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ABSTRACT

This study explores how and when physics became the last course in U.S. high school science and what impact this had on high school physics offerings and student enrollment. Four main areas of historical data were identified: (1) national and state education statistics; (2) reports from major organizations on reform and policy; (3) reports from professional educational societies and organizations; and (4) published educational research from professional journals and commentary by education reformers from particular time periods. The historical development of high school physics in the U.S. was analyzed. Findings were grouped into several pertinent areas regarding the order of the science courses, enrollment, and time allocation. (KHR)

Physics Last: A Historical Study of the Development of the US High School Science Sequence.

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Introduction

The Third International Math and Science Study (TIMSS) results have been widely publicized, particularly the findings that documented the relatively poor standing of American high school physics students (Takahira et al.1998). On the TIMSS physics assessment United States 12th grade students did not significantly outperform any other country. The American Institute of Physics (AIP) report, "Maintaining Momentum"(Neuschatz & McFarling, 1999) noted that direct comparison of achievement scores to those of other countries was difficult as students from other countries receive more instruction in physics than US students and often take the subject for several years. Additionally, many other countries have larger percentages of students enrolled in physics. Not unsurprisingly, the AIP report suggested that a main determinant to success on the TIMSS physics assessment was whether the physics content being tested had actually been taught to students. While some of these issues seem to account for US students' poor performance on the physics section of TIMSS, several important questions are raised. Why do other countries enroll more students in physics and devote more instructional time to the subject? Why is it that some physics content is not taught in the US? One possible contributing factor to these issues is the way that the science curriculum is structured in US high schools. The sciences are taught in one year courses in a fixed order, biology then chemistry and finally physics (B-C-P). Somewhat baffling to non-Americans, this B-C-P order is found in more than 99% of American high schools. The educational logic of the B-C-P order has been frequently questioned (Reeves, 1940; Hoag, 1945; Palombi, 1971; Meyers, 1987; Nappi, 1990; Lederman, 1996)

An increasingly significant reform effort in physics education is the push to reverse the sequence in which the sciences are traditionally taught in US high schools -the "Physics First" movement. This reform effort gained momentum recently when the AAPT issued a statement promoting the teaching of Physics First as being supportive of its goal of Physics for All (AAPT, 2002). So how did physics become the last course in US high school science? It is often asserted that the Committee of Ten in the 1890s initiated the B-C-P science sequence (Lederman, 1998; Mason, 2002), but as will be seen, this is an oversimplification.

Research Questions:

1) *How and when did physics become the last course in US high school science?*
2) *What impact did this have on high school physics offerings and student enrollment?*

The purpose of this study was to attempt to answer these questions by analyzing the historical development of high school physics in the USA. Few studies have been devoted to understanding science education from an historical perspective. Notable in its coverage of the history of science education ideas, DeBoer (1991) has produced the most comprehensive work. Yet no substantial historical work exists on examining curricular change in high school science education. Bybee (1982) was one of the first to note the paucity of literature on historical studies of science education. He found that within a span of sixty years of the publication of the journal *Science Education*, from a total of 3,074 peer-reviewed articles, only 49 involved the history of science education. The lack of historical research points to an unexplored potential for examining science education. In this study a historical approach is taken to set US science educational reforms in perspective.

Discovering its prehistory has illuminated the present state of life on Earth. In similar manner, the assumption of this study, is that science education itself might be illuminated by doing an archaeology of its past. Comparing present day reforms to those of those years gone by might allow us to delineate the forces that contribute to curricular changes and also explain or account for the present state of science education.

Design

Historical studies in education draw upon historical documents. This research identified four main areas of historical data that were used in the analysis.

1) National and State education statistics, from, for example, the National Center for Educational Statistics (NCES) and various state governments for enrollments and subject taking patterns.
2) Reports from major organizations on reform and policy: Starting with the National Education Association (NEA) *Report of the Committee on Secondary School Studies* in1893, popularly known as the Committee of Ten (*CoT*) Report up to and including *A Nation at Risk* in 1983.
3) Reports from professional educational societies and organizations, such as the National Science Teachers Association (NSTA), American Association for the Advancement of Science (AAAS) and National Research Council (NRC).
4) Published educational research from professional journals and commentary by educational reformers from particular time periods.

