of human decision-making and social policy (VanTassel-Baska, Gallagher, Bailey, & Sher, 1993; VanTassel-Baska & Kulieke, 1987).

For students to develop understanding in any scientific discipline, teachers and curriculum developers must address a set of complex and interrelated components; these include the nature of practice in particular scientific disciplines, students’ prior knowledge, and the establishment of a collaborative environment that engages students in reflective scientific practice. The three design components should be used by educators to create curricula and instructional materials that help students learn about science both by and as inquiry (Stewart, Cartier, and Passmore, 2005).
It is possible to help others realize the expectations for improving science education that are set forth in reform documents such as the National Science Education Standards, Framework for K-12 Science Education, and the Next Generation Science Standards. They all offer a new vision for K-12 education in science, representing a significant shift in how these subjects are viewed and taught. Such documents call for curricular reforms that allow students to be engaged in “inquiry that involves utilizing processes and scientific knowledge as they practice scientific reasoning and critical thinking to develop their understanding of science.” Recommendations for the improved teaching of science are solidly rooted in a commitment to build on and revise students’ knowledge and abilities over multiple years, and thus “support the integration of such knowledge and abilities with the practices needed to engage in scientific inquiry and engineering design” (Framework for K-12 Science Education, 2011).

Science Curriculum Development Projects

For over 20 years, researchers at the Center for Gifted Education at the College of William and Mary have been involved in several projects in which they have developed science curricula for gifted students. In this section of the paper, I will describe those projects.

Background: Research on Teaching Gifted Learners

Early opportunities to access advanced science content should be made available to gifted learners. Cross and Coleman (1992) surveyed gifted high school students and found their main complaint about general science instruction was frustration at being held back by the pace and content of the course. In a six-year study of middle-school-age gifted learners enrolled in biology, chemistry, or physics during a three-week summer program, Lynch (1992) found that these younger learners outperformed high-school students who were enrolled in the courses for a full year. Follow-up studies found continued success in science for participating students, thereby suggesting a need for high school science level courses to be accessible at earlier grade levels with flexibility in course length for students who can master the content in less time.

In an action research study of the effectiveness of problem-based learning in promoting the acquisition and retention of knowledge, Dods (1997) compared the effects of problem-based learning (PBL), traditional lecture (L), and a combination of (PBL+L) on student retention of the major concepts in a elective biochemistry course taught at a school for academically talented students. He collected data through student self-evaluation of the depth of understanding, a test instrument used to measure actual depth of understanding, and a student evaluation of the course. Dods found that in-depth understanding is enhanced by the PBL experience whereas content coverage is promoted by lecture.

In examining the effects of problem-based learning on problem solving, Gallagher, Steprien, and Rosenthal (1992) studied 78 students enrolled in a residential high school for students talented in mathematics and science. Students participating in the study received a problem-based course that incorporated social science, physics, and mathematics. The experimental group became significantly better at problem finding and performed better than the comparison group on fact finding, problem finding, and solution finding.

Lynch (1992) conducted a six-year study of accelerated high school science for academically talented students, 12 to 16 years old, who completed a one-year course in high school biology, chemistry, or physics in three weeks at a residential summer program. Students demonstrated subject mastery by taking college entrance examination science achievement tests. Their mean scores were higher than those of high school juniors and seniors. Follow-up studies indicated that students also performed well in subsequent science courses. The study suggested that academically talented students could begin high school sciences earlier than is currently practiced in most American schools.

Integrating technology with computer-based mathematics and physics for gifted students has been found to be efficacious for promoting student achievement in science. A group of 27 middle and high school students took computer-based advanced math classes at a middle school in which a tutor provided assistance that included correcting off-line work, grading tests, and certifying per-
formance in the course. 92% of those who took Calculus AB, the first two quarters of college calculus, 100% of those who took Calculus BC, the entire year of college calculus, and 88% of those who took Physics C received scores of 4 or 5 on Advanced Placement tests. The computer courses were designed at the Education Program for Gifted Youth (EPGY) at Stanford University. Ravaglia, Suppes, Stillinger, and Alper (1995) concluded that computer-based education makes it possible for gifted and talented adolescents to complete advanced courses in mathematics and physics earlier than expected.

