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Evaluation of a Secondary School Science Program Inversion: Moving from a Traditional to a Modified-PCB Sequence

Abstract

Studies of high-school science course sequences have been limited primarily to a small number of site-specific investigations comparing traditional science sequences (e.g., Biology-Chemistry-Physics: BCP) to various Physics First-influenced sequences (Physics-Chemistry-Biology: PCB). The present study summarizes a five-year program evaluation focused on the implementation of a modified-PCB sequence within a moderately large suburban high school, the findings of which highlight the importance of considering context-dependent support of PCB sequence implementations. This modified-PCB program transition was associated with increases in students' honors and Advanced Placement (AP) course enrollments, AP examination scores, understanding of the Nature of Science and experimentation, and self-reported affect toward themselves as learners and toward science in general. By contrast, no differential gains were observed in students' growth as measured by standardized tests (e.g., EXPLORE and ACT science scores). In addition to the program evaluation results associated with this course-sequence change, considerations are outlined related to the complexity of leading large-scale changes in secondary school science programs.

Introduction

The traditional Biology-Chemistry-Physics (BCP) sequence is the most common science course sequence in U.S. high schools. However, a movement to invert this course arrangement to a Physics-Chemistry-Biology (PCB) sequence has prompted growing discussion about the role of curricular sequences in science education reform (e.g., Pasero, 2003; Vazquez, 2006). Despite this recent attention, PCB proponents have only tepidly impacted secondary-school programs of study. As of 2005, only 3% of U.S. public schools began their science sequence with physics, of which fewer than half utilized a full PCB sequence (American Association of Physics Teachers [AAPT], 2006).

Theoretical arguments for PCB sequencing assert that exposing students to physics and chemistry coursework early in their secondary curricula better builds on the growing foundational convergences between modern biology and chemistry and gives students the opportunity to conduct experiments that illustrate cross-disciplinary scientific concepts (AAPT, 2006). Specifically, modern biology has evolved from a descriptive science of the natural world to a more experiment-based science that relies on an understanding of chemistry (e.g., genetics, proteomics, molecular biology); therefore, students' early chemistry experiences may enhance their understanding of the complexity of biological phenomena (AAPT, 2006; Bardeen et al., 1998; Cavanaugh, 2006; Vazquez, 2006). Similarly, synergy between courses is magnified by the opportunity students are given in physics not only to learn science skills fundamental both to Chemistry and Biology (e.g., graphing, math application, measurement), but also to engage in circumscribed, repeatable experiments in which they can more easily control variables of interest, laying a foundation for grappling with topics in subsequent courses in which variables are more difficult to control and topics are more complex (AAPT, 2006).

Despite the persuasiveness of these theoretical arguments, empirical research investigating the efficacy of PCB sequence inversions has been sparse. To date, studies have found that secondary-school freshmen are as capable of learning physics as are juniors (e.g., Liang et al., 2011; O'Brien & Thompson, 2009) and that the PCB sequence successfully increases substantive exposure to physics concepts for the general population of high school students (Popkin, 2009). The research has been less clear when considering the impact of PCB sequences on students' ability to scaffold scientific skills and topics in sequential courses. A 2007 study by Sadler and Tai, for instance, suggested that college students' prior exposure to high-school physics courses was not significantly associated with their college chemistry grades, and that their exposure to high-school chemistry courses similarly was not significantly associated with their college biology grades. Although these findings at first glance appear to undermine a key premise of PCB sequencing, both the time-lag between the participants' high-school and college coursework (O'Brien & Thompson, 2009) and the caution warranted against inferring statistically significant null findings (i.e., no relationship between students' high-school to college grades) from non-significant positive findings (i.e., positive, but not statistically significant, relationships between students' high-school and college grades) temper such a conclusion (Gaubatz & Gaubatz, 2007; cf. Cohen & Cohen, 1983).

