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James B. Conant in the Mid-20c. General Science Education Movement

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Abstract

At the heart of science education lies the question of whether one should learn science and if so, who should and what of science should be learned. Education is to serve – therefore, it must be considerate of its participants and what it intends to deliver to them. Quite frequently, people of the past have already pondered upon questions that trouble people of today. This research resorted to James B. Conant (1893-1978), the 23rd President of Harvard University for answers to these unresolved questions.

Conant was not a new name in literature. He could be described with the three words of science, politics, and education. As the president, Conant implemented new policies on student scholarships and faculty professorships at Harvard – thus, the two words *politics* and *education*. During WWII, he served several leadership positions in governmental agencies, namely the Chairman of NDRC to supervise scientific research for military defense and the Interim Committee to negotiate wartime use of the atomic bomb – thus, the two words *science* and *politics*. While conducting a literature review on Conant, a gap was found between the two words *science* and *education*. Thus, two research questions were established. What roles and contributions did James B. Conant make in the reformation of general science education at Harvard University post-WWII? What were his ideas and methods on general science education at the college level as revealed in one of his books on science education titled *On Understanding Science* (1947)?

When Conant returned to Harvard to revolutionize its education system after WWII, he was faced with a larger, broader student body with ambivalent attitudes toward science. To normalize education at Harvard, he paid special attention to general education. He commissioned the Harvard Committee on General Education, which published the widely-distributed *General Education in a Free Society* (1945), also known as the Harvard Red Book. The Committee argued for a wider definition of science in general education that saw science as a part of a larger intellectual and historical process, not just an accumulation of facts. The new aim for general science education was to foster an integrative understanding of scientific methods, the development of scientific concepts, and scientific worldviews. Conant personally taught a general science course titled “On Understanding Science”. His take on general science was a historical and philosophical approach incorporating case histories from the history of science. He worked in close proximity with Cohen, Holton, Nash, and Kuhn to assemble the historical materials on which Conant’s case histories were based. He also organized a series of conferences that discussed the future direction of general science education.

On Understanding Science (1947) contained Conant's response to the problems of general science education raised in the Harvard Red Book. Conant carefully concocted two phrases – "Understanding Science" and the "Tactics and Strategy of Science" – to embed his ideas on general science education. Understanding science was having the *feel* for the Tactics and Strategy of Science (e.g., having a sense of what science could and could not achieve) that supported people in their decision makings on future issues and plans. The Tactics and Strategy of Science represented the ways in which science progressed. Conant, using a metaphor on military tactics and strategy, depicted science, neither as the epitome of impartiality nor rationality, but as a complex process full of barriers and failures. The Tactics and Strategy of Science was further split into three large principles A, B, and C: A emphasized the dynamic interaction between scientific concepts and experimentation or observations; B recognized the intricate quality of experimentation and observations; C differentiated practical arts from science but emphasized its importance to science. Conant weaved his principles of the Tactics and Strategy of Science into the case histories in order to establish some understanding of science. He advocated a generalization learning where broad principles of science were studied from fewer, more detailed case histories. He used a non-linear, plot-driven narrative to discuss various sub-principles at prime moments in the case histories.

This research concluded that Conant was one of the protagonists of the general science education movement at the college level that occurred in the mid-20th century US. He was more than an administrator in science to transfer ideas on science education at the administrative level to actual practice. His principles not only demonstrated close resemblance to the Nature of Science (NOS), a popular concept in today's science education, but also in general, Conant was able to criticize issues in science education that were still relevant today. Lastly, despite that his approach waned, Conant's ideas on general science education had lasting impacts on the field, mainly NOS and scientific literacy.

Keyword: general science education, college education, James B. Conant, history of science, history of science education, case-study approach

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Chapter 1. Introduction

At the heart of science education lies the question of whether one should learn science and if so, who should and what of science should be learned. Education is to serve – therefore, it must be considerate of its participants and what it intends to deliver to them. Science educators have attempted to tackle these questions for decades or even centuries. However, to this date, they remain unresolved with science educators around the world proposing different ideas over these questions. Puzzling the situation may be, this also hints that it is likely the prime moment to look back on history. Quite frequently, people of the past have already pondered upon questions that trouble people of today.

Traveling about seven decades back into the history of science education, this research resorted to James B. Conant (1893-1978), the 23rd President of Harvard University for answers to these unresolved questions. Science education in the 1940s to the 50s underwent major changes at the college level, and at the center of the changes was Harvard University and its president Conant. This was a period of reformation with the university bringing in drastic changes to its general education curriculum. Science of all subjects received the greatest attention and, perhaps, also the greatest treatment. The effort gradually spread across colleges around the nation. The most probable explanation for this renewed attention on science education was the sense of crisis that gripped the entire country after two consecutive world wars. In response, new policies on science and science education poured out, among which was the seminal report of *Science, the Endless Frontier* (1945). In order to assimilate science into the lives of every man, Conant and many science educators of the time proposed new ways of teaching science.

1.1 James B. Conant

Three words could be used to define who James Bryant Conant (b. 1893-1978) was: science, politics, and education. During his lifetime, Conant pursued numerous roles that could all be described by one or more of these words. In brief, Conant was first a student with a keen interest in chemistry, then a researching chemist as well as a professor in chemistry. As he took on the administrative role as the President of Harvard University in 1933, he grew added interest in politics and education. His two-decade service as a powerful educational administrator was marked by progressive reforms in not only the university management but also its curriculum. Conant was also a man of war to have participated in all three major wars of the century – the two World Wars and the Cold War. The table below summarized the major offices and posts that Conant held during his lifetime, to provide an overview of who he was and just how much influence he had over the US and the world.

He was likely a respected man for several biographical memoirs from prestigious institutions and organizations such as the National Academy of Sciences and the Royal Society were found (e.g., Bartlett, 1983; Kistiakowsky & Westheimer, 1979).① As for the National Academy of Sciences, Conant was nominated without contest as president in 1950 but as some members insisted on the need for a full-time president, Conant withdrew his name for his friend, Detlev W. Bronk, who was finally elected (Bartlett, 1983). Entire books written on Conant were found, and this more than sufficiently explained the impact this man had on different areas of society, especially fields of national defense, arms control, and governmental policies. Some titles found were *James B. Conant: Harvard to Hiroshima and the Making of the Nuclear Age* (1992) by James Hershberg and *Man of the Hour: James B. Conant, Warrior Scientist* (2017) by Jennet Conant, both being massive books of over 900 pages.② Jennet Conant was the granddaughter of James B. Conant but also an acclaimed author with several bestsellers on WWII, and in her book, more intimate descriptions of Conant could be discovered.③

Table 1. Major Offices and Posts of James B. Conant

Title of Position	Period of Service
Major of the Chemical Warfare Service during World War I	1917-1919
Assistant Professor of Chemistry at Harvard University	1919-1929
Sheldon Emery Professor of Organic Chemistry at Harvard University	1929-1933
Chairman of the Chemistry Department at Harvard University	1931
23rd President of Harvard University	1933-1953
Chairman of the National Defense Research Committee	1941-1947
President of the American Association for the Advancement of Science	1945
American High Commissioner for Occupied Germany	1953-1955
United States Ambassador to Germany	1955-1957

① The former memoir had a science-focus to it, considering that it was published under the National Academy of Sciences, whereas the latter, which was also by the Royal Society, provided a broader overview of the achievements that Conant made.
② Hershberg wrote his doctoral dissertation on Conant which served to be the basis of his book on Conant. This dissertation was worked under Tufts University and published under the Office of Scientific and Technical Information of the US Department of Energy.
③ Jennet Conant's book on her grandfather was reviewed in the New York Times soon after publication by Kai Bird, a co-author to a Pulitzer Prize winning book. https://www.nytimes.com/2017/11/07/books/review/jennett-conant-man-of-the-hour.html

1.1.1 Conant as an Educational Administrator

Naturally, Conant was not a new name in literature. He was covered plenty in books and studies on educational management and administration, a field that could be epitomized by his career as a transformative president at Harvard. He began his post in 1933, before which his only leadership position was Chairman of the chemistry department, and this placed a stopper to his early ambition as an organic chemist. His belief in meritocracy and equal opportunity was reflected in the numerous policies, especially those related to student and personnel selection, that he introduced to Harvard. Just one year into the presidency, Conant established the National Scholarships that covered the college and living expenses of promising students. Unlike the existing honorary scholarships that were given to students with top academic achievements, Conant's scholarship was special in that it ensured especially the poor students with full campus experience (Kistiakowsky & Westheimer, 1979; Urban, 2010). In addition, Conant made amendments to the rusty policies on faculty promotion; Despite the financial pressures post the Great Depression, he risked to promote and offer University Professorships to promising faculty members as a means to create the strongest team of scholars in the world (Bartlett, 1983; Kistiakowsky & Westheimer, 1979; Reisch, 2019). Another of his relatively well-known yet controversial reforms was the 'up or out' policy that sacked teaching staff that failed to get promoted to a tenured rank for more than eight years and this served to liven up the stagnant faculty composition (Kistiakowsky & Westheimer, 1979; Reisch, 2019). Administrative reforms were mostly implemented in the 1930s before Conant's attention was diverted to the war.

Figure 1. Photo of Conant (Bartlett, 1983)

Conant saw public education as the key to achieving American democracy. In order to improve the learning and teaching at public high schools, people had to appreciate the purpose of it – for instance that a high school education could guarantee a college education that further secured a better job position. Conant was likely aware of this and on the basis that students should be selected by merit, he searched for ways to diversify the students entering Harvard. His name was easily found while tracing the history of standardized testing as a tool for student selection. Conant was a strong advocate of the Scholastic Aptitude Test (SAT), still notorious among students today, which was originally developed by Carl Brigham of Princeton based on a test used during WWI for recruiting military officers and applied locally for selecting students at Princeton (Calvin, 2000). Conant's interest in the test began as he sought out a standardized measure for picking the recipients of his National Scholarships whom he aimed to pull from a wider pool of applicants in terms of their geographical, economic, and social background (Calvin, 2000; Finneran, 2002; Urban, 2010).④ Note that this was still a time period when privileged, upper-class men composed most of the college student body. He had the vision that the SAT, replacing the existing essay test also from the College Board, would diversify the students on campus as this multiple-choice test could be more widely administered to students across the country (Calvin, 2000). He was neither the first to advocate the use of standardized testing for student selection nor the creator of the SAT. Nonetheless, his name was abundantly referenced in prior research as it was his voice that brought attention to the idea that student selection should be based on aptitude, not achievement (e.g., Atkinson, 2001; Tozer et al., 2013).⑤ Hence, Conant could be seen as one of the main contributors to the use of standardized aptitude tests in selecting students emerging from high school, whether this was for college admission or scholarship.

1.1.2 Conant as a Politician and a Science Advisor

ERNEST O. LAWRENCE, ARTHUR H. COMPTON, VANNEVAR BUSH, AND JAMES B. CONANT *(left to right), four of the Manhattan Project's scientific leaders (1940 photograph)*

Figure 2. Conant and the Scientific Administrators of the Manhattan Project (Jones, 1985)

Conant put down his identity as an educational administrator as the Nazi threat posed an imminent danger of another war (Bartlett, 1983; Kistiakowsky & Westheimer, 1979). He exercised vigilance even during the period of isolationism, and this was when he turned back to science – however, this time not as a working scientist but as a politician interested in using science to combat Nazism. It could be postulated that he formed an early-on opposition against Nazi Germany, quite ironically, due to his old fondness for the German intellectual culture.⑥ Gradually from his several lengthy visits to

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④ The SAT in its early days showed high reliability with decent correlation between the scores of the examinees and their grades in freshmen year of college (Calvin, 2000).

⑤ As to the effectiveness of using the SAT for student selection, it was found that Conant later recalled his such choice as being naïve. For greater detail on Conant, standardized testing, and student selection, refer to Tozer et al. (2013).

⑥ He even visited Germany with his wife for eight months shortly after their marriage in 1920. Conant highly praised the scientific achievements of Germany, attributing to the

Germany during the 1920s to the 30s, Conant dissented from the German culture developing particular hate against Hitler and his ideas (Kistiakowsky & Westheimer, 1979).

Conant took on a fierce interventionalist stance towards WWII, which was evident in the many activities that he took part in. Needless to say, he made frequent appearances in books and studies on the second World War, particularly those with an American perspective (e.g., Groves, 1962; Jones, 1985; Hershberg, 1992).⑦ Triggered by the German invasion of Poland, from 1939 to 1940, Conant expressed public disapproval of the neutrality act, joining the 'Committee to Defend America by Aiding the Allies' and calling out the need for military conscription (Kistiakowsky & Westheimer, 1979). As the previous world war had already proven the importance of science in war, the National Defense Research Committee (NDRC) led by Professor Vannevar Bush of MIT was established in 1940 under the support of President Roosevelt to make full use of civilian scientists and engineers for developing new war instruments. Conant was originally in charge of the chemical warfare division of NDRC but was made its chairman as the committee became subordinate to the Organization for Scientific Research and Development (OSRD) headed by Bush in 1941.⑧ Research on uranium was already demonstrating success with spreading optimism for atomic weaponry when the Japanese military attacked Pearl Harbor on December 7th, 1941 (Jones, 1985). This incident accelerated the process of developing the atomic bomb with Conant and Bush arguing for maximum effort on the project – they were the technical dignitaries at the cabinet-level policy group overseeing the project (Bartlett, 1983).

Conant was known for his support of the use of atomic bombs in WWII.⑨ It was not difficult to find out that he received the thickest coverage in literature with a vantage point on the development of the atomic bomb (e.g., Groves, 1962; Jones, 1985; Meigs, 1982). With the Trinity detonation being a success, he joined the

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"cosmopolitan, pluralistic, and highly competitive" nature of the German academia (Reisch, 2019).

⑦ *Now It Can Be Told: The Story of the Manhattan Project* (1962) was written by Lieutenant General Leslie R. Groves, one of the two along with J. Robert Oppenheimer that was chiefly responsible for the Manhattan Project. *Manhattan: The Army and the Atomic Bomb* (1985) by Vincent C. Jones, a historian at the US Army Center of Military History, provides detailed accounts of the Manhattan Project. Reviewed by the numerous participants of the project including Conant, it is a work of high historical value.

⑧ Conant was involved in the development of poisonous nerve gases introduced in the trench warfare of WWI as a Major in the Chemical Warfare Service. This background of his likely led to him heading the Division B, Chemical Warfare Division, of NDRC at the early stages of WWII.

⑨ The degree to which Conant affirmed the use of atomic bombs varied between books and studies but was confirmed that he was one of the relatively-stronger advocates of the bomb.

Interim Committee to advise President Truman on the wartime use of the catastrophic bomb. Feeling uncomfortable about himself delegating to the scientific community, he instigated the creation of the Scientific Panel, which invited the other scientific administrators of the project including Arthur Compton, Robert Oppenheimer, Ernest Lawrence, and Enrico Fermi (Bartlett, 1983). According to Jones (1985), both the committee and the panel agreed on the use of the bomb against Japan, although there were debates on where it should be dropped and whether precautions should be given.

1.1.3 Conant as a Science Educator

This research reviewed prior works on Conant to discover that his career could be described with the three words of science, politics, and education. As its president, Conant took on the identity of an educational administrator to implement new policies on student scholarships and faculty professorships at Harvard – thus, the two words *politics* and *education*. His reforms reflected his philosophy in education based on meritocracy in order to achieve true American democracy. During WWII, Conant involved himself in several leadership positions in governmental agencies, namely the Chairman of NDRC to supervise scientific research for military defense and the Interim Committee to negotiate wartime use of the atomic bomb – thus, the two words *science* and *politics*. Before proceeding to the last pair of science and education, one limitation should be addressed: an oversimplification had been committed. This research admits that to define someone like Conant who had countless obligations in his life using just three words could be a serious error, making the research narrow-sighted.

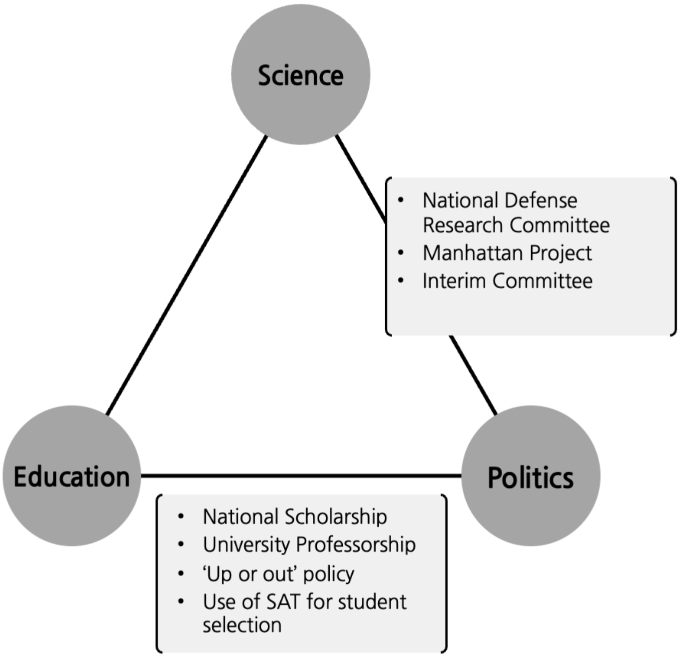

Figure 3. Identities of Conant as Portrayed in Prior Research

However, while conducting a preliminary literature review on Conant, a gap was found between the two words *science* and *education*. It would be an overstatement to suggest that there were absolutely no studies on Conant in terms of his contributions to science education. Small portions dedicated to Conant's activity in science education were found inside either biographical works on Conant or monumental books in science education.[10] Frankly, this research began from a book written by a science educator – *A History of Ideas in Science Education: Implications for Practice* (1991) by George E. DeBoer. DeBoer (1991) briefly mentioned Conant and the Harvard Committee of General Education proposing a general science education at the college level that emphasized a more holistic understanding of science instead of a compilation of facts. It was from DeBoer's page-long description of the Harvard Committee and Conant that the books *General Education in a Free Society* (1945) and *On Understanding Science* (1947) were initially recognized. The former of the two books, which was a report by the committee, was already a classic text in education; however, it was scarcely reviewed and analyzed with a science-educational lens. The latter was an independent piece by Conant, which DeBoer explained was his response to the committee report, that received little spotlight so far in science education.

[10] These were pieced together in the next chapter of this research that outlined the general science education movement at Harvard with particular focus on Conant.

To conduct research for the reason that a topic had not been studied would not pass as a satisfactory justification. Conant was chosen as the subject of this research not merely for his intriguing profile – such as him participating in the Manhattan Project or being the president of a prestigious university for two decades – but also because he was found to be associated with the roots of the history of science in science education. Matthews (2015) called the integration of the history of science into science instruction in the US a “Conant legacy” that began approximately 80 years ago when Conant took on the historical approach to teach science to nonscientific major undergraduates. Hamlin (2016) also claimed, though arguably, that Conant was the “most powerful champion” and an “instigator” of the history of science movement in science education. Hamlin’s study was reviewed thoroughly as its title – “The Pedagogical Roots of the History of Science” – at the least, seemed to coincide with what was to be dealt with in this research. It provided an overview of the rise and fall of the history of science as a pedagogical approach, setting Conant as the protagonist of his narrative. Mainly, his research questioned the irony of Conant being a power elite and expert advocating general education for political – e.g., meritocratic, egalitarian, Deweyan, democratic – purposes and revealed controversies over the historical approach that existed among contemporary scholars. He focused on the social turmoil surrounding the history of science as a Conantian pedagogy, such as the clash between Conant and historians like Sarton and Cohen or philosophers like Kuhn and Polanyi, and restrained from giving Conant’s works in science education (e.g., *On Understanding Science*) a pedagogical evaluation.