Data from these varied sources were used to synthesize responses to the research questions. While the analysis of reports and educational research is relatively straightforward, the use of historical educational statistics is more complex. Doran when attempting to document enrollments in advanced science courses pointed out some of the complexities, for example, there was no simple method of identifying advanced science courses from their titles (Doran, 1991). Similar issues arise when using historical statistics, often important data were not collected or were collected in a form that required interpretation. For example, enrollment statistics from the 1890s show the number of students enrolled in each science subject and the total enrollment in high schools, they do not give any information about the grades in which the sciences were taken. Later enrollment data is given as percentage enrollment in a particular grade, e.g. percentage of seniors taking physics which ignores the fact that some juniors are taking physics. Recent statistics use transcripts to denote whether students graduate HS with a credit in the subject, again ignoring the grade at which the subject was taken. For these reasons statistical data needs especially careful interpretation.

Findings.

The findings have been grouped in to several pertinent areas regarding the order of the science courses, enrollment and time allocation.

The History of the Biology-Chemistry-Physics Order:

In 1892, the National Education Association organized a committee of ten individuals, who were charged with determining what should be taught in high school so students from different schools would have a more uniform preparation for college (National Education Association, 1893). The *CoT* organized nine sub-committees each devoted to different academic subject areas including Latin, Greek, English, modern languages, mathematics and history. There were three science sub-committees, one for Physical Science (physics, chemistry and astronomy), another for Natural History (botany, zoology and physiology) and a third for Geography (physical geography, geology and meteorology).

All of the sub-committees were given the same set of questions to answer about what high school science should be studied, how much time should be allocated to science, how that science should be taught and assessed, the best methods for teaching science and whether the subjects should different for college-bound students. The physical science sub-committee was headed by distinguished scientists and educators of the day and in answering the questions, made 22 recommendations to the full committee. The recommendations that were pertinent to the sequencing of the sciences and to when students should study them were:

3. That the study of Chemistry should precede that of Physics in high-school work.
4. That the study of Physics be pursued the last year of the high school course.
5. That the study of Chemistry be introduced into the secondary schools in the year preceding that in which Physics is taken up…
8. That both Physics and Chemistry be required for admission to college.

In justifying their position on the relative placement of physics and chemistry, the majority of the sub-committee wrote:

> ... the order recommended for the study of Chemistry and Physics *is plainly not the logical one* [italics added], but all members with one exception...felt that the pupils should have as much mathematical knowledge as possible to enable them to deal satisfactorily with Physics. (p.119)

In dissenting Weggener, argued that chemistry being more abstract should follow physics, "it seems not unreasonable to suggest that the whole subject of elementary physics forms a desirable basis for the study of elements of chemistry" (p.123). The Physical Science sub-committee was the only academic group to offer a significant objection in the form of a minority report and the bulk of this objection was related to the proposed order in which the sciences were to be taught.

All sub-committees presented their recommendations to the full *CoT,* who combined and coordinated them into plans for high school education. In 1893, the *CoT* submitted their findings in a final report, known as *Report of the Committee on Secondary School Studies* (*The CoT Report*) (National Education Association, 1893). In *The CoT Report,* they outlined what a high school curriculum might look like and suggested four possible courses of study. The science classes and order they proposed are shown Table 1. The *CoT* is often cited as being the originator of the B-C-P sequence, but as can be seen in each of the suggested courses of study, chemistry was placed after physics. Biology is absent from the table, as it was not a distinct subject at the time, but was taught as separate half-year courses in botany, zoology, anatomy and physiology. The sub-committee on natural history recommended a full year of botany for high school study, but made no recommendation about its placement.

Table 1. Science Classes in The Courses of Study Proposed for High Schools by the Committee of Ten

YEAR	**CLASSICAL** Three foreign languages (one modern).	**LATIN-SCIENTIFIC.** Two foreign languages (one modern).	**MODERN LANGUAGES.** Two foreign languages (both modern).	**ENGLISH.** One foreign language (ancient or modern).
I.	Physical Geography	Physical Geography	Physical Geography	Physical Geography
II.	***Physics***	***Physics*** Botany or Zoology	***Physics*** Botany or Zoology	***Physics*** Botany or Zoology
III.		{Astronomy & Meteorology}	{Astronomy & Meteorology}	{Astronomy & Meteorology}
IV.	***Chemistry***	***Chemistry*** {Geology or Physiography} And {Anatomy, Physiology & Hygiene}	***Chemistry*** {Geology or Physiography} And {Anatomy, Physiology & Hygiene}	***Chemistry*** {Geology or Physiography} And {Anatomy, Physiology & Hygiene}