Keywords: secondary school science curricula, Physics-First, program evaluation

Table 1: Traditional course sequence, prior to 2008

8th Grade	9th Grade	10th Grade	11th Grade	12th Grade
Various science and math courses	Earth Science →	Biology →	Chemistry →	Physics or elective courses
	Biology or Biology H →	Chemistry or Chemistry H →	Physics or Physics H →	AP or elective courses

Other investigations of PCB sequences, reported primarily in dissertations and conference presentations, have found that students who begin their science education with physics subsequently take more science courses, attain improved scores on standardized science and math tests, demonstrate higher-level scientific reasoning, and express increased interests in science (e.g., Ewald et al., 2005; Glasser, 2004; Mountz, 2006; Williams, 2009). The present study, based on the findings of an internal program evaluation of a PCB program in a mid-sized secondary school, adds to this developing empirical literature.

A Transition to a Modified-PCB Sequence within a Secondary School

The present investigation was conducted in a suburban Midwestern high school with a population ranging from 1700 to 2000 students. The school's student body has recently become increasingly diverse. Between 2004 and 2011, minority student enrollment increased from 28 to 38 percent of all students and the percentage of student families qualifying for low-income assistance increased from 11 to 20 percent. The district goal of meeting the needs of all students and families has triggered multiple interventions across the school, such as offering courses that integrate reading and math skills and implementing programs to help students transferring from other districts to adjust to the culture of the school.

Prior to 2008, students followed a traditional science course sequence, beginning with Earth Science or Biology, then progressing to Chemistry and to Physics (Table 1). Departmental goals guided teachers' predictive assessments of specific interventions and programs (Table 2), and eventually sparked the transition from a traditional science course sequence to a modified-PCB sequence beginning with the 2008 Fall semester (Table 3).

Although the teachers in the school under study agreed that physics provides an important foundation for all students, they felt that students who lacked math skills would struggle with the conceptual understanding of physics-related content. This view was reinforced by consultations with other science educators in the area, and by published accounts of teachers' perceptions of freshmen and physics (e.g., Pasero, 2003). Additionally, teachers felt that Earth science content should also be part of students' high school science experiences. These considerations prompted teachers to propose a modified-PCB sequence, which included a "GeoPhysics" course designed to investigate Earth science concepts through the lens of physics. This course allows students lacking algebra skills to learn and apply fundamental physics concepts (e.g., waves, energy, velocity, acceleration) while exploring Earth science concepts (e.g., astronomy, earthquakes, plate tectonics). In this modified-PCB sequence, students who enrolled in Algebra I or lower-level math courses during their freshman year (~65%) were placed in GeoPhysics, and students who enrolled in Geometry or higher-level math courses during their freshman year (~35%) were placed in Physics Honors. Both of these freshmen-level classes were aligned with the Chemistry courses, which students take during their sophomore year.

Table 2: Department goals, teacher predictions as to how the modified-PCB might impact these goals, and teacher perceptions of how the modified-PCB sequence has impacted these goals as of 2012

Department goals	Prediction	Impact as of 2012
1. Upper level science course enrollment and student success.	+	+++
2. Student placement criteria.	++	+++
3. Student growth as measured by EXPLORE to ACT science scores.	0/+	0
4. Student understanding of the Nature of Science and experimentation.	+	+
5. Student affective outcomes	0	+

Methodology

Portions of an internal program evaluation of a curricular intervention are presented within this article. In alignment with program evaluation principles (e.g., McNamara, 2002), the evaluation aimed to: (i) increase teachers understanding of students' needs, (ii) increase the effectiveness of the provided department program of studies, (iii) facilitate teachers' understanding of department goals, (iv) produce data assessing the program change to share with stakeholders, and (v) collect data to share with other science educators as they examine their own practices. Selected department goals that appeared to be of most interest to other science educators are described in this article and delineated in Table 2.

A pre- and post-test approach was used to compare the impact of the modified-PCB sequence compared to the previous traditional science sequence at the school. Enrollment data and standardized test scores were gathered from archival and administrative data, and enrollment trends were assessed for the years before and after the transition to the modified-PCB sequence. In addition to enrollment data, Advanced Placement (AP) exam scores were analyzed for changes that coincided with the new course sequence. Student growth on standardized exams (EXPLORE and ACT) in science was also analyzed to assess for its correspondence with the implementation of the new course sequence.