1.2 Purpose and Aim

Therefore, this research aimed to evaluate Conant and his contributions to science education in terms of their educational value. The process legitimately involved setting aside some disputes over Conant as a person and some criticisms of his pedagogical nostrum from his contemporaries. For the least, this research considered the humbleness or kindness of a man trivial to the evaluation of his books in science education. It also believed posthumous values could be lifted from Conant's works to overcome those that in retrospect condemn the historical approach for its short shelf life. An underlying assumption was that his glamorous career and behind that, his strenuous efforts all gradually contributed to shaping his historical approach to general science education using case studies – now on, *the* case-study approach. One fallacy that this research did attempt to avoid was making hasty appeals on the practical value of Conantian science education; Instead, it strived to reappraise his works for what they had to convey in an explicit manner.

Hence, the research questions were as follows:

- What roles and contributions did James B. Conant make in the reformation of general science education at Harvard University post-WWII?
- What were his ideas and methods on general science education at the college level as revealed in one of his books on science education titled *On Understanding Science* (1947)?

This research aimed to reappraise Conant as a science educator by uncovering the roles he played in the mid-20th century, general science education movement at the college level and by investigating *On Understanding Science* (1947) that he wrote on a general science course that personally taught at Harvard. This period in the history of science education deserved special investigation as it was found that it coincided with when history and philosophy were first embedded into the teaching and learning of science. Conant and many others began interpreting science in a wider sense to introduce its history and philosophy as parts of science. Such views on science were responded to by the use of historical and philosophical approaches in science education, especially at the college level and for general education.

1.3 Operational Definition

This research limited its interests to Conant in general science education at the college level with particular emphasis on his historical approach to general science education as portrayed in *On Understanding of Science*. Before pleasing such interests, it was deemed mandatory to set clear operational definitions for some terminologies. This process was accompanied by a brief literature review of the terminologies as well.

1.3.1 General Science Education

This research was narrowed on Conant and his contributions to general science education at the college level. From this point onwards, the abbreviated phrase "general science education" was used synonymously, and discussions on general education at the level of secondary education were avoided. The phrase "general science education" was not common in literature with more books and studies using phrases such as "general education in science" or "science in general education" to refer to the same concept (e.g., Harvard Committee, 1945; Conant, 1945b; Cohen & Watson, 1952; Watson, 1988). However, dropping expendable prepositions was an intentional choice for making terminologies concise.

In literature, the endeavors to change science education for the nonscientists that took place during the mid-20th century more often alluded to reforms at the secondary level. Here and for the college level as well, the temporal setting of the mid-20th century referred to the time period lasting between the end of WWII to approximately the Sputnik shock of the Cold War. Anyways, the focus on secondary education was partially due to research in education being inclined toward secondary rather than tertiary, with tertiary education still being optional in contrast to secondary education being compulsory in most countries. Therefore, it was not surprising to find that DeBoer (1991), in his long summary of the history of science education mainly in the US, dedicated most discussions to high school. The concern when it came to general science education largely focused on the lack of students enrolling in science majors at college and a claim that general science both at high schools and colleges should educate students to form some appreciation of science (DeBoer, 1991). In order to provide an overview of changes in science education, details of how Conant and the Harvard Committee innovated general science education at the college level were omitted. Even in the committee's report *General Education in a Free Society*, which was analyzed in depth later on in this research, general science education at secondary schools and Harvard College had an even share as to how it should be run.

Nonetheless, the general science education movement at the secondary level was examined and briefly summarized based on DeBoer (1991). One of the issues that troubled the US was the low enrollment rates in secondary science courses. In response, the need for courses that were more relevant, useful, and appealing had spread. Progressive reforms reduced the structural content of science disciplines as the applicability and functionality of science were stressed. The objective of science instruction at secondary schools was to make its contents of learning "function" in everyday life, and in response, a line was drawn between general education and specialized education. General science and biology were taught as part of general education in contrast to physics and chemistry which were taught as college preparatory courses. Such an approach was nicknamed "life adjustment education" for its emphasis on education fulfilling the real-life needs of students. The general science education movement at the secondary level waned towards the end of the 1940s as criticisms of the decline in education standards and anti-intellectualism became popular.

To focus on the college level was a matter of choice, not of favor nor to convey any superiority of one over another. However, this research had to admit that one of the reasons the college level was chosen was due to it having less coverage in former studies and books than the secondary level.

1.3.2 History of Science in Science Education

The next terminology that required an operational definition was the history of science in science education. Although not as complicated to define as the one prior, history of science in science education needed to be differentiated from the history of science used on its own. In literature, the history of science more frequently referred to either the actual historical records of how science developed as a human activity or the field of study that organized and archived these records. In contrast, the history of science in science education handled the history of science as either a pedagogic content or an approach. This research involved both as it was found that Conant utilized a historical approach, i.e., the case-study approach, to teach the history of modern science. This would be detailed in Chapter 3 of this research.

Debates over the pedagogic value of the history of science in science education had not yet ceased. On the affirmative side, for instance, Matthews (2015) provided six reasons for having history in science education. He argued that history: allowed a better understanding of scientific concepts and methods, connected individual thoughts to the development of scientific ideas, had intrinsic value, formed an understanding of the nature of science, made science engaging, and connected science to other areas of knowledge. Similarly, Gooday et al. (2008) added that learning the history of science could not only train the skills of reading comprehension, critical thinking, and argumentation but also, most importantly, offer a broader understanding of science as a process. On the negative side, for instance, Höttecke and Silva (2011) analyzed the hardships in implementing the history of science, particularly physics, in classrooms. Some obstacles revealed included but were not limited to history being abstract, time-consuming, and less important than conceptual contents and clashing with teachers' epistemological beliefs on science.

A brief examination of the link between the history of science and Conant or Harvard University was done. In the field of science education, Conant was probably best known for his contributions to promoting and establishing a history-based science pedagogy (e.g., Russell, 1981; Hamlin, 2016). The academic domains of the philosophy of science and the history of science were established before and during Conant's tenure respectively, but both, especially the latter, were only stabilized as they were employed as pedagogical tools in the general education program (Hamlin, 2016; Harvey, 1999; Hershberg, 1992). Likewise, Harvard University was known in science education for cultivating the historical and philosophical approaches to teaching science but even more, for launching the Harvard Project Physics during the Cold War era. Conant at first established new courses on the history of science in the university's general education program. Simultaneously, he and his collaborators such as Holton, Watson, Nash, and Kuhn collaborated to finally put together *Harvard Case Histories in Experimental Science* (1957), an invaluable compendium of historical cases in science. These attempts were disseminated within a few decades to other undergraduate programs and even secondary education – e.g., Klopfer and Watson's work on the course of the History of Science Cases for Schools (HOSC) in the 1960s (Matthews, 2015).

1.4 Methodology

There was no textbook method for conducting research on a historical figure. This was especially the case for research in science education where the *history of science education* was a rather peripheral field – or as Rudolph (2008) put it, a niche field. Arguably, journals in science education such as *Science & Education* (established in 1990 under founding editor Michael Matthews) and *Journal of Research in Science Teaching* (established in 1963 under NARST) could be regarded as active archives of science education. Regardless of how valuable these were, they were not of practical use to this research. Although outdated, Brock (1975) once criticized the relative lack of biographical studies on science educators in comparison to the historical studies on societies or institutions (both educational and academic), legislations or policies, and biographical studies on famous scientists. Three decades later, Rudolph (2008) reported an update on the expansion of the history of science education to include more-recent topics such as classroom design, evaluation methods, and to the interest of this research, biographies of science educators. However, of all the studies introduced, little pursued biographical purposes. Bertomeu-Sánchez (2015) supported that more studies had been done on historical figures in science, including teachers, with a new light on the sociocultural aspect of the history of science but specified the lack of biographies of teachers (e.g., Lavoisier) and analyses on their publications. Hence, in order to conduct this research on Conant, which aimed to reappraise him as a science educator, prior studies in science education with similar goals had to be unearthed.

1.4.1 Reappraisal of Science Educators

With every change in science and society, there were science educators that incorporated these changes into education. Former studies that investigated science educators from the past revealed the ideas on science and science education that these historical figures possessed, which evidently led to reforms in the actual teaching and learning of science. It was based on their views and understanding of science that their idealistic science education was constructed and implemented into the education scenes. A literature review of the studies on science educators found that the number of studies that focused on an individual was not plenty: only a few (e.g., Song, 2006; Matthews, 2015) conducted full-blown biographical studies on science educators for their ideas and perspectives; rather, more studies tended to accentuate a particular idea or concept from science educators (Rudolph, 2008) and develop it to be more suiting to the contemporary education (e.g., Crawford, 1998).

There were several studies that reappraised individuals that were previously not recognized as science educators. These included but were not limited to the following: Song (2006) reappraised Joseph J. Schwab (1909-1988), better known as a curriculum reformer, as a science educator who asserted the relevance between how science functions and how, therefore, science should be taught. That is, for Schwab, the question of how science should be taught leaned on his answers to what science was. He acknowledged the diversity in scientific knowledge to classify four types including taxonomic science, measurement science, causal science, and relational or analogical science; and he identified two types of scientific enquiry – namely, static enquiry and fluid enquiry. He vouched for science education that covered this diversity and incorporated fluid enquiry where students could learn science in an investigative and progressive manner.

Matthews (2015) regarded the Englishman Joseph Priestley (1733-1804) as one of the precursors for bringing Enlightenment values into science education, stating that Priestley emphasized the close relationship between scientific theory and practice and advocated the connection of science to other subject matters of life. Priestley as a chemist in 17th-century England was an avid reader of works by some of the greatest scientists of his time (e.g., Galileo, Boyle, Newton), observed the birth of one of the earliest scientific societies – the Royal Society, and experienced firsthand the competition for scientific explanations (e.g., his opposition against Lavoisier's theory on oxygen). These likely provided grounds for Priestley's preference for laboratory science, enquiry teaching, and lively classroom engagement of students.

From briefly reviewing prior research on science educators in the history of science education, patterns could be found. Science educators were mostly also scientists that had keen interests in the teaching and learning of science. Hence, their view and understanding of science as a discipline and an activity hugely shaped their ideas on how science should be taught. That is, it was found that it is important to know how a science educator viewed science in order to fully comprehend the purpose and intention behind their suggestions in science education. Regarding scientists being doubled as science educators, Song (2006) suggested that this was largely the case prior to the 1960s when science education finally was established as an independent field. Note that one of the earliest journals in science education, the *Journal of Research in Science Teaching* began in 1963. Until then science education was usually a side interest of a few scientists that developed interests in the education of their field. Furthermore, the temporal and geographical settings, as well as the societies that the science educators lingered in, were shown to have an impact on the ideas of science and science education. These patterns found in prior studies on science educators were reflected in the structure of this research.

The mid-twentieth century was a period of rapid changes in science education, particularly in the US. DeBoer (1991) identified several names in his *A History of Ideas in Science Education* that phenomenally shaped and changed science education including Michael Faraday, John Tyndall, Thomas Huxley, Herbert Spencer, Justus von Liebig, Joseph Hooker, Henry Armstrong, Lancelot Hogben, and James B. Conant. Among these names, this research chose to study Conant as a science educator, particularly his ideas on general science education for non-science major students. There were two justifications for such a choice: *First*, Conant as an advocate of general science education at the college level could provide answers to one of the most fundamental questions of science education: to what extent should science be taught to the non-science population and why? Having experienced World War II on the frontline, he understood more than anyone the need for non-scientists to understand science in order to make informed decisions on macro-scaled (e.g., national, international, nuclear) issues. *Second*, if science was to be taught to the general non-science population, how so? Conant was one of the earliest to integrate the history of science into science teaching. Particularly, he proposed the case-study approach to science education for laymen. This idea was reified as new undergraduate courses in the history and philosophy program at Harvard University.

1.4.2 Research Methods

This research was a study of Conant as a science educator and his contributions to general science education through his case-study approach in the study of the history of science. It underwent a document analysis, which entailed the four stages of finding, selecting, appraising, and synthesizing (Bowen, 2009). Finding James B. Conant, specifically his identity as a science educator and his ideas on general science education, as the focus of this research, this research selected prior literature and studies on Conant. The main text was Conant's original work titled *On Understanding Science* (1947), abbreviated *OUS*, in which he briefly outlined his ideas and methods on science as well as provided examples of how looking at case histories could foster an understanding of science. To supplement *OUS*, articles, speeches, and extracts from other publications by Conant or those who cooperated with Conant in science education were examined. These not only allowed a deeper comprehension of *OUS* but also enlightened an understanding of the entire general science education movement at the college level, including the contributions Conant specifically made in the course. Then, these resources were all appraised based on the following overarching questions: What roles did James B. Conant play during the reforms of general science education at Harvard University from the 1940s to the 1950s? What were his ideas and methods on general science education at the college level? These were the research questions of this research, and they helped to maintain focus. Finally, the answers to these questions were synthesized into the two body chapters of this research – Chapter 2: “Mid-20c. General Science Education Movement at Harvard” and Chapter 3: “Conant’s Ideas and Methods on General Science Education in *On Understanding Science*”. In chapter 2, this research shed light on Conant as a science educator to garner and display his contributions to the reforms of general science education. In chapter 3, a more original analysis was performed on *OUS* to reveal his ideas on science and general science education.

This research had to admit that there were blind spots in its procedures, especially the limited access to primary sources. A major difference between the two chapters was that the first relied heavily on secondary sources while the latter concentrated on the original works of Conant. This was due to chapter 2 attempting to comprehend the contexts surrounding *OUS* and how this book came to be. Many resources required in this attempt were archival records that existed only in hard copies at Harvard libraries. Unfortunately, due to COVID-19 and other circumstances, firsthand access to these resources was not possible and this research had to resort to secondary sources that either had access to these sources or were written by authors who had close connections with Conant. As a result, it was subjected to inevitable researcher bias as the primary sources in these secondary works were deliberately chosen and interpreted in a specific way to suit the goals of these works.

Chapter 2. Mid-20c. General Science Education Movement at Harvard

One of the keywords of this research was general science education at the college level. Therefore, this section was dedicated to defining this keyword in a historical sense. To understand general science education in terms of how it was originally defined, this research investigated the process through which general science education gained attention, flourished, and declined. Nonetheless, it must be reminded that the primary aim of this research was to define James B. Conant as a science educator. This aim was fulfilled concurrently with the historical review of general science education by identifying the specific roles that Conant played in the movement. The whole investigation was conducted largely through the thorough study of books that were published during the movement and of the articles that were written by science educators who had firsthand experience with at least a part of the movement.

The structure of the following sub-chapters followed a typical pattern. The sub-chapters, overall, were placed in chronology; however, details within the sub-chapters defied the chronology if it was deemed better for them to be tied under a certain act in the general science education movement. Each sub-chapter first provided a general historical outline of that act in the movement; i.e., the outline was not specific to Conant. Then it highlighted the roles that Conant played in it in order to reveal his ideas on general science education or just plain science and/or education. All parts of this chapter were accompanied by original texts as means to support and vivify the history and the interpretations done by the researcher.

2.1 Prelude

There were probably a handful of factors that led to the general science education movement. However, there were fair few factors that enforced relatively stronger influences on the discourses on general science education at the college level. These included: the second World War and how it changed people's views on science; the second World War and how it changed the student body that entered college; and the existing debates, especially at Harvard, on the form of college education that the students should receive.

It was discovered, in hindsight after preliminary investigation on the causes of general science education, that Conant acknowledged these very same factors in his foreword of a book titled *General Education in Science* (1952). This book, which had been written during the general science education movement, would be handled in greater detail later in this research. Anyways, Conant stated:

Today, however, I doubt whether anywhere in the world the mere device of collegiate living (excellent though such a way of life may still be for young men with intellectual ambitions) suffices to provide the beginnings of a general education. The cultural background of the students is too diverse, the impact of modern science and scholarship has been far too great. These two factors have required a reëxamination of the older concepts of a liberal education. And in no field is this reexamination more necessary than in the natural sciences. (Conant, 1952a)

The college student body gained diversity as a result of the GI Bill which was enacted towards the end of WWII. Modern science consumed larger portions of people's daily lives. Hence, modern education faced even greater turbulence as to the form it should take on. In the following sections of 2.1, each of these factors was examined.

2.1.1 WWII and the Change in Views on Science

Needless to say, science made impressive achievements at the beginning of the twentieth century. The organized practice of science at universities and industrial laboratories (e.g., the General Electric Research Laboratory or the Bell Laboratories in the US) led to explosive growth in technology. Streets were embellished with the newest products of science such as automobiles, neon signs, electric bulbs, and yet more phone lines connecting buildings to buildings. Not only were there advancements in transportation, lighting, and communications, the science-industry interaction greatly expanded agriculture and chemical manufacturing, which implemented a chemical synthesis scheme. I. Bernard Cohen, a historian of science, commented that "a cult of the power of science began to develop" with the public believing that science could solve all problems in society (Cohen, 1981). He added that the general faith in science even spread to human affairs, for instance, in the form of "scientific management." Likewise, L. Pearce Williams, also a historian of science, commented that Francis Bacon's dream of the conquest of nature "seemed on the verge of realization" (William, 2022). Such a remark was not an exaggeration as improvements in medicine produced the world's first antibiotic, i.e., penicillin, combating once-invisible microorganisms. Confidence in the potency of science was not easily shaken – even at the immense loss of men during the two world wars. Militarism legitimized increased funding in weaponry development and the deployment of young scientists to wartime research. The fear of falling behind overwhelmed the awareness of the potential destruction that scientific weapons could have on people's lives. This fear fostered the development of bombs and vesicants during WWI and the creation of nuclear bombs during WWII.

Yet, in the preface of *On Understanding Science*, Conant constantly referred to this "problem of the atomic bomb," emphasizing the need for people to cope and live with it (Conant, 1947). Then, how did the urge and haste to build the bomb transform into terror? Here on to the next paragraph, this research mainly relied on a single source – *Nuclear Fear: A History for Images* (1988) by Spencer R. Weart, a former director of the Center for History of Physics of the American Institute of Physics. According to Weart (1988), at the beginning of the war, even the physicists working on nuclear research did not see atomic explosives as possible. However, German bombs were dropped over London and Berlin, and the lives of civilians were at stake. Rationalizations that an atomic bomb could end the war convinced politicians like President Roosevelt of the US and Prime Minister Winston Churchill of the UK and pressured scientists like Arthur Compton and Robert Oppenheimer to get to work. By the time the bombs were finished, the Manhattan Project scientists projected a future with no safety from the bombs except under domestic and diplomatic control. However, under wartime secrecy, the American public remained ignorant.

The bombs were dropped on Hiroshima and Nagasaki on August 6th and 8th, 1945, and finally, the catastrophic power of the atomic bombs was released to the public. Fear swept people from all around the world that science had created a monster – or a "Frankenstein" as one NBC broadcast stated. Apprehension sickened the public as they realized that with the doomsday atomic bombs on loose, there would be no shielding that could protect them in future wars. While a great majority in the US still considered the use of the bombs a just act, feelings of guilt and helplessness dominated their minds because the aftermath of the blast was radiation injuries and deaths. This was when voices on the need for control grew stronger. Actually, Compton already jotted in his memo back in 1944 the phrase "public education" feeling that people should properly learn about nuclear energy, not just weaponry – he was not alone in this feeling. Most scientists shared the idea that the public must be fully instructed on both the risks and opportunities that nuclear science possessed.