After the Committee of Ten, other committees met and the issue of the order in which the sciences were taught also arose. The Committee on College Entrance Requirements (*CCER*) was convened in 1896 to discuss how to implement the findings of the *CoT*. The committee followed the *CoT* proposals about sequencing and recommended chemistry be taught after physics (National Education Association, 1899). The *CCER* had a profound effect on how the sciences were taught in high schools, but not because of their sequence recommendations. For college admission they proposed that students complete 16 units of study: four would be in languages, 2 in English, 2 in math, 1 in history, *1 in science* and 6 units of electives. These units of study would later come to be known as Carnegie Units. An assumption made by the *CCER* was that many of the electives taken would be in the sciences. The *CoT* had recommended that both physics and chemistry be required for college admission, however, the *CCER* with its proposal of *only one year* of science for graduation, coupled with their late appearance in the sequence, essentially made chemistry and physics electives in high school.

Many states followed the *CCER* recommendations and so for high school students only one year of science was required for graduation. Furthermore, the *CCER* recommendations lead to another effect, unique to US science education, that is, individual sciences became one year courses, not taught over multiple years. There was some debate about offering the sciences continuously through high school (Smith & Hall, 1902), but lack of suitably qualified teachers made such proposals untenable.

In addition to the committee recommendations, major demographic changes were occurring in high schools. Most notably, the number of students in high school was increasing rapidly. Between 1890 and 1920 there was a tenfold increase in high school enrollment from approximately 200,000 to more than 2 million students. The courses of study endorsed by the *CCER* had targeted college-bound students, despite the fact that a smaller percentage of students were going on to college in these years. Consequently, the courses proposed by them were seen as unsuitable for the majority of students. This lead to several important curricular developments, which would impact the science sequence.

Between 1900 and 1920, General Science was introduced and became the most frequently taken science subject, as it met the needs of students for whom it would be a terminal science course and it was seen as a necessary introduction to another new course, general biology (Webb, 1959). Almost simultaneously the separate biology courses (botany, zoology, physiology, etc) were coalescing into a general biology course. Given the more descriptive natures of both general science and general biology courses, they were placed before chemistry or physics (Hunter, 1934). In 1920, *The Committee on Reorganization of Science in Secondary Schools* included general science and biology in their proposed four-year science sequence and recommended that they be offered in 9th and 10th grades respectively (see Table 2). The committee made no recommendation about the specific order of chemistry or physics (National Education Association, 1920).

Table 2. Recommendations for the High School Sequence from Historical Committees

Committee	Date	Sequence	Rationale
Committee of Ten: *(CoT)* *Conference on Physics, Chemistry & Astronomy* ***Majority Report***	1893	C-P	Chemistry before Physics because of more advanced Math level needed for physics.
Committee of Ten: *(CoT)* *Conference on Physics, Chemistry & Astronomy* ***Minority Report***	1893	P-C	Physics before chemistry because physics is foundational to chemistry.
Committee of Ten: *(CoT)* **Full Committee Report**	1893	P-C	All proposed sequences placed physics before chemistry.
Committee on College Entrance Requirements *(CCER)*	1899	P-C	Followed the recommendations of the Committee of Ten
Committee on the Reorganization of Science in Secondary Schools	1920	B-C-P or B-P-C	No recommendations about the placement of physics and chemistry, except that they should be after biology.
Committee on Chemical Education *of the American Chemical Society*	1924	B-P-C or P-B-C	Chemistry should be taught in the senior year after all other sciences.
National Society for the Study of Education: *Committee on the Teaching of Science*	1932	B-P-C or P-B-C or P-C-B	In all possible sequences physics would precede chemistry.
Harvard Committee *General Education in a Free Society*	1945	B-C-P or B-P-C	Biology should precede physics and chemistry. No specified order for either of these.
General Education in School and College: *A Report of the Faculties of Andover, Exeter, Lawrenceville, Harvard, Princeton, and Yale*	1952	P-C-B	Sequence reflects the historical development and relative interdependence of the sciences.