In addition, the department created a 25-item survey to assess students'

Table 3: Modified-PCB course sequence, 2008-present

8th Grade		9th Grade	10th Grade	11th Grade	12th Grade
Math 8	→	GeoPhysics	Chemistry or Chemistry H	Biology or AP Biology	Physics or Electives or AP Courses
Algebra I or higher	→	Physics H			Electives or AP Courses

understanding of Nature of Science and experimentation, as well as their affect towards themselves as learners, science as a field, and their science courses. This survey, which students completed anonymously, consisted of eleven items related to the Nature of Science and experimentation (e.g., "Scientific theories are supported by evidence" and "Scientific studies always begin with a hypothesis"), as well as sixteen items related to students' views of themselves as learners (e.g., "I'd like to take more science before I graduate" and "I think I'll do well in science classes in college"), of science as a field of study ("I can see why science is important" and "I'd enjoy working in a science field"), and of their specific science classes (e.g., "I get nervous in science class" and "My teacher thinks I can learn a lot in this class"). The survey was given annually beginning the Spring semester of the year preceding the course-sequence change.

Program Evaluation Outcomes

Multiple aspects of the transition to the PCB sequence were assessed as part of a five-year internal program evaluation designed to provide meaningful information to teachers, community members, and other science educators. The program evaluation data presented in the current report focuses on the impact of the modified-PCB transition on students' academic experiences. Department goals related to this line of inquiry are summarized in Table 2, which also lists the science teachers' predictions as to how the modified-PCB sequence might affect these goals along with their assessment of how well these goals were met following the new course sequence implementation. Data related to each of these goals are further elaborated in this section.

Enrollment in Upper-Level Science Courses

Teachers involved in the design of the course sequence predicted that the modified-PCB sequence would increase student enrollment in upper-level (honors and AP) science courses (Table 2). This was based on the premise that exposure to courses with progressive content would increase student confidence, skills, and understanding of science, resulting in students attempting more rigorous coursework. This potentially beneficial aspect of the PCB sequence was enhanced by teachers' alignment of content and skills between successive courses with the goal of promoting students' ability to progress from regular-level courses to honors-level courses in subsequent years. Additionally, teachers anticipated that more students would choose to take an AP Biology course their junior year within the modified-PCB sequence than had chosen to take the Physics Honors within the traditional sequence, based on their perception that students often have less fear of biology than of physics.

Figure 1 illustrates upper-level science course enrollments within the traditional (dashed line) and modified-PCB (solid line) sequences by student-cohort year. Traditional sequence cohorts (N = 4) tended to enroll in more upper-level courses in their sophomore year than they had in their freshman year, but this enrollment decreased markedly in their junior year. Cohorts who took classes within the modified-PCB sequence (N = 3) not only enrolled in upper-level courses in higher numbers than did the traditional cohorts, but this enrollment increased with each succeeding grade level. Two-tailed t-tests determined that a statistically significant difference emerged between upper-level enrollment in the traditional sequence compared to the modified-PBC sequence at each student grade level ($p < 0.05$ for freshmen; $p < 0.01$ for sophomores and juniors). Although the upper-level enrollment increase seen between the traditional and modified-PCB cohorts was a positive indicator of this program's