The gradual increase in the severity of WWII also impacted President Conant at Harvard. Despite his interventionist stance[11], he was initially more concerned with preserving pure science and fighting threats to student enrollment rates at Harvard. During the interwar period, he greatly disapproved of students leaving academics for industrial research judging them as "much less able[d]" to pursue

[11] In 1939 when the German troops invaded Poland, Conant assembled a group of American and European philosophers called the "Unity of Science Movement" to exchange views on scientific methodologies, the nature of science, the relationship between science and history, and most importantly how science could build an "intellectually-connected" world immune from the toxic Nazi ideology (Reisch, 2019).

second-class citizenship (Hounshell, 1996). Up till the attack on Pearl Harbor in December 1941, the university campus was split between the isolationists and the interventionists – there was a part of Conant that was still unwilling to mobilize the school for military science. In his autobiography, Conant called himself naïve for endeavoring to postpone the drafting of students and recent graduates even after the attack on Pearl Harbor (Conant, 1970). However, in January 1942, war policies were enforced on all colleges in the US. By this time, Conant's inner conflict seemed to have settled on the need for Harvard to take immediate action against German fascism (Schade, 2017). Under Conant's leadership, Harvard curtailed its teaching and learning facilities, and many university laboratories were performing military research to develop weapons to strengthen national defense. Wartime Harvard was not greatly academic. Conant publicly stated, "It is time for war, therefore, and not for peace that we must lay our immediate educational plans" (Downs & Murtazashvili, 2012).

Towards the end of December 1944, Conant's centrality in the war informed him that the atomic bomb would soon be ready. In January 1945, seeing hopes to end the war, President Roosevelt began advocating the need for universal, compulsory military training at colleges during peacetime but many university presidents were against the idea – these included Conant and those of Stanford, Cornell, Princeton, Chicago, etc. (Conant, 1970). Perhaps, this opposition was due to university presidents envisioning different plans to reform education at their schools. When the bombs were dropped, Conant commented that his earlier objections to the universal military training had gone to waste – the apocalyptic atomic storm blew away military plans, and the army was soon demobilized (Conant, 1970). He was now able to return to the general education program that he initiated back in 1943.

2.1.2 GI Bill and the Change in College Student Body

Whether it was enlistment in the military or recruitment in some war-related position, colleges in the US faced drainage in students during WWII. On June 22nd, 1944, President Roosevelt passed the Servicemen's Readjustment Act – or the G.I. Bill of Rights (abb. GI Bill) – to resolve personnel shortages and to support the civilian life of war veterans. The act was to provide financial aid in terms of education, insurance, and housing to men and women who served in the armed force and therefore would be unemployed post-war ("Servicemen's Readjustment Act of 1944," 1944). There were mainly two changes in college enrollment: one was the swell in enrollment numbers and the other was the change in the profiles of the students enrolled. Based on a literature review, this research could only conclude that whether these changes were a reaction to the GI Bill was still in debate (e.g., Olson, 1973; Clark, 1998; Kim & Rury, 2007). Nonetheless, there was a drastic swell in enrollment numbers towards the end of WWII. Based on a report from the National Center for Educational Statistics (NCES), student enrollment in postsecondary institutions in the US was 1,494,000 in the years 1939-40 but plummeted to 1,155,000 in the years 1943-44.[12] Then, the total enrollment increased to 1,677,000 in the years 1945-46, surpassing that of before the American intervention, and reached 2,078,000 by the fall of 1946, passing the threshold of two-million students.[13]

Table 2. Total Enrollment in Postsecondary Institutions in the 1940s (Snyder, 1993)

Year	Total Enrollment
1939-1940	1,494,000
1941-1942	1,404,000
1943-1944	1,155,000
1945-1946	1,677,000
Fall 1946	2,078,000
Fall 1947	2,338,000
Fall 1948	2,403,000
Fall 1949	2,445,000

Above were the factual, numerical data on the increase in enrollment number in postsecondary institutions. The controversy over the success of the GI Bill began immediately with surveys conducted on veterans at colleges and schools. This research intended to just briefly introduce three survey results organized in Mettler (2005). According to the US President's Commission on Veterans' Pensions, by the end of the eligibility period of the GI Bill, 2.2 million veterans attended colleges and universities, and 5.6 million obtained either vocational training or some other sub-college education. This meant that about 51% of all WWII veterans had benefited from the aid of the bill. However, the Frederiksen-Schrader survey conducted by the Educational Testing Center in 1946-47 reported that only 20% of the veterans in college would not have pursued a college education without the bill; i.e., the bill could have relieved some financial burdens but they would have gone to college nonetheless. Another survey, conducted on WWII veterans in 1998, questioned 49% of nonusers as to why they did not use the bill. Despite the bill being a financial aid, the responses included the preference for work over school (51%) and the lack of money (25%).[14] The cause of the changes in the college student body was out of the scope of this research. What mattered was that there

[12] Recall that the attack on Pearl Harbor was on December 7th, 1941, and war policies on universities to mobilize students were implemented in January 1942.

[13] This record has not been broken since then.

[14] For details on the evaluation of the GI Bill, refer to Mettler (2005) and Olson (1973).

was an evident bulge in the student population. A clear legacy of the bill was that it urged the NCES to start keeping records of enrollment in postsecondary institutions since 1947 (Snyder, 1993).

As much as the population changed, the characteristics of the college student body underwent sweeping changes. The heavy media coverage of the GI Bill likely captivated the minds of war veterans. Clark (1998) described that a common propagandized image in articles of the time was the average GI in college storming through ivory towers and joining the sophisticated, elitist lives of privileged, upper-class men.[15] The bill not only granted an average lower-to-middle-class man the right and the necessary funds for college education but it also served as a political rhetoric embodying the possibility and opportunity to live a better, higher life – i.e., a vehicle to the American dream. Therefore, the GIs in college were not necessarily signed up for purely educational purposes. Nonetheless, the bill did widen the college student body by changing the public perception of who could receive a college education. This added social, economic, and cultural mobility to the once rigid college education in the US (Clark, 1998). College was now a "viable option" to those from various sociodemographic backgrounds (Bound & Turner, 2002).

Regardless of how these men ended up in the corridors and halls of college campuses, they appealed for their rights to receive a new type of college education that was both more practical and promising to their future. This utilitarianist perspective on courses stripped the liberal arts to instead value vocational and technical courses – e.g., mathematics, chemistry, and physics were chosen as pre-requisites to becoming military officers but even more, engineering, pre-law, pre-medical, and pre-banking courses were popular amongst general students (Tresidder, 1946). Similarly, in article interviews, college veterans spoke of job-oriented education for "adult participation in the modern world" where, for instance, humanities courses would deal with real-life issues and science courses on radio-technology or engineering (Clark, 1998). Whether colleges should cater to these requests was a hot debate in college education at the time, as indicated in a journal article from 1947 that proposed a more relevant curriculum but with a philosophical outlook that would separate colleges from vocational schools (Cooke Jr., 1947).

Harvard University also became home to a more democratized, broadened student body. Many prestigious institutions like Harvard, being orthodox and

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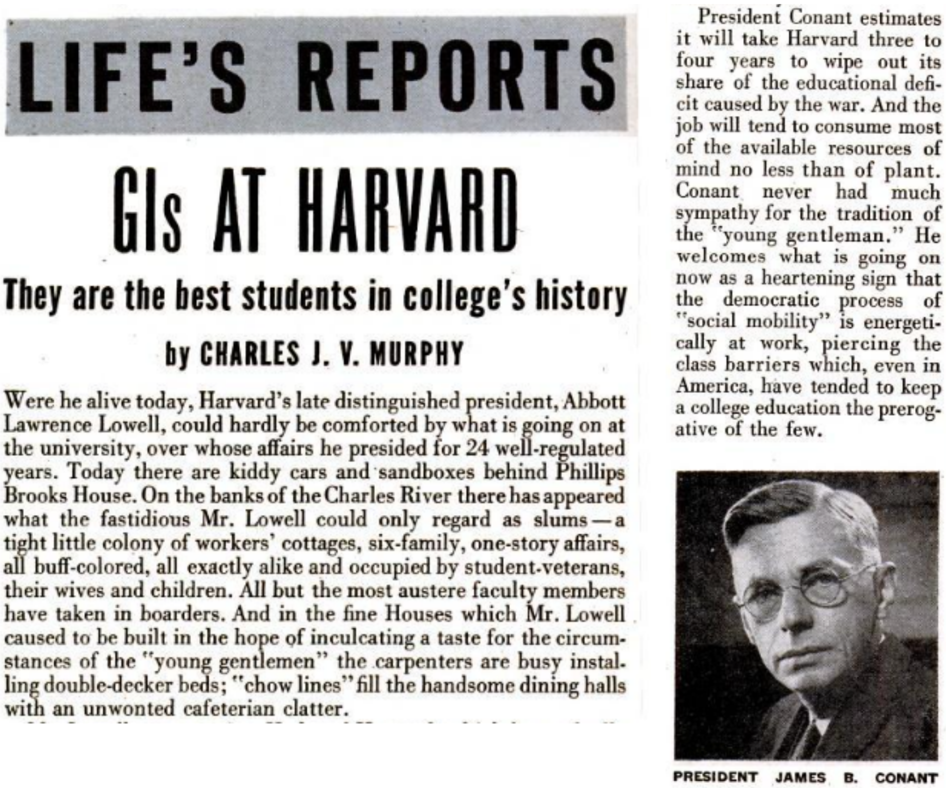
[15] War veterans were often nicknamed "GI Willie" or "Willie Gillis" in press based on the fictional character Willie Gillis (a.k.a. GI Willie) created by the famous illustrator Norman Rockwell. This character became known for appearance on several covers of *The Saturday Evening Posts* between 1941-46. The transformation of Willie throughout these years symbolized the American dream that an average lower-to-middle class man could pursue a college education to upgrade his life.

aristocratic, resisted but had to confront the drastic changes in students. Harvard was always an institution interested in offering academic assistance to underprepared students (Wyatt, 1992), as a means to maintain academic standards. Conant initially disapproved of the GI Bill due to concerns about the lack of discrimination among veterans entering Harvard (Olson, 1973). However, less than two years into the implementation of the GI Bill, Conant was pleased to interview that the war cohort was “the most mature and promising students Harvard has ever had” (Murphy, 1946). These students demonstrated strong determination to get through the lot on their plates. There were reports that the veterans, even though being far from meeting the criteria of traditional students at Harvard – over half of the veterans were married and half of those had children (Wyatt, 1992) – they were more mature and hardworking with some even succeeding beyond the younger students. The financial aid provided by the bill was an opportunity for veterans, many of whom were married and older than an average college matriculant, to make up their college education and return to society in improved positions.



LIFE'S REPORTS

GIs AT HARVARD

They are the best students in college's history

by CHARLES J. V. MURPHY

Were he alive today, Harvard's late distinguished president, Abbott Lawrence Lowell, could hardly be comforted by what is going on at the university, over whose affairs he presided for 24 well-regulated years. Today there are kiddy cars and sandboxes behind Phillips Brooks House. On the banks of the Charles River there has appeared what the fastidious Mr. Lowell could only regard as slums—a tight little colony of workers' cottages, six-family, one-story affairs, all buff-colored, all exactly alike and occupied by student-veterans, their wives and children. All but the most austere faculty members have taken in boarders. And in the fine Houses which Mr. Lowell caused to be built in the hope of inculcating a taste for the circumstances of the "young gentlemen" the carpenters are busy installing double-decker beds; "chow lines" fill the handsome dining halls with an unwonted cafeterian clatter.

President Conant estimates it will take Harvard three to four years to wipe out its share of the educational deficit caused by the war. And the job will tend to consume most of the available resources of mind no less than of plant. Conant never had much sympathy for the tradition of the "young gentleman." He welcomes what is going on now as a heartening sign that the democratic process of "social mobility" is energetically at work, piercing the class barriers which, even in America, have tended to keep a college education the prerogative of the few.

PRESIDENT JAMES B. CONANT

Figure 4. GI Bill Reaction at Harvard from *Life* June 17, 1946 Issue

According to Fuller (2000), it seemed Conant was quite impressed by the military discipline held by the veterans to entitle his new course for nonscience-major students as the course on "Tactics and Strategy of Science." However, this research hypothesized another factor that led to such naming – Conant was likely conscious of the utilitarian trend in science education. Not only were there internal pressures from veteran students but these years when veterans entered college also coincided with the progressive era in education. As stated in *Chapter 1* of this research, progressive reforms emphasized the applicability and functionality of science courses at both secondary and postsecondary levels. Likewise, there was an overall rise in skills-based subjects such as science, mathematics, and physical education during wartime for their higher reliance on paper-based learning materials and their applicability to wartime information (Giordano, 2004). For instance, high school chemistry was popular for providing practical knowledge basis on chemical weapons (e.g., explosives, gas weapons, bombs) and defensive equipment (Giordano, 2004). This research assumed that values in the practicality of education were carried over to colleges by veterans only to grow stronger as these veterans were mainly interested in finding a job afterward. To attract such students to take his course on general science education, Conant likely had to take into consideration publicizing the functional values within his heavily historical, thus theoretical course – hence, a more relevant course that provides a philosophical outlook as stated by Cooke Jr. (1947).

2.1.3 Old Debates on College Education at Harvard

The war was not the only factor that urged reforms in general education at Harvard – i.e., the reforms in college education were not radical, progressive acts of a single president, in this case, Conant. Kravitz (1994) argued that the establishment of the Harvard Committee of General Education in 1943 and its publication *General Education in a Free Society* (a.k.a. the Harvard Red Book) in 1945 must be understood in a wider context. Higher education in the US was in turbulence since the late nineteenth century. The Industrial Revolution was already changing the student body, although at a slower pace than the GI Bill, to invite students with wider socioeconomic backgrounds; thus, a demand for a more utilitarian, field-specific college education than the conventional classical education was on the rise. Each president of Harvard instituted massive reforms that were copied by universities across the US.

In the 1880s, president Charles Eliot (the 21st president of Harvard) introduced the elective system that permitted students to select courses based on their interests and capacities. Eliot valued individuality, considering that it was on the students to discover their innate aptitude, without the meddling of parents and teachers (Carpenter, 1951). Such a view was likely due to his teaching experience at the Massachusetts Institute of Technology (MIT), which led to Eliot tightly specializing deanships and faculty appointments when he returned to Harvard as its president (Beach, 1973). The result was the specialization of fields for both students and faculty and a new emphasis on research as faculties could concentrate on only those subjects relevant to their academic interests. In terms of science education, it was greatly expanded under the elective system as subjects like natural sciences, English literature, history, and economics were treated as equal to mathematics, Latin, and Greek in classical education[16] (Beach, 1973). However, the flexibility of Eliot's elective system had a side effect – the students were receiving an overly-narrow education with depth but no breadth. For instance, a student choosing physics graduated without any knowledge of other fields.

This prompted discussions on what a well-educated citizen in the US ought to learn from higher education. Such debates gave birth to the concept of 'general education' but as to the contents of this general education, educators and the public were hesitant to come to an agreement.[17] In 1909, president Abbot Lawrence Lowell (the 22nd president of Harvard) curtailed the elective system and alternatively proposed the concentration and distribution system as a solution to add breath to students' learning. Concentration maintained the benefits of Eliot's elective system as students had to devote at least a third to a half of their time to courses relevant to their fields. Distribution expanded the latitude of courses students took, requiring at minimum a quarter of the time to be spent on studying other fields. While Conant (1950) credited Lowell for the success of the new system, pointing out the little modifications made to the concentration fields, he identified the lack of consensus on what courses could offer proper breadth in the distribution fields. Conant was already receiving sharp criticisms from the Student Council at Harvard, during WWII, on the poor requirements for a bachelor's degree at Harvard.

Conant's response was the creation of the Harvard Committee on General Education, in which he began discussing the details with Dean Paul H. Buck of the Faculty of Arts and Sciences in 1942. One question that they confronted was on developing courses, for instance in chemistry or in classics, that would provide balanced and appropriate breadth to students (Conant, 1950). Conant and Buck were in unison on the idea that bachelors from Harvard should have acquaintance with fields outside of their concentration (Conant, 1970). However, their concerns were that general education courses provided at other institutions were superficial

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[16] The classical education was known for its rigid curriculum as unyielding as the student body mainly composed of white males occupying the uppermost level of the socioeconomic hierarchy.

[17] Meanwhile, the term "liberal education" was used synonymously with classical education composed of, for instance, the recitations of the Greek and Roman classics and the Bible. (Kravitz, 1994)

and falling below standards.[18] Another question was about creating a program of courses where students still had a choice over the specific distribution course that they would take. Previously, in June 1939, Conant received a report from the Student Council promoting the establishment of five mandatory, introductory courses – with two in the Natural Sciences, two in the Humanities, and one in the Social Sciences. He recollected that he did not sympathize with this urging of a "single program suitable for a heterogeneous group" (Conant, 1970).

Hence, the task was on Conant and his Committee on General Education to come up with a new program. Just briefly, as this part would be dealt with in the following subchapter, Conant and the Committee produced a report, the Harvard Red Book, on October 30, 1945, which served as a tentative system of general education to be experimented on students at Harvard until methods and materials could be perfected. Under the auspices of the Committee, the Faculty of Arts and Sciences provided four parallel courses in three areas of study – the Humanities, the Social Sciences, and the Natural Sciences – and students had to select one course in each area as part of their distribution.

2.2 General Science Education at Harvard

When Conant returned to Harvard to revolutionize its education system, he was faced with a larger, broader student body with ambivalent attitudes toward science. To normalize postwar education at Harvard, he paid special attention to the general education program as a replacement for the distribution program of former president Lowell. This subchapter began at the establishment of the Harvard Committee on General Education in 1943. The general education program at Harvard was covered plenty by former research in education. This research, therefore, focused on what the Committee had to say on general science education while acknowledging that Conant's ideas on general science education likely were not identical to those of the Committee. Then, this research examined the development process of Conant's general science course – Natural Sciences 4, On Understanding Science – leaving his ideas on general science education to be handled in the subsequent *Chapter 3*. To construct a brief understanding of the influence Conant had on science education as a field, this research investigated his collaborators – namely, Cohen, Holton, Nash, and Kuhn who continued their ideas on general science to other fields (e.g., history and philosophy of science, secondary science education) – and the Carnegie Conferences on general science education where science educators gathered on regular basis to discuss related

[18] Conant recalled that the 'general education' was not a favorable term in Cambridge in the 1930s.

topics.

2.2.1 The Harvard Committee and *General Education in a Free Society*

In January 1943, president Conant commissioned a University Committee on "The Objectives of a General Education in a Free Society" (for short, the Harvard Committee on General Education or simply, the Harvard Committee) with Paul H. Buck, Dean of the Faculty of Arts and Sciences and Professor of History, as its chairman. Sixteen faculty members at Harvard participated in the works to publish the widely-distributed *General Education in a Free Society*, also known as the Harvard Red Book of 1945 or the Harvard Report of 1945.[19] Kravitz (1994) also identified three non-official yet influential players that significantly influenced the committee and its report, and these included James B. Conant, Byron Hollinshead, and Robert J. Havighurst. This summed up to nineteen men who had served on the committee and whose names, titles, and descriptions of the roles that they played were summarized in *Table 3*. The Committee of Detail, which lasted between January to February of 1944, was one of the two major subcommittees of the Harvard Committee that arranged the basic principles of general education that the rest of the committee would follow. Within the Committee of Detail was Buck who closely communicated with Conant sharing their visions on general education and professors Leigh Hoadley and George Wald representing the Natural Sciences. Of the three areas of study that students had to take their distribution course in, only the Natural Sciences had delegates participating in the Committee of Detail.