Tyler-Wood, Mortenson, Putney, and Cass (2000) found an effective mathematics and science curriculum option for secondary gifted education. Georgia’s Project for Gifted Education in Math and Science involved 32 students in a two-year interdisciplinary math/science program that incorporated higher-level thinking skills and more real life laboratory experiences. Comparing this group to a control group who did not receive the program, the researchers found that the participants in the new curriculum performed significantly better on the ACT in the areas of science, math, pre-algebra, algebra, geometry, and trigonometry.

VanTassel-Baska, Bass, Ries, Poland, and Avery (1998) conducted a national study of science curriculum effectiveness with high ability students. The study examined the effects of a William and Mary Unit “Acid, Acid Everywhere” on elementary student achievement in science. The curriculum uses the national science standards and stresses advanced content, high level process and products, and a concept dimension. The authors found that students who were taught the units made small, but significant gains on the Diet Cola Test when compared to students who did not use the units. The teachers cited that the hands-on, problem-based and student-centered aspects of the units supported their teaching.

The Diet Cola Test

The Diet Cola Test (Fowler, 1990) was originally designed to be used as a process assessment of science aptitude. The Diet Cola Test is process-oriented, open-ended, and requires the student to apply his knowledge of experimental design. The test has parallel forms for the pre- and postassessments; the student is asked to design a test of the question “Are earthworms attracted to light?” As the student completes his design for an experiment, he must demonstrate his competency in all basic and integrated science process skills.

Adams and Callahan (1995) evaluated the reliability of the Diet Cola Test and its validity for identifying gifted students. They tested 180 students in grades 4 through 8 in six states; the data did not support the use of the Diet Cola Test in identifying students but was suited for assessing science process skills as part of an instructional program or evaluation.

Problem-based Learning Units

The study by VanTassel-Baska et al. described in a previous section was on aspects of the project in which problem-based learning (PBL) units in science were developed for gifted learners. Initially developed as a method for helping medical students to understand the lives of their patients, problem-based learning has evolved into a strategy that is used in many instructional contexts, including curricula for gifted learners (Gallagher & Stepien, 1996). The results suggest that students learn value-added skills as a result of exposure to the strategy, in addition to the skills required in a content area. PBL has been used most often in science and the social sciences, but also has applicability in mathematics and language arts.

When implementing problem-based learning (PBL) in the classroom, it is essential to keep in mind the nature of solving ill-structured problems like those that are experienced in real life. The specifics of the problem-based learning process dictate not only the pedagogy used, but also such things as the physical arrangement of the classroom and the nature of the interaction between the teacher and students. A problem encountered in PBL is one that comes with insufficient information to understand it well enough to make valid decisions about its causes or potential resolution. The selected problem becomes the basis of the learning and the instruction. Initially, more information is essential to understand and to define the problem. As new information is gained and the problem becomes more identifiable, additional information must be obtained through investigating, observing, asking ques-
tions, testing and probing. Decisions about what needs to be learned, how it relates to what is already known, and how it leads to resolution of the problem are actions that require the metacognitive processes of reflection, thought, and deliberation. The responsibility of bringing new information to the problem-solving situation rests with students as they grapple with ambiguous and conflicting information. The role of the teacher is that of facilitator, as he/she guides group metacognitive processes during the experience of solving a problem. Modeling, practicing, refining, and ultimately having students internalize the process as a group is done prior to expectations that each student can operate independently within a similar context.

The degree of assistance provided by the teacher in collecting and interpreting resources depends upon the prior knowledge, experiences, and abilities of students as well as their familiarity with the subject matter involved. It is important that the teacher work through all scenarios they anticipate their students may encounter in defining and resolving the problem. Appropriate resources can then be identified and collected, and potentially difficult reasoning tasks are anticipated in advance.