Figure 1

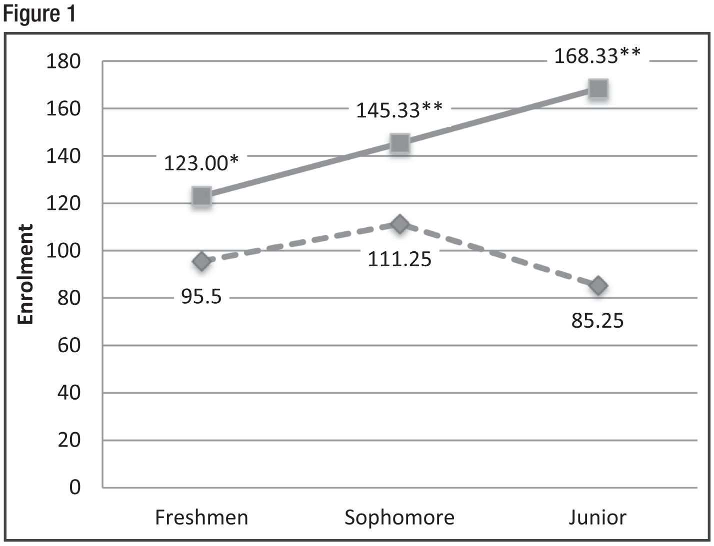

Figure 1: Upper-level enrollment by cohort year.

Note: The dashed line represents the average enrollment in upper-level courses (honors and AP) within the traditional sequence (N = 4), and the solid line represents the average enrollment in upper-level courses within the modified-PCB sequence (N = 3). Two-tailed t-tests resulted in statistically significant differences for each cohort (*$p < 0.05$; **$p < 0.01$).

Figure 2

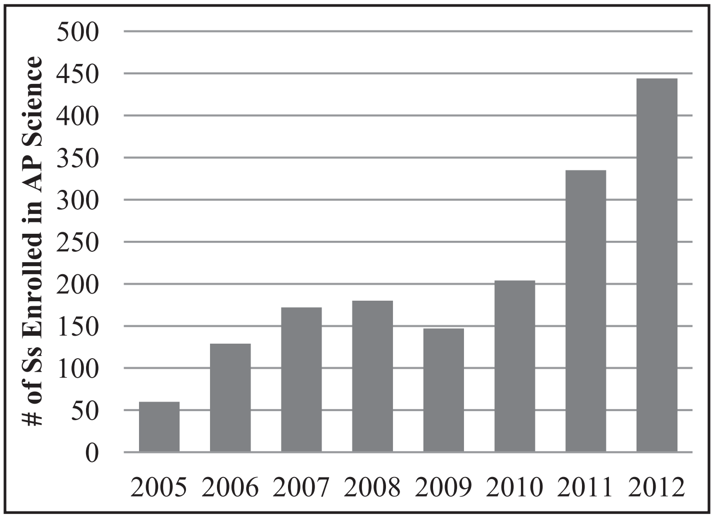

Figure 2: Total number of students enrolled in AP Science courses.

effectiveness, the fact that more students gained enough confidence in their regular-level courses to enroll in upper-level courses later in their high-school years demonstrated the concerted effort by the school's teachers to make full use of the benefits the modified-PCB program could offer their students.

Supplementary findings related to upper-level course enrollment are evident in students' AP course-specific enrollment and exam scores (Figures 2 and 3). Science teachers predicted an increase in AP Biology enrollments due to students' ability to take AP Biology as a first-year biology course their junior year; however, teacher-guided review sessions were implemented for students who struggled with the increased demands of AP coursework. Additionally, the College Board recently revised the AP Biology curriculum, which may impact students' ability to take AP Biology as a first-year biology course in the future. Teachers expected mild-to-modest enrollment increases in the school's other AP science courses due to the predicted increase in students' scientific understanding, skills, and confidence gained from the progressive nature of courses in the modified-PCB sequence.

The first modified-PCB cohort was able to take AP science courses during their junior or senior year, depending on students' schedules and interests. As PCB cohorts became eligible to take AP science courses, they did so in impressive numbers (Figure 2). AP Biology enrollment approximately tripled under the modified-PCB sequence, and AP Environmental Science and AP Chemistry both approximately doubled (Figure 4). The increase in AP Physics C enrollment was the most surprising; many science educators with whom the department consulted had predicted that a PCB sequence would substantially decrease students' AP Physics C course enrollment due to the time-lag they experienced between their freshman-level Physics course and their ability to take AP Physics C. However, this proved not to be the case for this particular program. Instead students' AP Physics C enrollment actually doubled when the first PCB cohort was able to take AP Physics C and has subsequently remained at this increased enrollment level (Figure 4). This might be due to students' early and positive experiences with physics content, or to their level of confidence in their science knowledge and experimentation abilities.