Table 3. Official and Non-official Participants in the Harvard Red Book (Harvard Committee, 1945; Kravitz, 1994)

	Name and Title in Committee	Descriptions
Main	Paul H. Buck Chairman	Professor of History, Committee of Detail
	John H. Finley, Jr. Vice-Chairman	Professor of Greek, Steering Committee, Committee of Detail
	Benjamin F. Wright Chair of the Committee of Detail	Professor of Government, Steering Committee, Committee of Detail
	James B. Conant	President of Harvard University

[19] Of the sixteen, only seven members served the entire period from the spring of 1943 when the committee was formed to the spring of 1945 when the report was completed. These included Buck, Finley, Wright, Demos, Hoadley, Schlesinger, and Ulich, and among them, the first three were considered the main players (Kravitz, 1994).

	Byron S. Hollinshead Research Fellow in Education, Chair of the Steering Committee	President of Scranton Keystone Junior College Past President of the American Association of Junior Colleges, Steering Committee[20], Committee of Detail
	Robert J. Havighurst Consultant-in-residence	Education professor at the University of Chicago, Consultant-in-residence, Member of the Steering Committee
Education	Phillip J. Rulon	Professor of Education, Committee of Detail
	Robert Ulich	Professor of Education
Science	Leigh Hoadley	Professor of Zoology, Committee of Detail
	George Wald	Associate Professor of Biology, Committee of Detail
English	Howard M. Jones	Professor of English, American literature Active only until May 1944
	Ivor A. Richards	Professor and Director of the Commission on English Language Studies
Philosophy	Raphael Demos	Professor of Philosophy, Committee of Detail
History	Arthur M. Schlesinger	Professor of History, Committee of Detail
Minor	Wilbur K. Jordan	President of Radcliffe College, Department of History, Committee of Detail
	John T. Dunlop	Teaching fellow in Economics
	John M. Gaus	Professor in Regional Planning at the School of Design
	Alfred D. Simpson	A representative from the School of Education
	Howard E. Wilson	A representative from the Graduate School of Education

The Harvard Red Book consisted of five chapters and neared 300 pages. For the sake of this research on Conant and general science education, only points deemed crucial for the understanding of the general education and general science education were summarized from this monumental report. Due to limited access to primary archives from the Harvard library, this research relied heavily on Kravitz (1994) to take a peek into the scenes behind the curtain.

■ Conant and His Views on General Education

Conant was not a part of the Harvard Committee but he was the one who commissioned and strongly influenced it. His introduction, which spanned four pages, rationalized the formation of the Committee and explicated the importance of general education. Conant emphasized in his introduction that the contents of the report were a "unanimity of opinion not based on compromise between divergent views" (Conant, 1945a). This was partially his attempt to add significance to the report, pointing out that it was not another work on the cliché topic of college

[20] The Steering Committee was one of the two major subcommittees of the Harvard Committee that set out the agenda and created the memoranda for the full committee.

education but was a unified voice of academic experts from diverse fields.[21] It could also be interpreted as Conant attempting to substantiate the general education program, which included his own general science course that he administered alongside the release of the report. Nonetheless, some of what Conant stated in his introduction and delivered in his report to the Board of Overseers of Harvard on general education were worthy of attention.

On one part, Conant was concerned with prevalent issues surrounding college education in the US that struggled between the intrinsic (i.e., more philosophical and theoretical) versus the practical, vocational values of learning. As mentioned earlier on in this research, the influx of war veterans into postsecondary institutions led to the rise of practical subjects as these students were keen on learning how to live a better life or how to gain an earning after schooling. Conant cited his own report to the Board of Overseers of Harvard University regarding this issue:

> *The heart of the problem of a general education is the continuance of the liberal and human tradition. Neither the mere acquisition of information nor the development of special skills and talents can give the broad basis of understanding which is essential if our civilization is to be preserved. (Conant, 1945a)*

He aimed for a general education that could persevere. Criticizing the skills-based emphasis favored by educators and the public, Conant sought greater value in college education than its practicality in securing a job. He yearned for a general education that would not easily sway in the trends of society. This research partially thought that such ambition was possible on Conant's part because he was steering a powerful institution in the US.

He was also interested in building a general education that would serve as a vehicle for fulfilling an American democracy. Conant was in the midst of combatting the German fascist ideology when he commissioned the Harvard Committee on General Education in 1943. As an interventionist, he likely considered ignorance as one of the causes of following an egotistical and violent regime. He found refuge in education; however, this education must be different from what was currently being provided:

> *[The current] program lacks contact with both man's emotional experience as an individual and his practical experience as a gregarious animal. It includes little of what was once known as 'the wisdom of the ages,' and might*

[21] However, Kravitz (1994) revealed quite the contrary; even the sixteen committee members representing Harvard's stance on general education failed to come to a consensus. Thus, what Conant stated was more of an overstatement, or perhaps even his desire to enforce general education as described in the report on Harvard's curriculum.

> *nowadays be described as 'our cultural pattern.' It includes no history, no art, no literature, no philosophy. Unless the educational process includes at each level of maturity some continuing contact with those fields in which value judgments are of prime importance, it must fall far short of the ideal. (Conant, 1945a)*

From what Conant had stated above, he implied that history, art, literature, and philosophy were fields in education that deserved reappraisal. These were the fields that could raise the morale of college students to make informed value judgments. These were the fields that could balance out practicality and rationality with humanitarianism and ethics. This research interpreted that Conant's emphasis on these four fields was not necessarily his attempt to belittle mathematics and natural sciences. Rather, it was a tactical withdrawal against the overemphasis on the skills-based aspects of mathematics and natural sciences. Supporting evidence for this interpretation was that the natural sciences still comprised a third of the new general education program but were featured with historical and philosophical ways of thinking.

As to the definition of the concept of 'general education,' the Harvard Committee provided a more comprehensive explanation. Conant only defended his choice of such a slogan as his attempt to clear away educational prejudices over the term 'liberal education' and foster new ideas through the use of a new term – 'general education.' The Committee defined general education as *a* portion of a student's whole education that would lead him to become a responsible, democratic individual and citizen. Therefore, general education embodied the value of lifelong learning that would persist beyond a student's career or profession. It would provide guidance to both personal and social lives. Such a definition of general education also helped to set basic principles that the Committee would keep to as they developed the specifics of their program. A key underlying assumption of Harvard's general education was the acceptance that a person no longer could become an expert in all fields. The Committee explained:

> *Since no one can become an expert in all fields, everyone is compelled to trust the judgment of other people pretty thoroughly in most areas of activity … From this point of view, the aim of general education may be defined as that of providing the broad critical sense by which to recognize competence in any field … General education is especially required in democracy where the public elects its leaders and officials; the ordinary citizen must be discerning enough so that he will not be deceived by appearances and will elect the candidate who is wise in his field. (Harvard Committee, 1945)*

According to such definition of a general education, general education under

Conant's presidency acquired definite guidelines that were unavailable to the distribution fields under Lowell's presidency. General education was to draw clear divisions from the concentration fields – i.e., it was not an introductory version of advanced courses in a profession as it was to earn other, new aspects that would fulfill the breadth of education that students needed. Furthermore, the committee was depicting a different world from that of the past. This world of mutual reliance and dependency required people to be able to evaluate the information provided to them in fields outside of their professional domains. This new epoch was particularly meaningful to science education as the period after WWII was accepted as an era of science and technology. People on a daily basis had to discern information and make decisions on issues related to science.

■ The Subcommittee on Science

The Harvard Committee on General Education only had two members – Leigh Hoadley (1895-1975) and George Wald (1907-1997) – from the natural sciences. There were two participants in managerial positions on the committee that had a science background. Conant was an erstwhile chemist and Havighurst was a former physicist but both had moved onto different professions by this time. Of the two practicing scientists, only Hoadley served the entirety of two years while Wald joined slightly later in December 1943. Hoadley was a professor of Zoology at Harvard. He received his doctorate in Biology at the University of Chicago, briefly taught as an assistant professor at Brown University, and finally settled at Harvard in 1927. Wald was then an associate professor of Biology and was later promoted to full professor in 1948. He maintained his interest in science research to later win the Nobel Prize in Physiology on the anatomy of the human eye and perception in 1967. Although this research did not manage to find the relationship between Wald and Conant, Wald was known for his open criticisms of the US military for their heavy bombings during WWII. Wald was one of the younger members of the Committee being only 36 years old at the time. This could have limited his contributions to the report. However, he remained an active contributor to the Committee till the end as he wrote the entire first draft of the report's fifth chapter on "General Education in Harvard College." The following paragraph was summarized from Kravitz (1994).[22]

The subcommittee on science and math was established a year after the deliberations of the Harvard Committee on General Education in February 1944. The subcommittee held monthly meetings to fulfill Buck's orders to create

[22] This research admits its lack of access to primary sources. It is highly suggested that further investigation on this topic should utilize archival records left by the subcommittee on science and math.

blueprints for natural science and mathematics, with Wald archiving summaries on the process. On April 6th, 1944, Wald wrote that the subcommittee had agreed upon setting no general requirements on mathematics and making one general science course mandatory for general education at the college level. At the same time, he pointed out that the general science courses would have to cater to more than a thousand students per semester; thus, the instructors of the courses would have to make necessary preparations to suit the large enrollment rates. Unfortunately, unlike the subcommittees on other subjects, this subcommittee never published a subject-specific report. Therefore, the ideas of the Harvard Committee on general science education at the college level could only be obtained through corresponding chapters in the Harvard Red Book.

■ General Science as Prescribed in the Harvard Red Book

The term science appeared in two section headings of the Harvard Red Book. Tied with mathematics as "Science and Mathematics," it was treated in Chapter 4, "Areas of General Education: The Secondary Schools" and Chapter 5, "General Education in Harvard College." As this research limited its scope to general education at the college level, only the contents in the fifth chapter were discussed.[23] A major criticism over the science education being provided at Harvard was its lack of consideration of the general students. The Committee, therefore, suggested new general science courses with added features that made them not just introductory versions of the specialistic courses. The report using a metaphor of bricks described that the current courses for general students lacked unity and thus were of little worth to these students that proceeded on to other professions. That is, with only the bricks, students were not able to construct a holistic understanding of "science as a whole and of the interrelationships of the specific fields with it" (Harvard Committee, 1945).

Accordingly, the Committee argued for a wider definition of science in general education that saw "science as a part of the total intellectual and historical process" and not just a systematic accumulation of facts (Harvard Committee, 1945). Guidelines on general science courses were designed to foster a broader, more synthesized understanding of science. This involved the creation of two types of introductory courses split between physical sciences (i.e., physics and chemistry) and biological sciences. The recommendations on the aims, contents, and methods and tools of new general science courses at Harvard were organized in *Table 4*.

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[23] Plus, it seemed that the college education was the main focus to Conant as well. Conant (1950) stated that he commissioned the Harvard Committee to resolve the problem of distribution.

Table 4. General Science Education for Harvard College as Prescribed in the Harvard Red Book (Harvard Committee, 1945)

<table>
<tr><td rowspan="6">Aims</td><td>Common</td></tr>
<tr><td>• Convey some integrative viewpoint, scientific method, or the development of scientific concepts, or the scientific world-view
• Give insight into the fundamental principles of the subject and the nature of the scientific enterprise (p.224)</td></tr>
<tr><td>Physical sciences</td></tr>
<tr><td>• Provide the clearest, simplest, and most rigorous examples of scientific analysis and approach (p.225)</td></tr>
<tr><td>Biological sciences</td></tr>
<tr><td>• Concerned with more complex level of material organization; thus, to convey some understanding of the ways in which science approaches such complicated and multivariant systems; and the complexity of the nature of problems encountered
• Present an integrated view of the science of living organisms, animal and plant (p.228)
• Lead to an appreciation the constant flux and motion that characterize all life (p.228)</td></tr>
<tr><td rowspan="6">Contents</td><td>Common</td></tr>
<tr><td>• General principles and concepts
• Methods by which principles and concepts have been developed
• Modes of scientific approach to scientific problems
• Conceptual interrelations, world-view, and view of the nature of man and knowledge
• Philosophy and history of science: to discuss outdated scientific topics that were matters of concern and controversy in the past (p.225); as parts of science and not to simply add humanistic garnish
• <u>Various means by which science progresses</u> (e.g., the evolution of fundamental concepts or the introduction of new instruments and procedures) (p.221, p.224)</td></tr>
<tr><td>Physical sciences</td></tr>
<tr><td>• <u>Physics as the core</u> with only pertinent matters from other sciences (chemistry, astronomy, and geology)
• Basic chemical concepts; e.g., atomic theory (p.226)
• Patterns in the development of basic physical principles and concepts
• Two versions of course that only differ in rate and rigor for freshmen and sophomores of various scientific and mathematical prerequisites</td></tr>
<tr><td>Biological sciences</td></tr>
<tr><td>• A program of lectures grouped in themes
• Materials from zoology, botany, physiology, paleontology, and geology</td></tr>
<tr><td rowspan="2">Methods and Tools</td><td>Common</td></tr>
<tr><td>• Lectures with slides, motion pictures, and demonstrations by a single lecturer and occasional special lecturers to: teach fundamental facts and laws; solve problems theoretically
• Lab work by individual students with highly selected subject matter, thus subserving the major aims of the course to illustrate the modes by which scientific problems are approached
• Weekly conference meetings in small groups with groups created based on student interests, preparation, and aptitude to: discuss views on concepts; organize outside activities (e.g., museum trips and outside reading)</td></tr>
</table>

	• For the advanced student: study of classic literatures in science; special courses (e.g., seminars) in the science departments that examine the philosophy, history, and interrelations of the sciences
	Physical sciences
	• Extra problem-solving or theme-based writing assignments • Lab work to: be solved by presenting student with problems of which he does not know the answer to; exercise the employment of scientific data, yielding general solutions, basic principles, and predictions
	Biological sciences
	• Abundant lab opportunities to examine living organisms with or without a microscope • Review of classic experiments; e.g., Pasteur's experiments on antisepsis and pasteurization • Staff-instructed group demonstrations for phenomena that cannot be demonstrated individually • Museum exhibits • Elementary textbooks and books by authorities for the nonspecialists: e.g., T. H. Huxley's *Man's Place in Nature* to lead student into deeper thoughts on biology (p.229)

There were both shared and separated guidelines for courses on physical sciences and biological sciences. As overall, the Committee proposed courses that satisfied their new definition of science to provide an outlook on science as a human activity. Students going through the course on general science would by the end of the semester have developed an integrative understanding of scientific methods, the development of scientific concepts, and scientific worldviews. The emphasis was not on the transfer of factual knowledge but more on how this knowledge was formed and how it in turn shaped people's perceptions of the world. Therefore, learning and teaching would employ the history and philosophy of science. The division between physical sciences and biological sciences implied that the Committee considered the two to possess innately different traits and values. From the aims of teaching physical sciences, it was evident that the Committee understood physical sciences as the epitome of what people called hard science characterized by, for instance, traits like rigor, exactness, and objectivity. Therefore, courses on physical sciences covered contents such as patterns in the development of scientific concepts and principles. From the aims of teaching biological sciences, on the other hand, it seemed the emphasis was on the appreciation and understanding of the complexities in life. Methods and tools for biological sciences were more descriptive than those of the physical sciences and this indicated that biological sciences required greater exposure to a variety of learning materials.

Whether Conant had participated in the meetings of the subcommittee on science remained unknown. However, this research found in the process of analyzing Conant's *On Understanding Science* that he shared similar views with the Committee on general science. This comparison was conducted in *Chapter 4*.

2.2.2 Conant's New General Science Course

The Harvard Red Book stimulated the faculty of Harvard to implement a new General Education Program that guaranteed greater distribution in the courses that the students took. General Education courses were provided in the three major areas at the time– the Humanities, the Natural Sciences, and the Social Sciences. The first introduction of courses in general education was released in 1946. As of 1950, the graduation requirement at Harvard was that students must complete a minimum of six courses outside of their area of concentration, i.e., major, where one course in General Education was mandatory (Cohen & Watson, 1952).[24] In that same school year, five introductory and three additions, more challenging, general science courses were being offered, with the former for underclassmen and the latter for upperclassmen. The courses in general science education offered in 1950-51 were as below.

Table 5. General Science Courses Offered in 1950-1951 (Cohen & Watson, 1952)[25]

Course Name	Lecturer
Natural Sciences 1, The Physical Sciences in a Technical Civilization	P. Le Corbeiller
Natural Sciences 2, Principles of Physical Science	E. C. Kemble G. J. Holton
Natural Sciences 3, The Nature and Growth of the Physical Sciences	I. B. Cohen
Natural Sciences 4, Research Patterns in Physical Science	L. K. Nash T. S. Kuhn
Natural Sciences 5, Principles of Biological Science	E. S. Castle G. E. Erikson
Natural Sciences 111, Organic Evolution	A. S. Romer and members of the Department of Biology
Natural Sciences 112, Introduction to the Philosophy of Science	P. Frank
Natural Sciences 113, Contemporary Physics and Its Philosophical Interpretations	P. Frank
Natural Sciences 114, Human Behavior	B. F. Skinner

Conant personally taught a course in the Natural Sciences – Natural Sciences 4, On Understanding Science – for three years until he handed it over to Leonard K. Nash and Thomas Kuhn. His take on general science was a historical and philosophical approach incorporating case histories from the history of science.

[24] Unfortunately, neither the graduation requirements nor the course catalog of the General Education Program in 1946 were available electronically.
[25] Natural Sciences 111-114 were courses for the upperclassmen or the advanced student.

This greatly differed from the conventional way of teaching science at the time, which tended to bombard students with theories and knowledge. Whilst teaching the course at Harvard, he also delivered a series of lectures under the Terry Foundation of Yale University (also known as the Terry Lectures) from 1945 to 1946. His course and lecture notes formed the basis of his publication in 1947 under the same title of *On Understanding Science*. Not much was found about students' responses to Conant's lectures but that they served as rare occasions for the students to meet their renowned president (Hershberg, 1992).

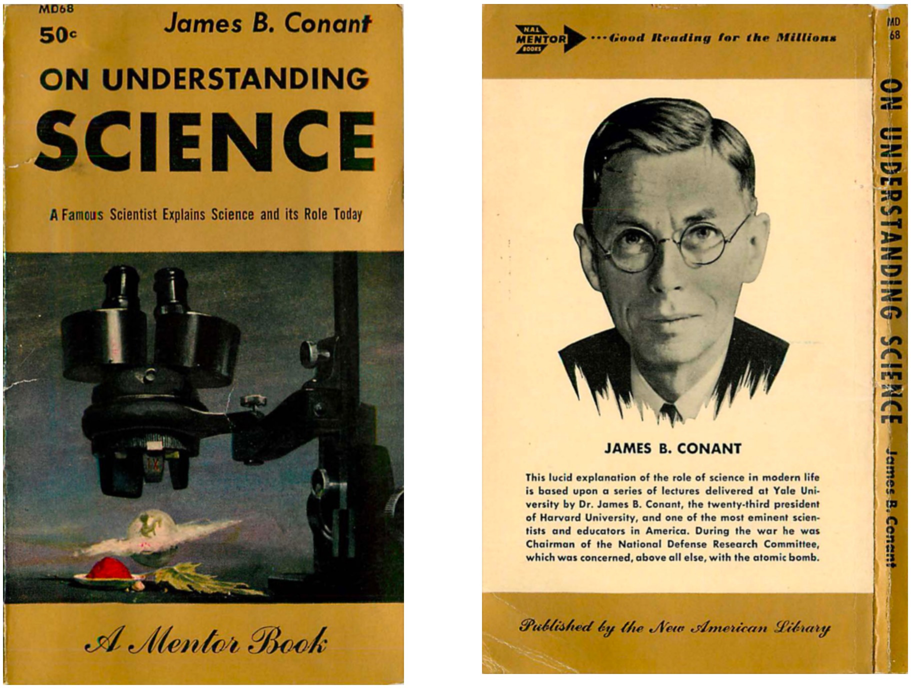

Figure 5. Cover Page of *On Understanding Science*

■ Sources of Inspiration

Conant was said to have been inspired by the case history method that L. J. Henderson once used in his classes on the history of science in 1911 (Harvey, 1999)[26]. However, as a student, it was the lectures from George Sarton, a Belgian historian of science who later joined Harvard, that Conant had been exposed to. This story required a brief overview of how the history of science slowly blossomed at Harvard during the first half of the 20th century. This research refrained from going into too much depth about the establishment of the History of

[26] Joy Harvey, from whom this research learned lots of the early days of the History of Science at Harvard, was herself an undergraduate in the History and Science in the 1950s and a graduate student and teaching fellow in the History of Science from the mid-1970s to early 1980s. Her article was reviewed by many professors who have met the first-generation scholars of the History of Science at Harvard in person.