In 1924, the American Chemical Society's Committee on Chemical Education met to discuss the high school chemistry (Gordon, 1924). They recommended that chemistry teachers seek to have chemistry taught in the final year of high school. Part of the rationale for this was that seniors were more mature than juniors and more content could be covered by them. The recommendations of later committees (National Society for the Study of Education.1932; Harvard Committee, 1945; Conant, 1959) about the order of the sciences in high school are also shown in Table 2. By 1930 while there was still no agreed upon order for physics and chemistry, though biology had established itself as first in the order. By World War II, with the exception of the physical science section of the *CoT*, no committee had actually recommended that chemistry be placed before physics.

Science Courses Offered in High Schools.

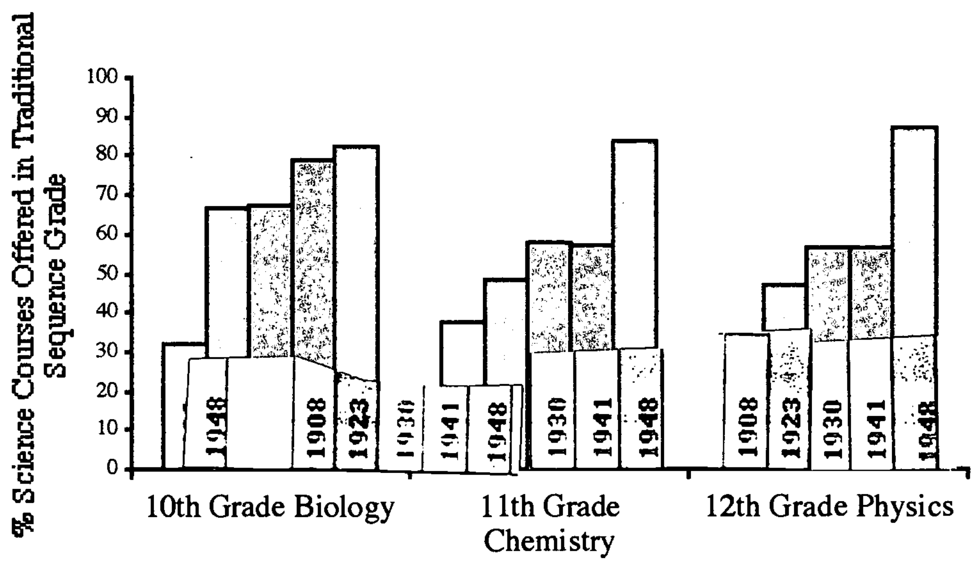
The recommendations of the various committees, surprisingly, seemed to have little effect on the practice in the schools. In 1906, Dexter (1906) surveyed schools to determine what impact the *CoT* recommendations were having, and noted that in the majority of schools, chemistry was being taught after physics. Over the next few decades, Hunter conducted a series of surveys across the country, investigating the order in which the sciences were taught (Hunter, 1910; 1925; 1931; 1942). Table 3 summarizes the results for the years 1908, 1923, 1930 and 1941 and shows the percentage of physics and chemistry courses that were offered in the junior and senior years. It should be noted that at this time many small schools did not offer physics and chemistry every year.

Table 3. Physics and Chemistry Course Offerings in US High Schools from 1908 to 1941

	Percentage of Courses Offered in Specific Grades			
	11th Grade		12th Grade	
Year	Chemistry	Physics	Chemistry	Physics
1908	37.5	55.4	57.6	33.7
1923	48.1	50.0	50.1	46.9
1930	58.0	41.8	33.8	56.7
1941	57.0	41.9	41.6	56.2

The results concur with the earlier Dexter study that chemistry was more often taught after physics in the early twentieth century, though there was a slowly evolving trend away from this practice. By 1930 the majority of schools were offering chemistry before physics and by 1948, more than 80% of students who took chemistry in high school did so in the 11th grade (Johnson 1953). Figure 1 shows how the specific subjects came to be fixed in particular grades[1].