Although students' enrollment in AP science courses is a positive indicator of their interest in science and their confidence in their scientific understanding and skills, teachers were uncertain whether increased AP course enrollment would translate into students earning "passing" scores on the AP exams. Data collected on this indicator demonstrated that although the overall *percentage* of enrolled students earning a 3, 4, or 5 on AP science exams decreased, the overall *number* of students earning a 3, 4, or 5 in the modified-PCB population increased markedly (Figure 3). When disaggregated by subject area, these findings mirrored the enrollment data. The number of students earning a 3, 4, or 5 approximately tripled for AP Biology, and doubled for AP Environmental Science and AP Physics C (Figure 5).

Student Placement Criteria

Prior to the transition to the modified-PCB sequence, incoming freshmen were placed either in Earth Science, Biology,

Figure 3

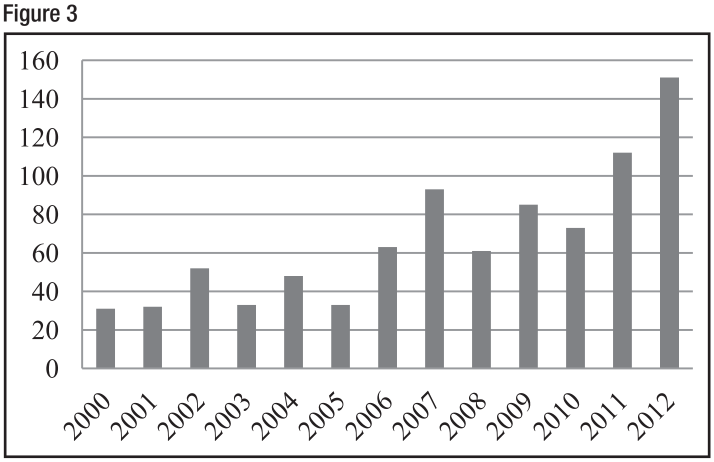

Figure 3: Total number of AP Science exam scores above 3.

Figure 4

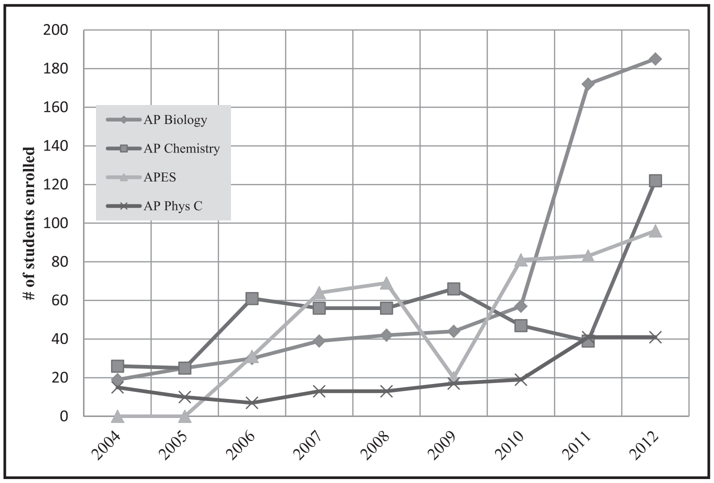

Figure 4: Number of students enrolled in each AP Science course.

or Biology Honors courses (Figure 1). This placement was based on EXPLORE reading scores and eighth-grade science teacher recommendations. Both of these criteria for freshman placement had significant limitations. Although the Biology course required substantial reading, students could be successful in the course without reading especially well, and eighth-grade teachers' recommendations for freshman course placement were often based on students' behavior as opposed to their ability. Many parents felt this heuristic was too subjective, and each year over seventy parents requested that their child be moved to a higher-level freshman course. This resulted in an Earth Science course enrollment consisting primarily of academically challenged students whose parents did not call to request a different class. Additionally, because of course sequencing permutations in place at the time, freshmen who began their science education in Earth Science would remain one course behind their peers throughout their high school careers.