Science at Harvard as this was already covered sufficiently in numerous journals and articles (e.g., Cohen, 1984; Edsall, 1984; Harvey, 1999). Instead, it retrieved only the relevant stories and garnered sporadic mentions of Conant from these sources. Conant first as a graduate student, later as a Professor in Chemistry, and lastly, as the President of Harvard had an ongoing relationship with the History of Science group at Harvard whom he formed a partnership in order to develop his general science course.

The story began in the 1910s with Henderson and Sarton (*Figure 6*). Henderson, then a young professor teaching chemistry at Harvard's medical school, persuaded President Lowell[27], whom he was close friends with, to establish a survey course on the history of science in his biochemical seminars.[28] This was before the history of science was established as a formal discipline. Henderson taught that there was no single scientific method, to examine, with his students, ideas from ancient Greek scholars such as Aristotle and Archimedes and examples in the history of science using classical writings left by, for instance, Harvey on blood circulation and Galileo on the Copernican heliocentrism (Harvey, 1999; Edsall, 1984). Henderson, being intrigued by a journal written by Sarton, invited him to Harvard where the two visioned the creation of an Institute for the History of Science.[29] Sarton also instructed lectures on the history of science where he detailed the evolution of a topic (e.g., laws of thermodynamics, theory of evolution) across one or two generations (Harvey, 1999). His lecture, according to an account from I. Bernard Cohen[30] who also sat in the lecture, was more centered on delivering the history as, "Sarton did not lecture on the history of ideas in history of science but rather on the history and lives of scientists, together with their achievements" (Cohen, 1984).

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27 President of Harvard from 1909-1933.

28 Henderson himself was inspired by the seminars on the philosophy of science being provided at Harvard by Josiah Royce, Professor of the History of Philosophy since 1892 (Harvey, 1999).

29 Sarton initially joined Harvard temporarily for a two-year lectureship in 1916, then returned in 1920 to find the journal *Isis*, a reputable peer-reviewed academic journal on history of science, medicine, and technology.

30 Originally interested in theoretical mathematics, physics, and chemistry, Cohen after auditing Henderson's course and taking Sarton's course turned to pursue history of science in 1937 for his graduate years under the Committee on Higher Degrees in the History of Science and Learning (Cohen, 1984).

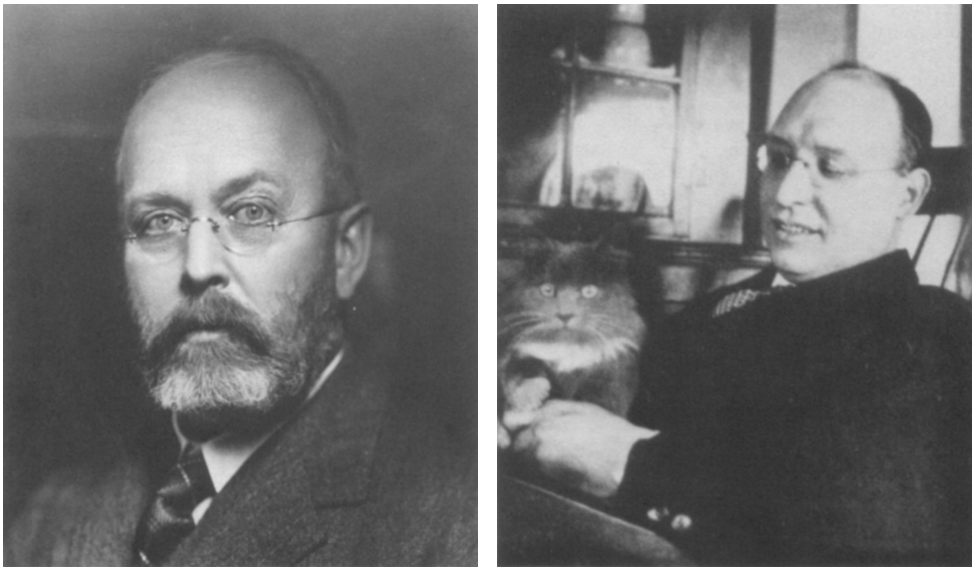

Figure 6. Photos of Henderson (Left) and Sarton (Right), Inspirers of Case Study Method (Edsall, 1984)

Nonetheless, Conant, sitting in Sarton's lectures[31], was clearly fascinated by his way of teaching as Sarton was one of many whom Conant often acknowledged in his later works on the history of science and science education. He recalled later when he as a graduate student told Sarton at an evening party about his impressions of the course:

> *You have undoubtedly forgotten it, but the conversation then and your writings at that time made a deep impression on me and have influenced a great deal that I have said and done in subsequent years, in particular 'On Understanding Science' and my whole attempt to draw from the history of modern science wisdom for the teacher of general science springs from the inspiration I received from you as a young man.* (Conant, 1952b; as cited in Harvey, 1999)

He also wrote in a letter to Sarton in 1927 that "as a specialist in one very special department of a somewhat narrow science, your undertaking brings most needed intellectual refreshment and stimulant" (Conant, 1927; as cited in Hershberg, 1992).[32]

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[31] This research could only find that Conant's original interest in the history of chemistry expanded after taking Sarton's lectures (Hershberg, 1992). It remained unsure whether Conant initially enrolled in the course for his interest in history of science. According to Cohen (1984), Sarton's course was popular among students for having "practically no assigned reading and no term paper," plus the fact that "everyone in the course received high grades."

[32] The degree to which Conant highly thought of Sarton was also evident as Conant

From the point of view of this research having dissected apart Conant's *On Understanding Science*, Conant was prompted by both Henderson and Sarton to synthesize their methods into his case-study method for general science education. He likely borrowed the use of historical cases from Henderson and the idea of evolving scientific concepts across a few generations from Sarton. This was examined in further detail in Chapter 3 of this research. On a side note, this finding was interesting as, clearly, the case-study approach proposed by Conant was not a purely original creation of his own. This was not to criticize his lack of originality but simply to point out that ideas in science education do not come out of nowhere. Even a clever man like Conant had sources of inspiration, in his case the history of science teachings of Henderson and Sarton, from which he retrieved ideas on which he further developed as means to suit his educational aims.[33]

■ Collaborators of General Science Education

So far was Conant as a graduate student and a professor at Harvard. His interaction with the History of Science group continued as he moved on to being the President of Harvard in 1933. However, it took nearly a decade until Conant realized the need for a better understanding of science among laymen. In the mid-1940s, Conant personally took on the job to create a general science course at Harvard with a heavy touch on the history of science. This job was not solely done by Conant – he worked with many scientists and historians of science but in exceptionally close proximity to I. B. Cohen, Thomas Kuhn, Gerald Holton, and Leonard K. Nash (Hershberg, 1992). Hence, this section briefly covered how Conant came to acknowledge the importance of science education and how these 'collaborators' of general science education came to help with Conant's new general science course.

Flashing back to the 1930s, growing optimism spread within the History of Science group at Harvard upon Conant's appointment as president – he was a nephew to Henderson by marriage and a student once enrolled in Sarton's lecture. However, these hopes were soon turned down as, contrary to his early enthusiasm and support, Conant vetoed requests for increases in funds for staff recruitment, library expansion, and establishment of an institute for the history of science. He later revealed that he was unwilling to invest in a field with "little prospect of future advancement" (Hershberg, 1992). It was only after the Hiroshima and

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arranged an honorary degree in June, 1935, along with Albert Einstein (Harvey, 1999).

[33] While this research considered Henderson and Sarton as the sources of inspiration to Conant's case-study approach, opinions on where the approach originated varied in literature. For instance, Matthews (2015) suggested that the case-study approach came from Ernst Mach, an Austrian physicist of the late nineteenth century. Therefore, as to the origins of the case-study approach, additional research is required.

Nagasaki bombings that Conant took an actual and practical interest in the history of science.

Conant was never as passionate about Harvard's education after the war, being preoccupied with many diplomatic, political, and military issues, but then he suffered from a public, anti-science backlash after the bombings, which he clearly advocated the use as means to end the war.[34] This was when he was reminded of all the letters that Sarton, earlier on, wrote to him for financial and administrative support, persuading that the study and teaching of the history of science was "the only way of bridging the widening abyss between science and the humanities" (Sarton, 1940; as cited in Hershberg, 1992). Further quoting Hershberg (1992), Conant conveyed his concern over the lack of understanding of science among "lawyers, business men, writers, public servants (and not a few Army and Navy officers) when confronted with matters of policy involving scientific matters" to openly acknowledge the need for a new science program at the college level on November 15th, 1945 (Conant, 1945b; as cited in Hershberg, 1992). He secured financial support from the Carnegie Corporation in New York for the development of courses, resources, and materials in the general science education (Hershberg, 1992).

The course that Conant personally taught was named Natural Sciences 4, On Understanding Science.[35] Its contents, according to the Preface of the book *On Understanding Science*, were largely prepared by I. B. Cohen, whom he was "deeply indebted… not only for this assistance [of cataloging the bibliographies in the Appendix of the book] but for his collaboration in assembling the historical material on which [the] case histories are based" (Conant, 1947). Cohen was one of Sarton's protégés who, initially majoring in physics at Harvard, had transferred to study the history of science and was still finishing his Ph.D. whilst doing wartime physics teaching when he worked for Conant's course.

Despite all the help that Cohen offered, he was not the one who took on Conant's course in general science education – he aspired to something else. Cohen had separately submitted a proposal to the Committee on General Education for a course in general physical science. Exhilarated by the acceptance of his proposal, he wrote to Sarton in 1947 about his visions for the "course in general physical science using a considerable amount of materials from history of science" (Cohen,

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[34] Details on Conant and the atomic bombings of WWII are available in the colossal, 900-page book *James B. Conant: Harvard to Hiroshima and the Making of the Nuclear Age* by Hershberg (1992).

[35] The name of the course seemed to have evolved over the years as different sources alluded to different titles for the course Natural Sciences 4. For instance, while Hershberg (1992) introduced the course as "On Understanding Science," Reisch (2019) referred to the course as "The Growth of Experimental Sciences."

1947; as cited in Harvey, 1999). Cohen hurriedly finished his Ph.D. that same year to be appointed an assistant professor in General Education and History of Science[36], which enabled him to instruct the course Natural Sciences 3 right away that fall. The full course title was the Nature and Growth of the Physical Sciences, as shown in *Table 5*, and mainly covered Galileo and Newton all the way to the modern relativity theory.[37]

Meanwhile, Conant had recruited three young scientists at Harvard – Fletcher Watson, Leonard K. Nash, and Thomas S. Kuhn – as teaching assistants to his course.[38] Whilst Conant received support from many other collaborators, these three were the ones that he worked closest to for his general science course. Briefly, Watson who earned a Ph.D. in astronomy in 1938 at Harvard turned to become a science educator as he was appointed professor at the Graduate School of Education in 1946. Nash received his doctorate in analytical chemistry in 1944 and had a brief teaching experience at the University of Illinois before he returned to his alma mater in 1948 as an associate professor in chemistry. Kuhn was meandering through his career when he joined Conant on his Natural Sciences 4 (Reisch, 2019). In 1947, Professor Wright, the new head of the Harvard Committee on General Education, pleased with Kuhn and his younger brother Roger's review of the Harvard Red Book, offered Kuhn a teaching position in the general science program. This was a tantalizing opportunity for Kuhn, with heightened interest in the philosophy of science[39], to teach science courses that took a philosophical and historical approach.

The course began off with Conant and Watson and was later joined by Nash and Kuhn. For three years, Conant held frequent lunch meetings with the three to converse about the course and its case histories. *OUS* served as their preliminary course guideline. Conant investigated the chemical revolution in the eighteenth century, specifically the phlogiston theory being overthrown by the combustion of oxygen. Kuhn who majored in physics was assigned to study the history of science

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[36] Cohen was the first American to earn a formal Ph.D. in the history of science under the Committee on Higher Degrees in the History of Science and Learning.

[37] For details on this course, please refer to Cohen's The Nature and Growth of Physical Sciences (1954)

[38] Watson later became the founder and director of Harvard Project Physics in 1964. With hindsight, the latter two and Conant were better known for their appearance in two of Kuhn's publications – *The Copernican Revolution* (1957) was dedicated to Nash and the first edition of *The Structure of Scientific Revolutions* (1962) was dedicated to Conant.

[39] As an undergraduate in physics and electrical engineering, Kuhn was part of the editorial board of *The Crimson* and the president of the Signet Society, a distinguished undergrad society in the arts and humanities. While serving in the radar department during the second World War, he was immersed in books by philosophers of science such as Percy Bridgman and Philipp Frank. When he returned to Harvard as a war veteran, he even enrolled in some philosophy courses (Reisch, 2019).

surrounding Plato and Aristotle (Reisch, 2019). When the course was passed on to Nash and Kuhn, the two fashioned a new, perhaps less ambiguous name of Research Patterns in Physical Science. The full course description of this course offered in 1950-51 was as follows:

> *This course is intended to acquaint students who will not concentrate in physical science with the manipulative and intellectual procedures of the working scientist. These are displayed through detailed historical and technical study of selected investigations of the physical world. Each of these case studies is directed primarily to the discovery of those factors which determined the productivity of the investigation; the creative interactions of scientific, social, and philosophical activities provide a secondary theme. No comprehensive survey of the technical products of scientific activity is attempted, but students are expected to master technical and mathematical materials to the extent that these are necessary for an understanding of the case histories. The prerequisite is a course in physics, or in chemistry, or in general science with emphasis on physics or chemistry, taken in secondary school*.

Conant visited the course from time to time to deliver special seminars on, for instance, Pasteur in 1952. He also kept in touch with Watson, Nash, and Kuhn to produce further publications on science education and case histories. In 1950, Kuhn shared with Conant some of his new ideas on Galileo and Torricelli around the concept of atmosphere and welcomed him to use them in his work (Reisch, 2019).[40] These were reflected in Conant's following book *Science and Common Sense* (1951), which served as an extension to *OUS*. Nash was an associate editor of the *Harvard Case Histories in Experimental Science* (1957), a compendium of case histories gathered under the joint effort of Conant and all his collaborators.[41] He was the author of cases 4 and 5, respectively titled "The Atomic-Molecular Theory" and "Plants and the Atmosphere."

The course was finally left in the hands of Nash alone as Kuhn transferred to

[40] The two were not quite in unison with their views on science. Despite that Kuhn acknowledged Conant for influencing his view on scientific progress in *The Structure of Scientific Revolutions* (1962), he argued for revolutions and paradigm shifts in contrast to Conant's gradual and cumulative progress of science. This discrepancy was covered in greater depth in *The Politics of Paradigms: Thomas S. Kuhn, James B. Conant, and the Cold War* (2019) by G. A. Reisch.

[41] The book was written across years and while the full publication was out in 1957, individual chapters were released earlier. For instance, "The Atomic-Molecular Theory" by Nash was completed in 1950. Although Kuhn had contributed to collecting case histories for the course, he did not write a chapter in this book.

Berkeley in 1956.[42] According to Nash himself, he continued the course for over two decades during which he added his own extensions such as the German dye industry (Jacobs, 2010). He confessed that he suffered from lingering frustrations and eventually sympathized with the felling of having to "sell" outdated theories and concepts in science such as the phlogiston theory to students who found them pointless. The 1960s faced the waning of historical approach to science education.

2.2.3 The Carnegie Conferences on General Science Education

Science of all subjects in general education received special attention (Watson, 1988). This could be supported by the gatherings of science educators over the years 1947 to 1950 for open discussions on the direction of general science education. The conferences were also financially backed by the Carnegie Foundation that had been supporting the general science program at Harvard; thus, this research referred to them collectively as the Carnegie Conferences. Organized by President Conant of Harvard, Dean Sidney B. French of Colgate and Dean Hugh Stutt Taylor of Princeton, the first pair of meetings were held at Princeton in the winter of 1947 and the spring of 1948. These were followed up by additional conferences hosted at Harvard in the summers of 1949 and 1950. The 1950 conference was upscale of the previous meetings to formally earn the title of the Workshop in Science in General Education and to be held at the Harvard Summer School in July.

The papers presented by many senior professors at the 1950 Workshop were bound into a book called *General Education in Science* (1952) with a foreword written by Conant. Cohen and Watson consented to Conant's request to be the editors of this book. The workshop was likely held on five themes based on the composition of this book. The papers in each theme and their presenters were organized in *Table 6*. Some familiar names such as Cohen, Nash, and Watson were found in this list. The entire publication could be the subject of entirely new research. For this research, only the chapter "The Use of Historical Cases in Science Teaching" by Professor Leonard K. Nash of Harvard University was chosen for its relevance to Conant. Nash was one of two, including Thomas Kuhn, that was handed over the course "On Understanding Science" by Conant.

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[42] Nash remained at Harvard to teach mainly teach chemistry and later published two chemistry textbooks, *Elements of Statistical Thermodynamics* and *Elements of Chemical Thermodynamics*.

Table 6. Titles and Authors in *General Education in Science* (Cohen & Watson, 1952)

Theme	Title	Author Name and Affiliation
Science for the Nonscientist	Science and the Layman	René J. Dubos, Rockefeller Institute for Medical Research
	General Education and Special Education in the Sciences	Sidney J. French, Colgate University
	The Assimilation of Science into General Education	Paul B. Sears, Yale University
The Philosophy of Science and the Teaching of Science	The Role of Philosophy in a General Education Course in Physical Science	Edwin C. Kemble, Harvard University
	What Teachers of General Education Courses in the Sciences Should Know About Philosophy	Philipp Frank, Harvard University
The History of Science and the Teaching of Science	The History of Science and the Teaching of Science	I. Bernard Cohen, Harvard University
	The Use of Historical Cases in Science Teaching	Leonard K. Nash, Harvard University
	Acquiring a Knowledge of the History of Science	Frederick G. Kilgour, Yale University
The Sciences in a Technical Civilization	Applications of Science and the Teaching of Science	Philippe Le Corbeiller, Harvard University
	What the Layman Needs to Know About Science	S. A. Goudsmit, Brookhaven National Laboratory
	Education for Citizenship in a Technical Civilization	Edward C. Fuller, Champlain College, State University of New York
Some Problems in the Teaching of Biology	An Approach to the Teaching of Biology to Nonscientists	Edward S. Castle, Harvard University
	The General Education Course in Biology: Laboratory Work and General Objectives	George E. Erikson, Harvard University
The Evaluation Problem	Can General Education Courses in the Sciences Be Evaluated?	Henry S. Dyer, Harvard University
	What the Instructor Can Do About Evaluation: Techniques and Examples	Fletcher G. Watson, Harvard University

■ Forward by Conant

In the foreword, Conant briefly explained the necessity to reexamine general science education and described what it meant for a person to be well-educated in general science. His thoughts seemed consistent with those that propelled him to design a new general science course at Harvard. He again recognized the arrival of the modern scientific era and the change in the college student body as the two factors that urged reforms in general education at the college level (Conant, 1952a). As to the rationalization of general science education, Conant argued that it was also the era of experts where people to a certain extent had to rely on the advice of experts but also had to know how to appraise conflicting advice. Living in a yet more specialized society, it could be interpreted that Conant considered it unfeasible for a person to master all areas of expertise.