Figure 1. Science course offerings by subject and grade level



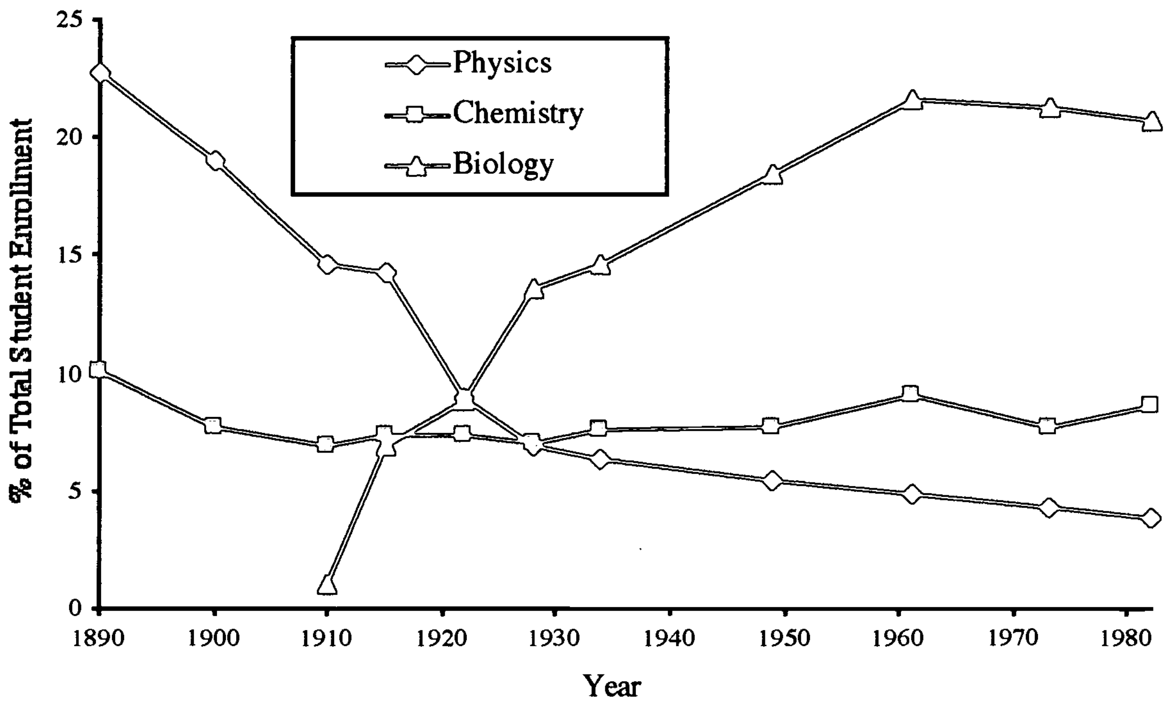
Enrollment.

With the CCER's one credit requirement, coupled with the evolving B-C-P sequence, physics became an elective and its enrollment as a fraction of the high school population fell (see Figure 2). Simultaneously, the percentage enrollment in biology rose, while in chemistry enrollment remained approximately constant. From the introduction of science into schools until the early 1920s, more students had enrolled in physics than in either biology or chemistry. By 1930, the situation had changed and physics had the lowest enrollment of the specialized science courses. This decline in the percentage enrollment in physics continued for much of the 20th Century. Physics enrollment as a percentage of the population reached its nadir in the 1980s with less than 20% of high school graduates ever having enrolled in physics (Pallrand & Lindenfield, 1985). This contrasts with the recommendation of Committee of Ten that all high school students take physics.

[1] The 1908 - 1941 data is calculated from the Hunter studies. The 1948 data is from Johnson (US Office of Education, 1950). The 1948 data has been calculated from student enrollment and course offerings.

Presently, approximately 30% of students enroll in physics in high school, which is a considerably lower percentage than many other countries (Neuschatz & McFarling, 1999).

Figure 2. High School Enrollments in the Sciences 1890-1982



Another important trend in enrollment concerns advanced physics classes. In 1996, only 1% of graduating high school students had taken a second year of physics. That so few enroll in a second year of physics is understandable given that introductory physics is usually taken in junior or senior year effectively curtailing advanced physics study in high school. These enrollment statistics in advanced physics are much lower than those of other countries, where historically, no rigid science sequence arose (Neuschatz & McFarling, 1999). In many countries, all students take an introductory physics class and numerous countries have more than 10% of their students enrolled in advanced physics classes.