The teacher must keep the group process in a dynamic mode. He/she must emphasize that no phase of the learning process can be skipped and each phase must be done in order. Often students want to postulate solutions before they have an operational definition of the problem. For students to reason their way through a problem, the teacher must ensure that students use appropriate analytical reasoning skills and integrate new information they have acquired with the existing knowledge at each step of the problem. The transition to each new phase of the process requires reflection, through, and deliberation before proceeding.

The teacher must also investigate the student's knowledge deeply. This is probably the single most important task facing the teacher. Students must constantly be challenged to examine critically the true meaning of information or thoughts about their proposed solutions. Probing questions serve to force students to examine the matter confronting them in an in-depth manner. The teacher should guard against indicating "right" or "wrong" answers, which is a task that should ultimately belong to the group. Students should be challenged to elaborate when giving appropriate responses.

An important task for the teacher is to ensure that all students are engaged in the group process. Depending on the size of the group and the personalities involved, this can be difficult to facilitate. Getting the children to contribute important ideas and to engage in cognitive interaction with their peers is challenging but critical to the group as well as to the process of PBL. Common strategies already used in the classroom such as using sufficient wait time and directly asking reluctant students to share important information can help to get all of the students involved.

Another critical teacher role is to maintain an ongoing educational diagnosis of each student as well as the whole group, particularly regarding their reasoning difficulties and understanding of information. The use of probing questions together with other assessments should disclose areas of difficulty so that appropriate remediation can take place. Ongoing diagnosis will also allow the teacher to incorporate labs and demonstrations that can assist student understanding of newly acquired information. Authentic, formative assessments built into the problem scenario are particularly helpful.

The teacher must also modulate the level of challenge of the problem. It is important that an appropriate level of cognitive dissonance be present through the experience. The level of challenge can be addressed with both the total group as well as with the small group. Specific areas of investigation can be assigned to appropriate groups in order to meet differing academic or intellectual needs of students.

The teacher's understanding and consistent adherence to these tasks is imperative for the success of PBL. If the goal is to enhance the autonomy and self-efficacy of our students and to promote independent thinking and learning, it is important that to avoid the dependence of the groups on the teacher. The teacher as facilitator must evolve from modeling, to coaching, to reducing assistance throughout the problem. The teacher must at first model the thinking process of the group. Frequent metacognitive challenges must be made to students, including presenting an accurate reasoning process. Searching for
appropriate resources is a critical part of the problem finding and solving. The frustration and difficulty in locating and understanding information is a real part of the process. Initially, the teacher must convey that professionals often go through the same difficulty.

Coaching becomes the next phase of teaching: stepping in to question when it is apparent that a step has been missed, regaining the focus of the group when it begins to wander, and stepping in to lend assistance when confusion overcomes the group. The amount and duration of the intervention will be dictated by the level of difficulty, ability, and age of students, and the development rate of the group dynamics.

Ultimately the teacher wants to be able to fade into the background and reduce his/her level of assistance, allowing the group when it begins to wander and stepping in to lend assistance when confusion overcomes the group. Like coaching, the amount and duration of the intervention will be dictated by the level of difficulty, ability, and age of students, and the development rate of the group dynamics.

Problem-based learning represents the world of science well, in terms of its openness to change, the greater complexity, and the need for collaboration with others in order to reach resolution. It provides the gifted student with essential elements for learning: autonomy, challenge, and meaningful learning connected to the real world (VanTassel-Baska & Wood, 2010). It is not surprising, then, that gifted students report that PBL is one of the most motivating processes they have ever used in school (VanTassel-Baska, 1998).

Project Clarion

The National Research Council (2000) has provided convincing evidence that expertise develops over time and through practice. In response to these findings, the Center for Gifted Education developed science curriculum units that nurture scientific habits of mind beginning in the primary grades while providing specific strategies to mediate gaps in understanding and skills.