■ Use of Historical Cases by Nash

Nash discussed the case-study approach to general science education at the college level in his chapter titled "The Use of Historical Cases in Science Teaching".[43] He was in partnership with Conant, Watson, and Kuhn in developing and improving the new general science course, Natural Sciences 4. Along with the change in course name to "Research Patterns in Physical Science," there were some minor tweaks made to the case-study approach. This section examined the case-study approach as put forth by Nash to establish a further understanding of the underlying philosophy in this approach. However, as this section was placed prior to the investigation of Conant's ideas on science and the case-study approach as presented in *On Understanding Science*, it would serve as more of a trailer for the following chapter.

As for the aims and purpose of using case histories in science teaching, Nash was greatly in line with Conant. This was only the third year of Nash and Kuhn teaching the course so presumably, they had not yet deviated greatly from the previous lecturer. He criticized that scientific facts and theories should not be taught for their own sake and denied "the scientific method" to instead propose the teaching of "the recurrent basic patterns of scientific endeavor and of the real-life complexity that attends any of their specific manifestations" (Nash, 1952).

A large portion of the text was dedicated to Nash denouncing *the* scientific method for its oversimplification of science – he called it the "traditional dogma." Calling the overthrow of Aristotelian physics by Galileo's leaning tower of Pisa experiment a "legend" or a "fable," Nash used his case histories on the tedious process through which phlogiston theory was displaced and the disorderly manner through which Dalton worked out his atomic theory to persuade that most of the science was much complicated than what students had been taught in traditional science education. He persuaded that the case-study approach could provide "empirical evidence" to students for them to process and understand the scientific enterprise. He stated:

> *By selecting a number of our illustrative cases from the past we are enabled to secure a better perspective on a number of relevant influences – scientific, philosophical, economic and social – that are too often seen out of proportion… [T]he somewhat slower pace of the older advances presents*

[43] Nash referred to this approach as the "case approach" and the evidences as "case histories". Therefore, this research was in lines with Nash in his use of "case histories" but differed in the way of naming the approach.

> *important advantages…permitting us to follow the small separate conceptual and experimental steps leading up to the final denouement*. (Nash, 1952)

Hence, this case history should be selected and annotated with care to be embedded with a technical and historical core, illustrated within a setting in scientific history and general intellectual and social history, and featured with human aspects alongside modern relevance. Most importantly, materials on the case histories should be reduced and edited to be sufficiently comprehensible by a non-science major student.

Although these criteria were phrased differently from how Conant set out his in *OUS*, they ultimately conveyed the same sense – the revision in language simply cleared away the ambiguities of *OUS*. Perhaps the major changes that Nash and Kuhn had implemented to the course and the case-study approach was the replacement of jargon. For instance, Nash no longer referred to the ways in which science progressed with the phrase "tactics and strategy of science," a characteristic nomenclature of Conant inspired by military and war tactics. The somewhat ambiguous course title "on understanding science," another one of Conant's nomenclatures condensed with his ideas on science had disappeared from Nash's text.

Whilst other contents of Nash's chapter were similar to what was found in *OUS*, Nash added a short evaluation of the case-study approach. This was the only evaluation of the case-study approach that this research could find. Nash, towards the end of this chapter, briefly provided his impressions on a course assignment. Students were given unannotated extracts of original writings on the discovery of rare gases by Ramsay and Rayleigh and requested to write a short essay on the significance of their work especially in terms of how they reveal patterns of the scientific enterprise. Nash pointed out two "heartening aspects" of the case-study approach: first, it helped students develop some appreciation and willingness to continue science as some expressed that they felt competent enough to complete the assignment; second, it allowed to a certain extent for students to critically read the given texts and adduce the more important contents that demonstrated patterns in science.

Chapter 3. Conant's Ideas and Methods on General Science Education in *On Understanding Science*

On Understanding Science: an Historical Approach (1947) was Conant's response to the problems raised in *General Education in a Free Society* by the Harvard Committee on General Education. Although Conant was one of the chief members of the committee, it was found that he was in unison with but also in conflict with the committee on certain ideas regarding general science education. Thus, in order to filter out Conant's ideas on general science education, an investigation of Conant's individual work on the movement was called. This section of the research analyzed Conant's *On Understanding Science* (from now on OUS) for his ideas on general science education at the college level, his views on science and scientific methods, and his case-study approach while weaving in related contemporary discussions in science education to his ideas.

The chapter first provided an overview of the book, summarizing the contents covered in it and the contexts, mainly historical, during which the book was written. Then, it discovered Conant's particular nomenclature composed of word phrases that repetitively surfaced throughout the book. These were "Understanding Science" and "Tactics and Strategy of Science." Finally, the chapter studied Conant's case-study approach to general science education at the college level, pointing out some unique properties that his approach had. Specifically, these were his particular scope and selection of case histories, his layout of the case histories, and the external approaches to science.

3.1 Brief Overview

3.1.1 Contents

OUS consisted of a preface followed by four chapters. In the preface, Conant set up the context of the book, which was post-WWII, asserting the importance for the American public to learn to live with scientific advances. He also acknowledged the shortcoming of his short book and delivered some warnings to those reading his book, stating that the book is neither a full instructor's manual nor a syllabus for a college course. The first chapter, "The Scientific Education of the Layman," was Conant's rationale for writing the book and his definition of "understanding science." It was made clear that the audience of his case-study approach (not technically the audience of the book) was college students of non-science majors, not future science specialists; hence, the book pertained to general science education at the college level. The second chapter, "Illustrations from the Seventeenth Century 'Touching the Spring of the Air'," was set at the early stages of pneumatics; i.e., the evolving conceptual understanding of vacuum and atmosphere, or air, that eventually yielded Boyle's law. It staged Galileo, Torricelli, Viviani, von Guericke, and most importantly Boyle to demonstrate the development of air pumps that allowed experimentation with air and vacuum, which in turn yielded the quantitative relationship between the volume and pressure of gases. The third chapter, "Illustrations from the Eighteenth Century Concerning Electricity and Combustion," split into two parts: the first part narrated Galvani's accidental discovery of animal electricity, which prompted Volta's invention of the first electric battery; the second part was the overthrow of the phlogiston theory led by Lavoisier and his work to demonstrate the role of oxygen in combustion, during which he received unintended help from Priestley. The fourth and last chapter, "Certain Principles of the Tactics and Strategy of Science," recapitulated the principles of science, or more specifically "The Tactics and Strategy of Science" which were to be later defined, that were alluded to in the case histories of the previous two chapters.

3.1.2 Contexts

The book was completed in 1946 and published in 1947 subsequent to his lectures under the Terry Foundation of Yale University.[44] Conant had been on the Harvard Committee on General Education since its establishment, so it had been at least five years long since he began his contemplation of an approach to general science education at the college level. Actually, his pedagogic nostrum was already being prescribed to students at Harvard through a course in the nascent General Education Program under the same title of "On Understanding Science." According to Conant, this course and his approach were already confirming their effects. Naturally, OUS was also a success being a paperback bestseller to have its sixth printing within a decade of its publishment. Conant further published an expanded version of the book under a new title *Science and Common Sense* in 1951.[45]

Conant was serving multiple important positions in US society at the time he was writing this book. He was the president of Harvard University and was in his fourteenth year when the book was published. He was also in his last year as the chairman of the National Defense Research Committee, in which he demonstrated his role as a statesman and military man. Finally, he was a retiring president of the

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[44] The Terry Lectures or the Dwight H. Terry Lectureship established in 1905 under the grant from Dwight Harrington Terry of Bridgeport, Connecticut invites to this day scholars of science, philosophy, and religion to deliver two or three lectures over two weeks on topics related to science and philosophy, especially in terms of how they inform us on religion and human welfare. The lecture had yielded some important and enduring books. To name two names that are important in science history and education, Joseph Needham in 1934-35 delivered his lectures to publish his *Order and Life* (1935) and John Dewey in 1933-34 delivered his lectures to publish his *A Common Faith (1934)*.

[45] This explained why many contents of the two books were same. Readers can find quotes only phrased with slight difference.

American Association for the Advancement of Science. These social roles served as vantage points, granting him overviews of the public, academic, military, governmental, and diplomatic worlds of the US – thus shaping his views on science and science education to hence influence the contents of OUS.

In terms of its historical context, the book was written within a year after the end of WWII on September 2nd, 1945 with the dropping of the two atomic bombs. The Atomic Energy Commission (AEC) was signed into law by President Truman on August 1st, 1946 to discuss the peacetime control and development of atomic science and technology. These served as important contexts for the book as Conant brought up the atomic bomb several times throughout the chapters. Conant stated in the very beginning of the preface written on November 20th, 1946 that:

> *To write a book about science in the year 1946 without some consideration of the atomic bomb may seem the academic equivalent of fiddling while Rome burns. For all intelligent citizens must place the international control of atomic energy at the top of any list of urgent matters. (p.xii)*

He supervised the Manhattan Project and was appointed a member of the Interim Committee on behalf of the scientific community for wartime use of the atomic bomb. Despite Conant later affirming that the use of the atomic bomb was "correct," he was also one who strongly advocated nuclear control and served the AEC.

Conant separated the public from the stakeholders of the bomb to admit that private citizens had little to say on international nuclear control; he assigned a different task for them to be "patient and courageous" and to learn to "live with" the problem of the atomic bomb. Referring to Ralph Waldo Emerson's Law of Compensation[46], Conant stated that for people to take joy in the marvels brought by science in medicine and health, communications, transportation, and other luxuries in life, they also had to compensate for the destructiveness that nuclear weaponry held. Although the atomic catastrophe had provoked horror and fear of scientific advance, Conant was convinced that blind refusal or indifference merely hindered scientific advances for the future welfare of mankind. He sought remedy in education. In his book, Conant abstained from value-laden judgment over science as either "a benign or a malignant activity of man" and instead aimed to foster a better understanding of science as a "process of unveiling many things" through education, specifically using his case-study approach.

[46] Ralph Waldo Emerson (1803-1882) was an American poet, essayist and philosopher famed for his transcendentalist ideas. Law of Compensation was an idea proposed in one of Emerson's essays titled "Compensation" that addressed the dualism present in nature. He believed that it was dualism which balanced life, stating that for every pleasure there is an equal penalty for its abuse.

3.2 Characteristic Nomenclature

"Understanding Science" and the "Tactics and Strategy of Science" were idiosyncrasies of Conant's ideas on general science education. He carefully concocted the two phrases so as to embed his ideas on general science education into these peculiar phrases. It was from the two phrases that his aims and concerns on general science education, his educational philosophy, and his thoughts on the nature of scientific methods were revealed. Throughout the book, Conant consistently referred to his course using the case-study approach as either the "course on Tactics and Strategy of Science" or the "course on Understanding Science." This was a simple example that substantiated the importance of these phrases. Thus, this section was dedicated to studying the etymology of Conant's characteristic nomenclature to hence understand his ideas on general science education at the college level.

This section was written not solely based on *On Understanding Science*. As it was seen as the core chapter of this research to directly investigate Conant's views on science and science education, it was supplemented with other original writings by Conant written around the same period of time and on a similar topic. The use of multiple resources was an attempt to enrich and triangulate the findings of this research. Limiting the time scope was necessary as one's view on a particular subject is prone to change over time. Primary supplements included "The Role of Science in Our Unique Society," an evening address at the 114th meeting of AAAS on December 27, 1943, and the expanded version of *Science and Common Sense* (1951).

3.2.1 Understanding Science

■ Who Should Understand Science and Why

Conant projected a different goal for the laymen. These laymen could be any private citizen but for the sake of this book, Conant was concerned with the recipients of general education who would graduate and set out to become "lawyers, writers, teachers, politicians, public servants, and businessmen" (p.17). Hence, the understanding of science that Conant aimed to achieve was at the level of a college education. It was likely that he began at the college level for it was the most approachable. Furthermore, pre-selected as the brightest of the nation, these students were the most likely to occupy positions in society as future leaders and men of influence to exercise power over national issues like nuclear weaponry.

As to why these future leaders had to understand science for important decision-making, Conant provided three reasons for desiring the widespread understanding of science. The first reason was for science to be assimilated into the secular cultural pattern to hence proceed toward "a unified, coherent culture suitable for our American democracy in this new age of machine and experts" (p.19). Conant was particularly attached to the word *assimilation* which was also one of the objects of the Terry Foundation, seeing that the US society had not yet or had failed to assimilate science into its secular culture. He thought that it was because science was not integrated into the cultural stream that it was alienated or renounced. The second reason was that the matters of public policy were "profoundly influenced by highly technical scientific consideration" (p.19). The menace of nuclear control was in itself sufficient to prove the change in the quality of issues that the few decision-makers had to handle. This was also the point where Conant's pedagogic concerns at the college level extended to adult education. Those already occupying positions of authority and responsibility need some understanding of science for the sake of national welfare. The third reason was to clarify the extent to which the methods of science could be transferred to other human activities and thus be used to resolve issues not pertaining to science. This had to do with questions such as, "Is there such a thing as a scientific method of wide applicability in the solution of human problems?" (p.20). To that, Conant was opposed to the idea of scientific methods being *the* rational and impartial method and considered it an erroneous understanding of science.

Hence, Conant indirectly defined Understanding Science, stating:

> *In my experience, a man who has been a successful investigator in any field of experimental science approaches a problem in pure or applied science, even in an area in which he is quite ignorant, with a special point of view. I designate this point of view "understanding science." (p.26)*

It was a point of view. This understanding was independent of the knowledge acquired in an area but was universal to all the natural sciences. Therefore, Conant added that it was what even the highly educated and the intelligent would easily overlook. He also stated that:

> *Being well informed about science is not the same thing as understanding science, though the two propositions are not antithetical. (p.26)*

By this, he meant that knowing scientific knowledge and technical terms were not critical to understanding science. Understanding science was having the *feel* for the Tactics and Strategy of Science (e.g., having a sense of what science could and could not achieve) that supported people in their decision makings on future issues and plans (p.26).

■ What Is Not Science

Despite being a chemist or perhaps because he was a chemist, Conant was opposed to scientism. This justified his third reason for a wider understanding of science. He was against the idea that scientific methods were all exact and impartial and thus could be the framework for impartial and rational inquiries on non-scientific matters. Calling it a "very dubious educational hypothesis at best," he criticized Karl Pearson's *The Grammar of Science*[47], which advocated science education for its training on an exact and impartial analysis of all human affairs (p.25). He denounced this false perception of scientific methods by referring to history that this exact and impartial attitude was neither invented nor considered important by those who were first concerned with scientific inquiries. Rather, the history of natural sciences, especially at its embryonic stages, was embroiled in violent polemics. He stated that it was not until around the 17th to 18th century that prejudice and vanity were seen as hindrances to science; thus, the standards of exactness and impartiality were raised. The formation of scientific societies around the same period also called for the need for greater professionality and self-control; for only then, scientists were juried by other well-informed scientists and thus had to present exact and impartial facts void of emotion. Conant found the ancestors of exactness and impartiality in scientific inquiry outside of science. He considered the Greek and Roman scholars and the early explorers, statesmen, and military commanders, but neither the early scientists nor the alchemists, to be those who first contemplated unprejudiced, impartial, and fact-based answers to old questions; thus, the precursors of modern science.

Although Conant deemed a better understanding of science necessary for a free democratic society, he did not privilege science over other fields for its exactness and impartiality; i.e., he was against the idea that science education should be promoted for the reasons of science being of higher status than other subjects or science being the only means to practice such attitudes. However, he did not reject the idea that science had an exact and impartial aspect, stating that science still had the potential to teach such attitudes. This must be made clear. What he disapproved of was the idolatry of science that exaggerated the single aspect of exactness and impartiality, which, he considered, did not even originate from science.

He also considered the practical arts as not science. He viewed the practical arts to have developed separately from the development of science until the 20th century, to even quote that:

[47] Karl Pearson (1857-1936) was an English mathematician and statistician particularly known for establishing the discipline and the department of mathematical statistics at the University College, London. His book *The Grammar of Science* (1892) was recognized by Albert Einstein and used as the first discussion book in his Olympia Academy. This possibly popularized the book as several themes (e.g., relativity in motion to a reference frame, antimatter) in it employed in the works of Einstein and other scientists.

...one may recall that the late Professor L. J. Henderson was fond of remarking that before 1850 the steam engine did more for science than science did for the steam engine. (p.36)

By the above quote, Conant asserted that it was not until a little before his time that science and practical arts had seriously become intertwined. Therefore, he believed that a limited understanding of science was gained by studying the practical knowledge related to science and the history of its application. This point of view also explained why he aimed for a proper understanding of science independent of all the products that science delivered to society. It was not just to avoid the biased and rash judgment of science; he simply considered the practical arts as not science.

Furthermore, Conant criticized that the current general science education only taught students the result of scientific inquiries. This, he considered, contributed to people forming this flawless, cultured image of science. Textbooks left their readers with somewhat dogmatic, faith statements of scientific laws and principles and little room for thoughts and value judgments. Learning only the results, people also tended to reduce the complex process through which science progressed. These, all together, led people to blindly trust science for all the useful applications it brought.

Recall that Conant wanted people to learn to "live with" science. To achieve that, general science education should not leave people to embark on their new careers in society with the impression that science could solve every issue or that science could destruct the world. These people who had to make important decisions in this science-embedded society needed an unbiased understanding of science; therefore, came one of Conant's better-known quotes:

The stumbling way in which even the ablest of the early scientists had to fight through thickets of erroneous observations, misleading generalizations, inadequate formulations, and unconscious prejudice is the story which it seems to me needs telling. (p.30)

Conant was eager to convey the arduous, interminable process of science. He remarked despite all the efforts Darwin put in persuading the scientists and the educated public, his evolutionary theory still placed people today in a position no closer to finding out how life began on Earth than that of his time.

■ What is Science

In some ways, the definition of understanding science hinged on the definition of science. Conant was clearly aware of this, confessing that he intentionally eluded the initial title of 'what is science' that was proposed by the Yale Committee.

He sought "a less ambitious and more ambiguous" replacement, which came to be the current title of "On Understanding Science," only to realize that he was to return to the question that he attempted to dodge (p.36). He was humble in defining science, admitting that his definition was feeble compared to those of the philosophers. Nonetheless, his definition provided some insights into science as a discipline and, for this research, some understanding of how *he* viewed science.