Discussion

The B-C-P order of taking sciences in US high schools was not planned and did not arise as a result of decisions made by any education or policy committee - it is the product of historical accident more than educational design. There were three important historical factors that influenced how high school science came to be sequenced.

1. Decisions made by educational committees before 1900, established individual sciences as one-year courses. This in turn forced the sciences to be taught in a specific order.
2. The rapidly expanding high school population in the early 1900s lead to the introduction of General Science and General Biology as subjects. Given the descriptive nature of these subjects at the time, they were taken before physics and chemistry. With most states having only a one-year science graduation requirement, physics and chemistry became electives.
3. The practice in the schools of placing physics before chemistry slowly changed. Despite its being considered a foundational science, physics was by 1930 being offered after chemistry in the majority of schools. This trend continued through the twentieth century until B-C-P became the status quo.

While it may appear to be obvious and trivial that science became one-year courses, this did not happen in other disciplines, English, history, mathematics, modern and classical languages, all became taught sequentially over several years, with correspondingly larger curricular time allocations per subject. Science, however, came to be treated as a single subject in high school, with physics, chemistry and biology combined having the curricular time of other subjects. This was not how high school sciences developed elsewhere in the world. Even in 1902, for example, Germany, England and France were teaching physics in schools over three or four years and with proportionally greater time allocations (Smith & Hall, 1902). Further, in many countries it has always been possible to take more than one science per year, greatly increasing the amount of curricular time for science.

The impact of teaching the sciences in one-year courses in a specific order has placed a large constraint on their development. Despite the sciences having undergone great advances in breadth and content, over the last century, there has been little change in curricular time devoted to them. Further, the time allocation is also considerably lower than what the original reports recommended. The science sections of the *CoT* suggested that 25% of curricular time in each year of high school be given to science, with an actual time allocation of 200 hours in both chemistry and physics. In the full *CoT* Report, the time was slightly reduced, but still science was allocated more than 20% of curricular time in three of the four high school courses they proposed. Presently, students spend only 10-15% of the available curricular time in high school science. Again this is considerably less than many of their international counterparts and helps to explain for why some content is not taught in US high schools- there simply isn't time. The lack of time also lead to "teaching-by-telling" methodologies for instruction. With large amount of content to cover in a short period of time leaves little, if any time for experimentation and inquiry based learning.

Robinson has argued that the B-C-P sequence is strictly not a sequence, as biology is not a prerequisite for chemistry, nor chemistry a prerequisite for physics (Robinson, 1960). Haber-Schaim (1984) supported this view by analyzing the concepts included in high school science texts, and showed that from a conceptual point of view a Physics-Chemistry-Biology order was more logical. A glance at any introductory biology text or curriculum shows that it contains a wealth of chemistry and consequently much elementary chemistry is understandably being taught by biology teachers. While physics educators are calling for 'Physics First' (AAPT, 2002), biologist teachers could convincingly argue for 'Biology Last', if high school science is to be taught in a fixed order.

The historical development of high school science education via the B-C-P order coupled with low graduation requirements inevitably lead to low enrollments. With most states initially having only a one-year science graduation requirement, physics and chemistry became electives, taken by a minority of students. When the majority of states moved to a two-year requirement in the 1980s, enrollment for all sciences increased, biology essentially became a requirement and the percentage of students taking high school chemistry doubled (NCES, 1999). Presently, the majority of high school students graduate with a chemistry credit. With a significant number of states moving to a three-year requirement, chemistry will become a requirement in these states.

The sequencing of science subjects in US high schools has recently become a hotly debated topic. A growing number of schools have changed or are considering changing to a "Physics First" approach in which physics becomes the first science subject in secondary schools. This approach, has garnered wide discussion among teachers and educational reformers. Recent meetings of the American Association of Physics Teachers included whole sessions on Physics First and the 2002 National Science Teacher Association (NSTA) Annual Conference similarly devoted time to examining sequencing and freshman physics. Notably the NSTA annual conference was held in San Diego, a school district that is in the process of moving to Physics First.
There are many implications to placing physics first. As a freshman course and as a foundation for other sciences, it would at least triple its present enrollment and most students would graduate with a credit in physics. The status of high school physics would change immediately, because as a core subject, physics would be viewed as a component of a modern and liberal education accessible to all.

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