The modified-PCB sequence provided the department with more objective and relevant placement criteria for freshman based solely on mathematics prerequisites. If students are placed in Algebra I or lower as freshman, they are automatically placed in GeoPhysics, and if students are placed in Geometry or higher as freshman, they are automatically placed in Physics Honors (Table 3). Although GeoPhysics students frequently use mathematics, teachers could assume students would have a limited working knowledge of algebra, whereas Physics Honors teachers could require students to apply algebra skills on the first day of class. This criterion reduced parents' concerns about the subjectivity of science course placement and decreased the number of freshman placement consultations to fewer than two per year. Parents also were comforted by the fact that students in GeoPhysics could progress to Chemistry Honors by their sophomore year, provided they earned sufficiently strong grades in Algebra I and GeoPhysics (Table 3).

Student Growth Based on EXPLORE to ACT Science Scores

Teachers predicted that the modified-PCB sequence would have little-to-no impact on overall student growth as measured by the EXPLORE science assessments (taken in the 8th grade) and by ACT science assessments (taken in the 11th grade). Nationally, the average growth from EXPLORE to ACT science assessments was 3.3 points during the period of this evaluation, whereas students at this particular high school consistently grew by an average of 5.5 to 6.3 points. When growth by these measures was compared between students who had experienced the traditional sequence versus the modified-PCB sequence, no significant differences were found (M = 5.55 vs. 5.68, SD = 3.74 and 3.96, respectively). Although these data consisted only of two PCB cohorts for a total of 652 students, teachers predict that the PCB curriculum may continue to have little impact on student growth due to the non-specific nature of these assessments.

Student Understanding of Nature of Science and Experimentation

Data assessing students' understanding of Nature of Science constructs and experimentation logic was collected through the department-created internal survey given each spring. Science teachers predicted that the increased emphasis on experimentation provided by a physics-based course during the freshman year would increase students'

Figure 5

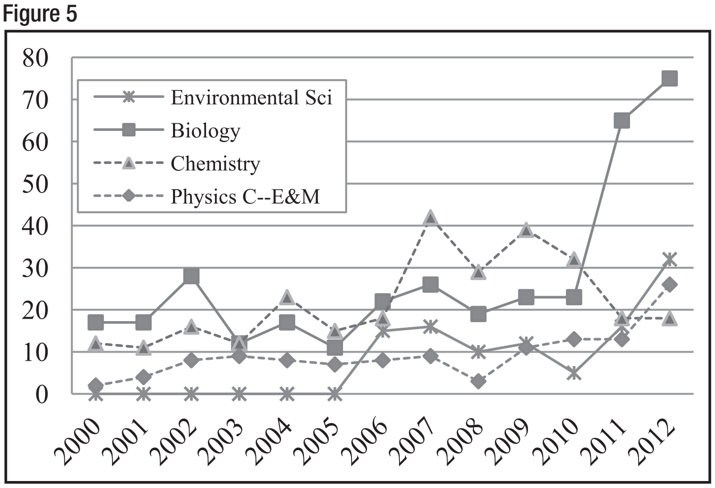

Figure 5: Total number of AP exam scores of 3 or higher by course.

understanding of how science works, and that this understanding could be built upon in subsequent courses. The premise of this prediction was reinforced by content analyses of lesson plans, which indicated the use of approximately 27 lab activities in the traditional sequence freshman Biology Honors course, compared to 49 in the freshman Physics Honors course and 36 in the GeoPhysics course.

Although students on the traditional sequence of science courses already exhibited a robust baseline understanding of the Nature of Science and experimentation, statistically significant changes emerged for some items in the modified-PCB cohort groups. These included statements regarding the role of evidence in theories, error in experiments, and the interconnection between different scientific fields. Only one item, related to the necessity of hypotheses, showed a decrease in student understanding.