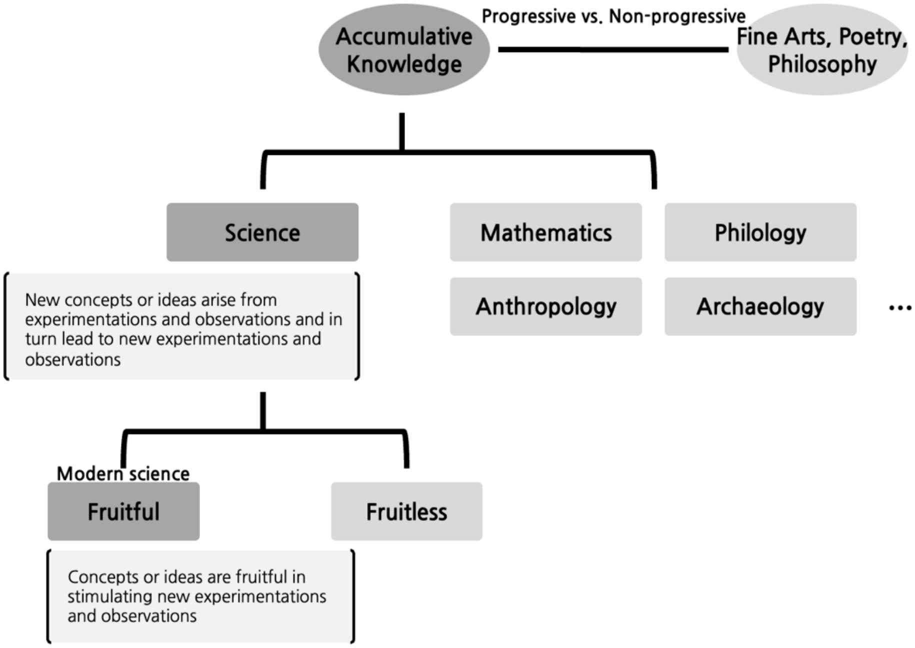

Figure 7. Conant's Process of Defining Modern Science

Conant defined science by ruling out science from other areas of knowledge. The process through which Conant defined modern science followed the left series of branches in *Figure 7*. He saw science as a part of accumulative knowledge, to first compare accumulative knowledge against fine arts, poetry, and philosophy. Whereas the latter three lacked advancement, according to Conant, the accumulative knowledge underwent great progress.[48] He performed an "operational test" where he asked readers to imagine whether great philosophers, artists, and poets of the past would consider the present state of their respective areas as progress (p.34). Conant stated these people would not be able to reach unanimity; In contrast, he was certain that scientists of the past like Galileo, Newton, and Harvey and scholars of other accumulative knowledge would think otherwise – i.e., see the present as progress. This operational test was interesting as

[48] Conant did not distinguish between advance and progress. The two words and their word forms were all seen as being synonymic. The general trend in OUS was that he began with the use of advance but later almost entirely replaced the word with progress or progressive.

progress is always talked about in hindsight, making it tricky to define – contemporaries tend to see the present as progress, or else how are they motivated? Conant paradoxically brought figures of the past to the present days and asked them whether they considered the present a progress.[49] Unfortunately, he did not explicate why scientists would see science as progress, but it could be conjectured that scientists of the past were more likely to consider today's science as progress because science aspired to better depict and explain the natural world. This goal of science could be seen as being asymptotic; therefore, scientists would be ever so closer to the goal.

Next, he singled out science from the other accumulative knowledge, which included mathematics, anthropology, philology, archaeology, etc. He stated that science differed in the way in which it progressed. An overt definition of science could be found in his AAAS speech:

> *Science, thus defined, is to be regarded as a series of interconnected conceptual schemes which arose originally from experimentation or careful observation and were fruitful of new experiments or observations…Science advances not by the accumulation of new facts…but by the continuous development of new and fruitful concepts.* (Conant, 1948)

Fruitfulness was his criterion for science and was interpreted as the dynamic trait of scientific concepts or ideas, born from experimentations and observations, to foster further experimentations and observations. The fruitful concepts and ideas would survive to consist modern science. This trait was independent of the ability of a scientific concept or idea to facilitate the practical arts of science, i.e., technology. Hence, the progress that defined science was the progress in theoretical or conceptual knowledge, not practical knowledge and arts.

Therefore, to summarize, Conant saw science as an accumulative knowledge that progressed not by the brute compilation of facts but by the mutual development of concepts and experimentations. The word accumulative held not the meaning of a mere pileup. As to why he valued the dynamic quality of science, he provided another operational test. This time, he asked his readers to imagine a time in the great future when the scientific age had come to its end and the conceptual schemes of science had paused in the late nineteenth century (p.37). To the people living in that time, Conant asserted, these schemes of science would be

[49] While Conant described accumulative knowledge as progressive and others to be not, he made clear that he was not attempting to denounce fine arts, poetry, and philosophy. progressive was a defining aspect of science that allowed him to single out science from other areas of knowledge, but it did not necessarily grant science any superiority. His short operational test of the dictator on pg.34-35 conveyed that perhaps fine arts, poetry, and philosophy held even greater influence over people's actual thoughts and actions than science.

like religion, and for that reason, it was this defining aspect of science as a dynamic activity that should endure and be passed on through education. *He* emphasized that it was the process through which science progressed that needed to be taught in general science education.

■ Conant and Bacon

So far, the process through which Conant defined science as shown in *Figure 7* could sound baffling. This could be remedied by briefly understanding the classification of knowledge by Francis Bacon (1561-1626), to whom Conant owed such classification as well as his definition of advancement or progress (Conant, 1948). Be in mind that this research was neither a research on Bacon nor a research on how much influence Bacon had on Conant; therefore, only a light study had been done on this part. Interpretations below remained at a very personal, nonprofessional level.

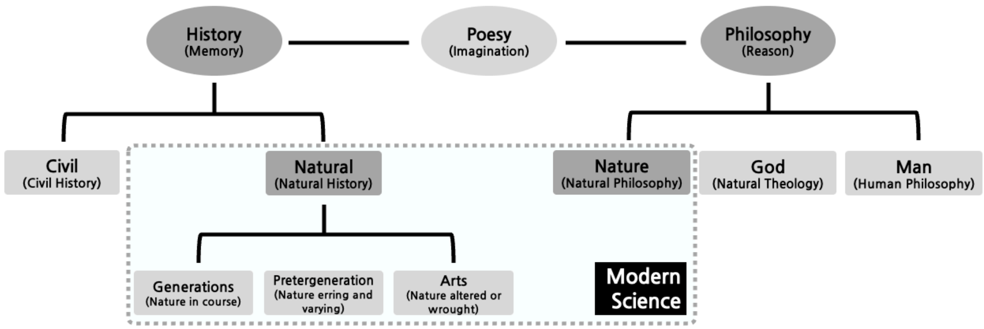

Figure 8. Modern Science in Bacon's Classification of Knowledge

According to Libby (1917), Bacon, in the *De Augmentis Scientiarum* (1638), grouped human knowledge into three groups – philosophy, poesy, and history – which respectively corresponded with the three faculties of mind – reason, imagination, and memory.[50] Bacon ranked philosophy above poesy and poesy above history but stated that philosophy was based upon history (Kusukawa, 2006). That is, for instance, Bacon viewed that natural philosophy, which was categorized under philosophy, relied on the compiled knowledge of natural history, which was categorized under history. Kusukawa (2006) explained that Bacon placed greater value on natural history for its inductive use within natural philosophy and considered natural history on its own lacking value.

Combining what were stated by Libby (1917) and Kusukawa (2006), this research interpreted that modern science, as understood in Conant's age and today,

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[50] A 1917 textbook was intentionally chosen in order to establish some understanding on how scholars in the early 20th century interpreted Bacon's classification of knowledge. However, reading and interpreting this 1917 textbook required supplementary resources.

was closest to the combination of natural history and natural philosophy as classified by Bacon. This was expressed as a diagram in *Figure 8*. Under natural history was the natural history of generations, of pretergeneration, and of arts. These were likely divided based on the degree to which men understood and had control over nature. The natural history of generations was on nature acting in accordance with the laws of nature as discovered by men. The natural history of pretergeneration was on the irregularities of nature that seemed not to be following the laws. The natural history of arts was on nature under men's full control to be manipulated mechanically and experimentally.

As Conant mentioned that he barely altered Bacon's classification of knowledge, a comparison between *Figure 7* and *Figure 8* was called. The correspondence between the poesy and philosophy of Bacon and the fine arts, poetry, and philosophy of Conant was quite explicit. It could be confirmed that Conant replaced history with accumulative knowledge. This was likely due to history, by the time of Conant, being used in a narrower sense. Whereas Conant classified science solely under accumulative knowledge, Bacon placed this science, according to its newer definition of modern science, under both history and philosophy. This was assumably because science held different definitions and social status at the times of Conant and Bacon. It seemed that philosophy as classified by Conant was also used in the narrower sense. Therefore, this research concluded that Conant, despite stating that he barely reinterpreted Bacon's ideas, changed the classification of knowledge to better fit the understanding of areas of knowledge in his days. Such deduction was also made possible as scholars in Harvard Red Book suggested that the history and philosophy of science should be seen as parts of science.

An implication of the comparison above was that scientists and scholars by the time of Conant were seeing science in a broader sense. It was already found that Conant's aim for general science education was to provide non-scientists with not the mere catalog of scientific findings but with an understanding of science as a dynamic process. This supported how he reclassified knowledge and science as science had absorbed many of which Bacon originally placed under philosophy.

3.2.2 Tactics and Strategy of Science

■ Analogy to War

For Conant, understanding science in general science education was to gain some understanding of how science progressed.[51] He expanded on this progress by

[51] The word some was seen to be a crucial aspect of Conant's general science education at the college level. Conant did not think that a full understanding of science was possible, at least for the non-scientists. This particular view of Conant was further investigated in sub-

defining another characteristic nomenclature – the Tactics and Strategy of Science. The Tactics and Strategy of Science were the ways in which science advanced and garnered its fruits. This reminded the more familiar term of scientific methods, but Conant was reluctant to use scientific methods for its ambiguity. His weight was on the ways in which science or scientific knowledge advanced, and he considered that using scientific methods in place would enforce an impression that his course was a manual for conducting scientific experiments. It was not a hands-on course that he intended; actually, quite the opposite being narrative and logical. His course was dedicated to students of non-science majors who had little prospects nor personal urge to perform the experiments themselves. Thus, he developed his own nomenclature that satisfied his purposes for general science education.

The words tactics and strategy could sound foreign to science education but based on OUS it was likely that Conant decided to use them being inspired by the military. Note that he had served in the two world wars of the century. He stated:

> *The analogy with the teaching of strategy and tactics of war by examples from military history is obvious. And the success of that educational procedure is one reason why I venture to be hopeful about this new approach to understanding science.* (p.31)

Conant knew that in war, not all battles were won, and winning often involved tactical withdrawal. Likewise, he wanted to show that science more frequently faced barriers and therefore required many tactics and strategies to battle through. He wanted a better depiction of science, neither as the epitome of impartiality nor rationality, but as a complex process full of barriers. Having general science education in mind, he limited the range of science that he intended to illustrate, and this became his Principles of the Tactics and Strategy of Science.

■ Principles of the Tactics and Strategy of Science

These principles were not scientific principles like the principle of Bernoulli in fluid dynamics that suggest a mathematical relationship between liquid speed and pressure. The scientific principles that people more commonly refer to were closer to what Conant would call the fruits of science, and clearly, the "greater dissemination of scientific information [including the principles] among nonscientists" was not a priority in his general science education (p.26).

He deemed some understanding of the ways in which science progressed essential and thus presented only *certain* principles of the Tactics and Strategy of Science. Little classification of the principles and sub-principles was required as Conant synthesized all that was stated in chapters two and three in an organized manner in the last chapter. *Table 7* presented the Principles of the Tactics and

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chapter 3.3.

Strategy of Science, including the sub-principles. There were multiple sub-principles within a principle. Principles were sequenced alphabetically, and sub-principles were sequenced numerically. For instance, the first sub-principle of the first principle, which stated that concepts may arise from systematic experiments or observations, was referred to with the code [A1].

Table 7. The Principles of the Tactics and Strategy of Science *Simplified* (Conant, 1947)

Principle A. New concepts evolved from experiments or observations are fruitful of new experiments or observations.	
1	New concepts may result from systematic experiments or observations.
2	New concepts may result from a consideration of difficulties inherent in an old concept.
3	New concepts may result from accidental discoveries which are followed up.
4	New concepts may evolve step by step with each step never being so drastic as to completely jettison the older idea.
5	A hypothesis or conjecture may be a limited working hypothesis that is tested frequently through a series of planned experiments.
6	A hypothesis or conjecture may be fruitless and short-lived, or it may be long-lived and useful to become a conceptual scheme.
7	A new concept may be revolutionary to fit in many old facts and to discover many new facts.
8	A new concept must be distinguished from the “explanation” of this concept.
9	A scientific discovery must fit the times.
10	A well-established concept may hinder the acceptance of a new one.
11	Both old and new concepts may be retained even with contrasting, alleged facts to the contrary.
12	Advances in practical arts are not the same as advances in science; likewise, the amassing of data does not constitute advance in science.
Principle B. Significant observations are the result of “controlled experiments” or observations; the difficulties of experimentation must not be overlooked.	
1	Experiments have many variables, and the failure to identify and control the significant variables will vitiate the result.
2	Often it is not easy to answer a simple question unambiguously by experiment.
3	Most experiments involve measurement. For the measurements to be significant, they must have some relation to the accidental variations in numbers.
4	Erroneous observations or interpretations of experiments frequently confuse the development of new concepts.
Principle C. New techniques arise as a result of experimentation and influence further experimentation.	
1	New techniques, apparatus, or procedure may lead to new discoveries.
2	New techniques may evolve gradually with new apparatus and methods. When a certain degree of accuracy or convenience is reached, new observations are made.
3	New techniques may arise from a consideration of a practical art.
4	A new technique may be developed for the purpose of exploring new phenomena.
5	A new technique may arise from an accidental discovery which is followed up.

Principle A emphasized the dynamic way in which science progressed, where new concepts originating from experimentation and observations were fruitful for further experimentation and observations. This was precisely what Conant repeatedly emphasized as the trait that defined science and thus should be taught in general science education. The sub-principles specified how new concepts were evolved: from systematic experimentation and observations [A1]; from recognition of limitations in old concepts [A2]; through accidental discoveries [A3]; and through gradual improvements on existing concepts [A4].

Principle B recognized the intricate quality of experimentation and observations. Conant provided examples of some details in experimentation and observations that scientists have to pay attention to in order to achieve meaningful findings. Each subprinciple seemed to correspond with different stages in experimentation and observations. At the stage of defining the variables, he stated that it was important for the scientist to identify the variables, especially those that are confounding [B1]. Next, he recognized that once the variables were set and the procedures were conducted, the scientist needs to filter out values that are significant against possible noises [B3]. An erroneous implication drawn from the findings could put the scientist on the wrong path [B4]. Throughout all stages, Conant stated that often, experimentation fails to answer what appears to be an easy question [B2]. These sub-principles brought to light how difficult it was to conduct fruitful experimentation and observations; thus, achieving Conant's aims to "show the hazards which nature puts in the way of those who would examine the facts impartially and classify them accurately" (p.32). Hence, the entire Principle B also tackled the false perception that science could cruise through all societal issues.

Principle C grouped the various relations that new techniques, apparatus, and procedures have with experimentation and observations. It was not just new concepts that were fruitful of further experimentation and observations, but some assistance from the technical parts and the practical arts was necessary. Despite Conant stating that the practical arts were not science, he also explicitly admitted that they shared some mutual dependency. The sub-principles [C1], [C2], and [C3] suggested that the practical arts as well as new apparatus and methods could lead to the development of new techniques, which in turn could lead to new scientific discoveries. The motive behind this development of new technique would be for the investigation of a new phenomenon [C4], but it could also be the new, accidental phenomena that give rise to the new technique [C5].

3.3 His Case-Study Approach

Conant was convinced that his case-study approach was the better option for general science education at the college level. He justified his approach by comparing the ways in which complex human activities (e.g., science) and their products could be studied.[52] One was to logically "retrace the steps" by which the products were developed (p.27); hence the historical method. The other was to "dissect the result" to reveal structural patterns, logical relations, and inconsistencies (p.27); hence the logical method. Conant associated the former way with historians and the latter with philosophers and mathematicians. He found the historical method more suitable for general science education. He argued that to attain some understanding of science with a relatively small amount of study, it was more effective to study a few examples of science than to try and interpret the complex philosophical analyses of science (p.28).

This section looked into Conant's methods of general science education at the college level. His case-study approach was analyzed for first its scope and selection of case histories, then how these selected case histories were laid out. Particular attention was placed on how Conant weaved his principles of the Tactics and Strategy of Science into his case histories in order to establish some understanding of science. Conant was also aware of the many areas of knowledge that surrounded science, namely mathematics and philosophy. Therefore, this section also investigated what he had to say about these areas, especially whether and how they should be included in general science education.

3.3.1 Scope and Selection of Case Histories

Conant's case-study approach involved the use of case histories. These case histories were actual incidents from the past where scientists had faced new phenomena, attempted to explain the phenomena, conducted experiments, and observations on the phenomena, etc. For instance, he opened his second chapter on a case history covering the early stages of pneumatics with Galileo Galilei's attempt to explain the 34ft limit of water pumps with the Aristotelian concept of air abhorring vacuum. These case histories were likely withdrawn from classic texts in science written personally by scientists as Conant complained about the lack of properly translated classic texts that could be used as class material.

■ Scope

The time frame from which Conant selected the case histories pertained to the early days of modern science, which varied depending on the specific discipline. For instance, he paid attention to aspects of physics in the seventeenth to the eighteenth century, chemistry in the eighteenth to the nineteenth century, geology in the early nineteenth century, and biology in the eighteenth century. He provided two rationales for such a temporal setting: first, relatively little amount of factual

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52 Here, the word products was used as the theoretical or conceptual knowledge of science, not the practical arts or knowledge from science.

knowledge of science and mathematics was a pre-requisite; second, the trials and errors of great scientists at the pioneering stage were clearly portrayed. He refused to select cases from then-recent scientific advancements. He believed that they would leave overgeneralized and flawed impressions of science for their precedence in the US society was high.

Regarding the number of case histories, Conant deemed scrutiny of a few historical examples of the development of science tactically effective for students of non-science majors at the college level to develop some understanding of science. Despite the number being few, he intended to choose case histories from as many areas of science as possible. Conant limited the number of case histories as a trade-off for the depth in which he intended to go into each. Thus, students were exposed to a very restricted number of historical figures or incidents but were instead able to learn the details surrounding the evolution of a particular scientific concept. This could be interpreted as generalization learning where broad principles of science were studied from fewer, more detailed case histories.

As for the casts of his case histories, Conant restrained from the overemphasis on a single, brilliant scientist such as Newton, Carnot, Darwin, Planck, and Einstein and focused on the less spectacular and the less known. This criterion was set at the time of Conant and was set for the nonscientists; thus, from the point of view of a scientist or a science educator, especially that of today, the casts in Conant's case histories could seem familiar or sufficiently well known. Such criterion was likely suggested as means to prevent a false impression of science as being led or revolutionized by a single hero and to introduce new names and concepts in science.