Project Clarion was a five year Javits project funded by the United States Department of Education, and was initiated by the Center for Gifted Education at the College of William and Mary (VanTassel-Baska & Bracken, 2004). Project Clarion’s purpose was to “scale up” rigorous science curriculum with broad populations of K-3 students. Project Clarion has been implemented and researched in Title I schools.

The Clarion Curriculum

The Clarion curriculum was developed based on the Integrated Curriculum Model, which provides for equal emphases on the teaching of rigorous content, process/product development, and concept development (VanTassel-Baska & Stambaugh, 2006). Clarion curriculum develops multiple levels of conceptual understanding. Macro-concepts, such as systems or change, provide a framework for teaching key science concepts (Coxon, Bland, & Chandler, 2010; National Research Council, 2002; National Research Council, 2007). In the unit Budding Botanist (Center for Gifted Education, 2010a), for example, the macro-concept of systems is explored with a terrarium. Understanding a terrarium as a system helps students to understand key science concepts, such as:

- Plants have basic needs, including air, water, nutrients, and light.
- Plants produce oxygen and food.

Clarion also cultivates scientific habits of mind, including skills in scientific inquiry, reasoning and investigation, and creativity. Units present problem-based scenarios to help students understand that real scientists conduct experiments to solve a problem. In the unit, Weather Reporter (Center for Gifted Education, 2010c), students are asked to take on the role of meteorologists. Students learn specific science content as they make observations or conduct experiments to help address the problem-based scenario presented at the beginning of the units. For instance, students build their own barometers and measure air pressure over the course of several days. Units culminate with a final project and concluding lesson that unify the solution to the problem with the science investigations, key science concepts, and the macro-concept.

Clarion Teaching and Learning Models

Each unit includes multiple teaching and learning models that provide the instructional scaffolding to integrate
concept development, content attainment, and process/product development. Problem-based learning acts as the foundation for helping students to understand how science is conducted by scientists (VanTassel-Baska, 1998). The Frayer Model of Vocabulary Development (Frayer, Frederick, & Klausmeier, 1969) helps children build scientific vocabulary. Teachers use the Taba Model of Concept Formation (1962) to build understanding of the macro-concepts. Students use concept maps (Novak, 1998) to develop their understanding of key science concepts. Finally, the students learn that science is an iterative and integrated process using the Wheel of Scientific Investigation and Reasoning (Center for Gifted Education, 2008a; 2008b; 2010a; 2010b; 2010c; Kramer, 1987; Paul & Binker, 1992). (See Figure 2 for the Wheel of Scientific Investigation and Reasoning.)

Research Findings: Clarion Works

Research highlights from the curriculum implementation include:

- **Clarion** produced positive gains in conceptual understanding, science content attainment, and the scientific process on the curriculum-embedded performance-based assessments. (Bland et al., 2010).

- **Clarion** improves critical thinking. Results from the Test of Critical Thinking (Bracken, 2004) indicate that **Clarion** students had statistically higher and educationally important gains in critical thinking than the comparison group students, who had higher ability scores (Kim et al., in press).

- More **Clarion** is better. When students begin receiving instruction on the **Clarion** units in kindergarten and first grade, they score higher on standardized measures of science content than students who have had little or no experience with the units (Kim et al., in press).

- The sky is the limit with **Clarion**. The performance based measures and rubrics are effective with more advanced students as no ceiling effects were observed (Bland et al., 2010).

- **Clarion** acts as an equalizer. Traditionally under-served and under-identified students in science perform well on science achievement measures after receiving instruction on **Clarion** units over multiple years (Kim et al., in press).