Student Affective Outcomes

The student survey on Nature of Science and experimentation also contained a section designed to measure students' affect towards themselves as learners, science as a field, and their science education experiences at their high school. These statements were rated by students (1 for strongly disagree to 5 for strongly agree). Teachers predicted that the science course sequence change would have no impact on how students felt in these areas; however, several slight improvements were identified. Items that showed improvements focused on students' desire to take more science classes prior to graduation, interest in their science courses, anticipation that that they would be successful in college-level science courses and science-related fields, and perceptions that their science teachers felt positively about their ability to learn. These responses mirrored the number of upper-level courses students chose to enroll in each year (Figures 1 and 2).

Discussion/Conclusion

The Physics-Chemistry-Biology (PCB) course sequence has been argued to benefit students by progressively building their science-related knowledge and skills across sequential courses (e.g., AAPT, 2006; Bardeen et al., 1998; Cavanagh, 2006). Data to support the adoption of this sequence, however, has heretofore been limited. The current report presents the findings from an internal program evaluation in which a mid-sized suburban high school transitioned from a traditional science-course sequence to a modified-PCB sequence. These findings support previous reports on the impact of PCB sequences, such as prompting an increase in student enrollment in upper-level courses (e.g., Mountz, 2006; cf. Liang, 2012). Other findings from this transition evaluation include an increase in the number of students earning 3, 4, or 5's on AP science exams, in students' understanding of the Nature of Science and experimentation, and in student affect related to their science experiences, as well as a decrease in confusion over freshman course placement. As predicted by the school's science teachers, however, this program evaluation did not find that the modified-PCB sequence impacted student growth on national standardized exams.

Among its most salient limitations, the present manuscript reports the results of a five-year program evaluation and not of a controlled or quasi-controlled experiment. As with most studies completed within school systems, factors other than the variable of interest could, and probably did, influence these results. In this particular school, these additional factors may have included the increased percentage of minority and low-income students, the gradual shift in teacher philosophy regarding upper-level courses, the increased use of inquiry in curriculum, and the team-building that occurred as teachers rallied around common challenges, goals, and inspirations during the implementation of the modified-PCB sequence.

Importantly, future factors also may disrupt the positive outcomes recorded thus far, such as changes in state science standards and assessments or changes in College Board AP science course curricula. These potential factors will require teachers to maintain a focus on internal data and external information to better adjust curricula as the program continues to develop.

It is hoped that the findings presented in this article can contribute to the decision-making processes of other science educators who are considering, or merely exploring, course sequence changes. However, an intervention's supporting data and theoretical base is only part of a successful change story. Committing to a course-sequence change within a high-school science department is a complex, time-intensive, and difficult process. For such a change to be successful, the predicted outcomes must be viewed by stakeholders as worth the effort. Science department leaders should carefully consider multiple factors prior to a change of this magnitude, starting by conducting a needs assessment and by gathering input from a variety of sources, the most salient of which may be the input from science teachers from within the department. Science department leaders should also consider the stages of the change process itself, leadership roles and styles, team-building, change-participant development, and program evaluation techniques. These foundational factors that contribute to successful change may be found in general leadership literature (e.g., Blake & McCanse, 1991; Havelock & Zlotolow, 1995; Northouse, 2004) or embedded within discussions of course-sequence change (e.g., Hanuscin, 2012; Korsunsky, 2008). Without a holistic view of the change process involving multiple aspects of innovation implementation, even the most promising innovation is likely to falter.

Based on the findings of the present program evaluation, science educators considering ways to enhance students' science education may wish to consider a PCB sequence as an option that has the potential to increase student participation and success in rigorous courses, decrease student placement issues, enhance student understanding of science, and improve students' attitudes towards themselves as science learners. However, these findings, which contribute to a growing body of evidence on the effectiveness of PCB programs, should be tempered with the understanding that successful change within educational settings is context-dependent. Although the presently reported transition to a modified-PCB sequence resulted in multiple markers of success in this particular high school, each school has different needs, goals, strengths, and weaknesses. One-size will not fit all, but the present research adds incrementally to the growing body of information that can guide science educators as they consider curricular reform.

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