- **Clarion** is “more than the sum of its parts.” **Clarion** units are most effective when implemented fully. Science achievement is supported with the teaching of macro-concepts (like change and systems), problem-based learning, and the scientific investigative process which work together to help students construct and organize their understandings of science concepts in order to show long-term gains (Bland et al., 2010; Bland, Chandler, Stambaugh, & VanTassel-Baska, 2010; Kim et al., in press).

The **Clarion** curriculum can be used effectively with students from a variety of backgrounds. The model simultaneously builds upon students' abilities and interests while providing instructional scaffolding to address knowledge and skill gaps characteristic of urban students. Furthermore, the teaching models and strategies are integrated such that they are mutually supportive of students achieving multiple goals, including language acquisition, concept development, scientific habits of mind, and development of social skills and independence.

Conclusion

The curriculum units developed at the Center for Gifted Education provide multiple opportunities to help gifted students to develop understanding and skills. However, the real strength of the materials lies in the excitement and interest in science that they build. The science units actively engage students. The science classroom looks different from traditional classrooms (Bland, Chandler, Stambaugh, & VanTassel-Baska, 2010). Students call out answers; students talk with their peers; students stand at tables or desks or make their own decisions to get up to get more materials. Most importantly, children make their own decisions about how to plan and conduct the science experiments. At the beginning of the units, teachers provide direct instruction in the scaffolding and strategies that students will need to use at the end of the units to help them become self-directed learners. As the units progress, students become more self-directed. By the conclusion of the units, students are able to use their understandings and skills developed throughout the unit...
to solve the problems posed in the units and share their solutions as practicing professionals in the field.

The science curriculum materials discussed in this paper represent an important step forward for the field of gifted education in crafting systematic science interventions that provide multiple opportunities for learners to practice scientific habits of mind yet also serve the gifted learner effectively in the areas of concept development, content attainment, and scientific investigation skills. When planning and developing curricula to meet the multiple needs of gifted learners it is important to consider the teaching models and the scaffolding that will be provided to support the learner.

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References


Center for Gifted Education: *What’s the Matter: A physical science unit for high-ability learners in grades 2–3*. Waco, TX: Prufrock Press, 2008b.


Center for Gifted Education: *Dig It!: An earth and space science unit for high-ability learners in grade 3*. Waco, TX: Prufrock Press, 2010b.

Center for Gifted Education: *Weather reporter: An earth and space science unit for high-ability learners in grade 2*. Waco,

TX: Prufrock Press, 2010c.


Paul, R., & Binker, A. J.: *Critical thinking: What every person needs to survive in a rapidly changing world*. Dillon Beach,
SCIENCE CURRICULUM FOR THE GIFTED

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才能ある児童・生徒のための科学カリキュラム — 学習者のニーズに応える教育革新 —

ウィリアム＆メアリー大学才能教育センター

要 旨

本論文の目的は、米国ヴァージニア州にあるウィリアム＆メアリー大学才能教育研究センターにおいて開発されたカリキュラムを中心に、科学カリキュラムの革新について概説することである。才能ある児童・生徒は、自分たちの特性に配慮された科学カリキュラムを通じて、知識の生産者となる基盤を得る。そうした児童・生徒にとって重要なことは、観察や実験、測定のような科学のスキルを習得すると共に、科学者ものの見方を通じて世界を観る態度や思考様式を身につけることである。それらは、いかなる領域の研究においても基本的な枠組みとして利用可能なものである。本論文で議論する科学カリキュラム教材は、才能教育として体系的な科学教育の介入を策定していく重要なステップを示すものであり、科学の思考習慣を実践する多様な機会を提供すると同時に、才能児の概念発達、内容理解、科学調査スキルに有効である。才能教育分野では、カリキュラム教材に関する研究・実践が多数行われている。才能ある児童・生徒が科学の内容とプロセスに関する学習達成の向上を実感するためには、高度な学習内容を伴う特別な教授学習モデルの活用が必要である。

キーワード：才能児、科学カリキュラム、問題基盤型学習、Clarionプロジェクト

（訳：隅田 学）