Table 8. Outline of the Case Histories in OUS

<table>
<tr><th></th><th>Time Period</th><th>Scientist</th></tr>
<tr><td rowspan="8">EARLY PNEUMATICS AND BOYLE'S LAW</td><td>Mid-16c.</td><td>Galileo Galilei</td></tr>
<tr><td colspan="2">• Aristotelian concept of nature abhorring vacuum failed to explain the 34 ft height limit of water lift pumps.
• Galileo made a wrong analogy to the breaking point of copper wires to the pump columns that broke at 34 ft.</td></tr>
<tr><td>1643</td><td>Evangelista Torricelli & Vincenzo Viviani</td></tr>
<tr><td colspan="2">• Torricelli speculated that air had weight and exerted pressure on the surface of water preventing it to rise above 34 ft.
• Torricelli with Viviani created a mercury column to find that mercury which was 14 times heavier than water only rose 1/14 ft as high as that of water in the column. They also created the Torricellian vacuum.</td></tr>
<tr><td>1648</td><td>Blaise Pascal</td></tr>
<tr><td colspan="2">• Pascal carried the mercury barometer up the Puy-de-Dôme mountain to find that as elevation increased, the height of mercury column decreased.</td></tr>
<tr><td>1650</td><td>Otto von Guericke</td></tr>
<tr><td colspan="2">• Von Guericke invented the first air pump to produce vacuum.</td></tr>
</table>

		• In 1654, he conducted demonstrations with the Magdeburg hemispheres where the two evacuated hemispheres were held together by external atmospheric pressure.
	1660	Robert Boyle
		• Boyle created improved air pumps that were larger and thus could have objects inserted. • He developed this concept of air being elastic, assuming a spring in the air or taking on the Cartesian corpuscle explanation. • He found the inverse relationship between volume and pressure at a constant temperature through experiments.
	1660	Thomas Hobbes
		• Hobbes and the plenists questioned Boyle and the vacuists on the idea that a vacuum could exist.
DISCOVERY OF THE ELECTRIC BATTERY	Mid-17c.	Jan Swammerdam
		• Swammerdam observed a similar phenomenon but did not follow up like Galvani.
	1786	Luigi Galvani
		• Galvani observed the twitching of a frog’s legs when the leg nerves came in contact with a metallic scalpel with an electrostatic machine in the vicinity. • He conducted several experiments to explain this phenomenon. • He further found that the electrostatic machine was unnecessary if the leg and the nerve were connected by two different metals.
	1800	Alessandro Volta
		• Volta experimentally found that frog could be replaced by any moist material. • Volta created his first battery with layers of tin and zinc between lye-soaked pasteboards.
COMBUSTION AND THE CHEMICAL REVOLUTION	1630	Jean Rey
		Rey had already found that calx weighed more than tin.
	1673 to Early 18c.	Robert Boyle, John Mayow, Robert Hooke, Stephen Hales
		• Boyle also confirmed this increase in weight but wrongly hypothesized that it was the fire the passed through glass vessels to combine with metal, thereby giving it weight. • He, along with Mayow, Hooke, and Hales, were all aware that air in which material had burned or undergone respiration no longer sustained life and that the volume of air decreased after burning.
	1703	Johann J. Becher & Georg E. Stahl
		• Becher and Stahl suggested the phlogiston theory, stating that phlogiston added to calx yields metal.
	1772	Joseph Priestley
		• However, Priestly and the chemists of 18c. considered that air no longer supported combustion because it became too rich in phlogiston. • Priestley discovered how to prepare pure nitrogen and oxygen. He labeled nitrogen as phlogisticated air that does not support combustion and oxygen as dephlogisticated air where candle lit brightly. • He carried out numerous original experiments to discover 11 more “airs” including oxygen with his techniques.
	1772	Antoine Lavoisier
		• Lavoisier discovered that sulfur and phosphorus in burning increased in weight but had trouble showing this as calcination experiments were tricky. • After Priestley’s discovery of oxygen, he was able to uncover that oxygen was the something absorbed from air.

■ Selection Criteria

The three case histories that Conant selected for his OUS were organized in *Table 8*. The case histories were not necessarily presented in chronological order but were fixed to be so for a clearer depiction of the case histories that were handled.

The case histories were replaceable – i.e., Conant did not consider his case histories as the only suitable choices for general science education at the college level. That is, if there was a better example that could demonstrate any of the principles in *Table 7*, the instructor could freely replace his. For instance, he suggested Roentgen's accidental discovery of X-rays as a possible replacement, especially to demonstrate the sub-principle [C5], which states that new techniques, in this case, X-ray scans, can arise from following up accidental discoveries. He also recommended the invention of telescope and Galileo's observations of celestial objects for the sub-principle [C1]. However, he did avoid the use of classic cases such as the Copernican theory because they were already cliché and thus did not warrant yet another pedagogical approach.

Furthermore, Conant while stating that there was no greater merit in using his case histories, he still required three criteria to be met. First, the field of science from which case histories were chosen must have undergone significant progress in the recent century; second, he defined this progress as a clear evolution of scientific concepts and schemes accompanied by new experiments and observations; third, the case histories should allude to more than one principle of the Tactics and Strategy of Science.

3.3.2 Layout of the Case Histories

■ Incorporation of the Principles

The third criterion of selecting case histories was that they could incorporate multiple sub-principles of the Tactics and Strategy of Science into the narration. Hence, this section sought how various sub-principles were weaved into the case histories. Only a case history supplemented with sub-principles would complete the case-study approach of Conant. *Figure 9* illustrated how Conant presented the case history in Chapter 2 on the concepts of pumps, vacuum, atmosphere, and pressure along with the different sub-principles that could be discussed in each incident within the case history. This chapter was particularly chosen for discussion due to its length and detail.[53]

Conant's case histories followed a non-linear, plot-driven narrative. He set out the incidents with clear intentions to discuss various sub-principles at the right

[53] Conant mentioned that his case histories were limited and lacked details due to OUS being such a short book.

moment. This, in the case of Chapter 2, was close to the chronological order but was not the case for the case history on combustion and the Chemical Revolution in Chapter 3 where the case history unraveled from its end – i.e., how Lavoisier revealed to the world the role of oxygen in combustion with his classic experiment involving the heating of mercury in a closed space. All case histories were led by the interplay between new scientific concepts or ideas and new techniques, apparatus, or procedures. In *Figure 9*, the relatively more conceptual developments were colored in a darker shade than the technical or practical developments. It was the development of new concepts, techniques, apparatus, and procedures that drove the plot forward, not the scientists. A scientist could have reacted to the work of another scientist, for instance, Boyle was inspired by the air pumps developed by von Guericke, but Conant ensured that this was not told in a biographical way. That is, through his case-study approach, it was difficult to establish a value judgment over the scientist whether it be his personality or his competency in science. This was evident as Conant deliberately used Boyle in two of his case histories, the first and the third, to demonstrate how Boyle succeeded in developing new concepts on the pressure of gases but was not as successful in explaining the increase in weight in calcination.

In *Figure 9*, most of the incidents induced one or more sub-principles of the Tactics and Strategy of Science as shown in *Table 7*. Some links to sub-principles were done in the book whereas some were added by this research. Nevertheless, to give an example, Pascal's experimentation of carrying the mercury barometer up Puy-de-Dôme could be discussed with the sub-principles of [A1], [A4], [C1], and [C4]. Respectively, from systematic observations, Pascal developed a new concept that atmospheric pressure was greater nearer the surface of the Earth. This was made possible by Pascal coming across Torricelli and Viviani's mercury barometer and then extending it to his observations. The mercury barometer had become a useful apparatus to investigate the concept that air has weight, and Pascal had additionally found that height or elevation from the surface of the Earth was another way to study this concept. Taking another example, Boyle's extensions to conduct quantitative measurements and further investigation on water and sound could be linked to the sub-principles of [B1], [B2], [B3], [C2], and [C4]. Boyle created a new apparatus, now known as the J-tube, to investigate the quantitative relationship between the volume and pressure of gas indirectly by estimating the change in pressure based on the change in height of mercury. His measurements were able to hint at some quantitative relationship between the two variables (as this relationship was later coined by his name –i.e., Boyle's law) but still lacked precision as the practical arts of his time could not make bent glass vessels with a uniform diameter. He also made attempts to control the confounding variable of temperature to observe the expansion of compressed air when warmed with a candle flame, but this was not so successful. He extended his experimentation to replace air with water and to test sound in vacuum. The former, despite being seemingly simple, failed as Boyle was unaware of the dissolved air in water and the boiling water at room temperature when ambient pressure was low. The latter, through the development of a new technique to suspend a watch by a thread inside a vacuum container, Boyle observed that no ticking sounds were heard.

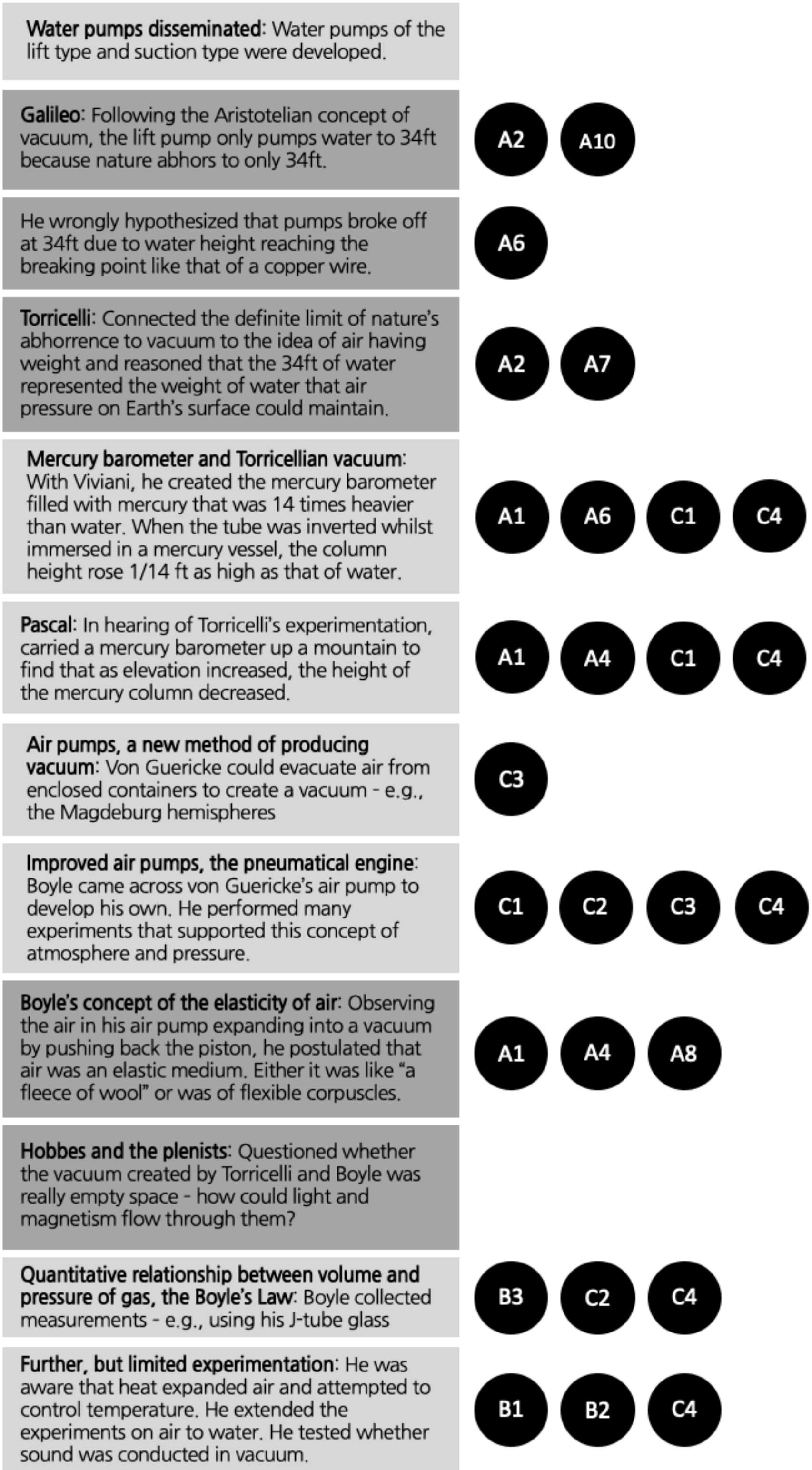

Figure 9. The Layout of a Case History – Early Pneumatics and Boyle's Law

■ Use of Visual Aids and Primary Sources

The case histories were supplemented with ample diagrams as visual aids. These would provide a picture of the apparatus that scientists developed for their experimentation and observations. For instance, in *Figure 10*, on the left was a diagram of the simple lift or suction pump that was abundant at the time of Galileo. The diagram was labeled with arrows explaining the different parts of the pump. This would allow the readers of OUS to visualize what it meant for the pump to have a 34ft limit from the cistern to the valve. Furthermore, the caption supplemented the mechanism of the lift pump explaining how the piston was loose so that water could pass by when the piston was pushed downwards. Likewise, the figure on the right was a diagram of the air pump created by Boyle. Conant added an original quote from Boyle in its caption that explained how the air pump worked.

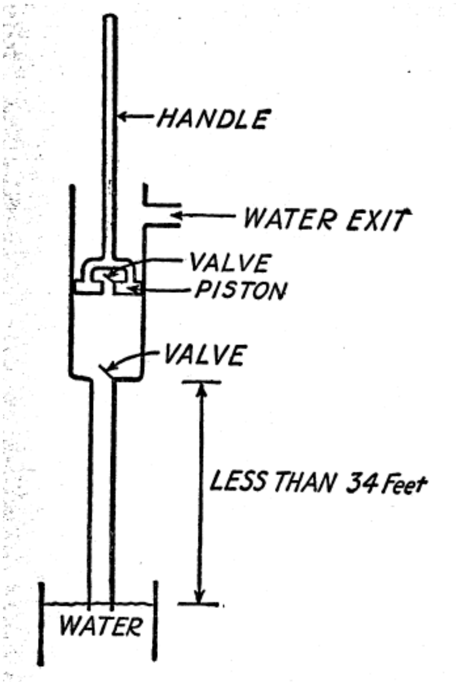

Fig. 1. Diagram of simple lift or suction pump for raising water. The primitive pumps of Galileo's time appear to have had in place of a valve on the piston, a loose packing around the piston which allowed water to pass by on the down stroke but was tight on the up stroke.

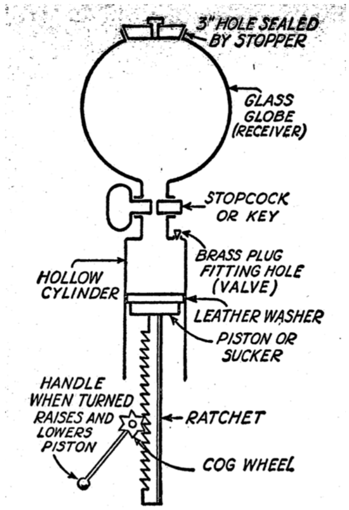

Fig. 5. Simplified diagram of Boyle's air pump.

The following description of the working of the pump is in Boyle's own words: "Upon the drawing down of the sucker (the valve being shut) the cylindrical space, deserted by the sucker, is left devoid of air; and therefore, upon the turning of the key, the air contained in the receiver rusheth into the emptied cylinder. . . . Upon shutting the receiver by turning the key, if you open the valve, and force up the sucker . . . you will drive out almost a whole cylinder full of air; but at the following exsuctions you will draw less and less of air out of the receiver into the cylinder because there will remain less and less air in the receiver itself. . . ."

Figure 10. Use of Diagrams in *On Understanding Science*

Conant also included images from historical texts. These images, as shown in *Figure 11*, were more realistic than the diagrams drawn by Conant in terms of them allowing readers to visualize the apparatus within its historical context. On the left was an illustration from *De Re Metallica* (1556) by the 16th-century mineralogist and metallurgist Georgius Agricola showing the use of water pumps in mining.

Conant stated that this illustration indicated that men of the 16th century were aware of the water pump having a height limit to create this vertical arrangement of lift pumps. This also hinted, as said by Conant, that practical arts developed independently with science. On the right was an illustration from a book written by Gaspar Schott, a Jesuit scientist and professor at Würzburg, in 1657 through which Boyle, the Earl of Cork (in today's Ireland), was introduced to the Magdeburg hemispheres by von Guericke, the Burgomaster of Magdeburg (in today's Germany). Conant stated that it was unclear how much influence von Guericke had on Boyle. However, this illustration nonetheless demonstrated how there was a time delay from 1654 when von Guericke performed his demonstrations to 1657 when Schott's book was published until Boyle who lived far away became aware of science happening elsewhere.

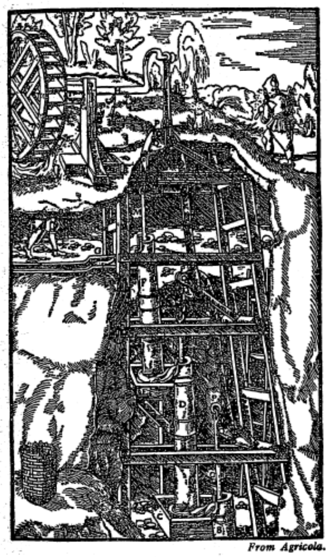

Fig. 2. Reproduction of wood-cut of primitive water pump.

Fig. 4. Von Guericke's Magdeburg hemispheres.

Figure 11. Use of Images from Historical Texts in *On Understanding Science*

Although only a single example was found in OUS, the book also had original, quantitative data from the scientist. The example that Conant decided to insert, *Figure 12*, was the quantitative data of the height of the mercury column along with the estimation of pressure from Boyle's J-tube experiment. Each column of the data table was labeled with an alphabet, which linked to the legend provided on the right side of the table. By comparing columns D and E, readers could find that Boyle's experimental findings in D were close to his hypothesized values in E. The data not only fosters an understanding of the form of data collection and measurement that Boyle conducted but also an understanding that by the time of Boyle, the practical arts of making glass vessels were advanced enough to yield sufficiently precise measurements – thus, again summoning the sub-principle [C2].

A Table of the Condensation of the Air (Boyle's original data)

A	*B*	*C*	*D*	*E*
48	00	Added to $29\frac{1}{8}$ makes	$29\frac{2}{16}$	$29\frac{2}{16}$
46	$01\frac{7}{16}$		$30\frac{9}{16}$	$30\frac{6}{16}$
44	$02\frac{13}{16}$		$31\frac{15}{16}$	$31\frac{12}{16}$
42	$04\frac{6}{16}$		$33\frac{8}{16}$	$33\frac{1}{7}$
40	$06\frac{3}{16}$		$35\frac{5}{16}$	35
38	$07\frac{14}{16}$		37	$36\frac{15}{19}$
36	$10\frac{2}{16}$		$39\frac{5}{16}$	$38\frac{7}{8}$
34	$12\frac{8}{16}$		$41\frac{10}{16}$	$41\frac{2}{17}$
32	$15\frac{1}{16}$		$44\frac{3}{16}$	$43\frac{11}{16}$
30	$17\frac{15}{16}$		$47\frac{1}{16}$	$46\frac{3}{5}$
28	$21\frac{3}{16}$		$50\frac{5}{16}$	50
26	$25\frac{3}{16}$		$54\frac{5}{16}$	$53\frac{10}{13}$
24	$29\frac{11}{16}$		$58\frac{13}{16}$	$58\frac{2}{8}$
23	$32\frac{8}{16}$		$61\frac{5}{16}$	$60\frac{18}{23}$
22	$34\frac{15}{16}$		$64\frac{1}{16}$	$63\frac{6}{11}$
21	$37\frac{15}{16}$		$67\frac{1}{16}$	$66\frac{4}{7}$
20	$41\frac{9}{16}$		$70\frac{11}{16}$	70
19	45		$74\frac{2}{16}$	$73\frac{11}{19}$
18	$48\frac{12}{16}$		$77\frac{14}{16}$	$77\frac{2}{3}$
17	$53\frac{11}{16}$		$82\frac{12}{16}$	$82\frac{4}{17}$
16	$58\frac{2}{16}$		$87\frac{14}{16}$	$87\frac{3}{8}$
15	$63\frac{15}{16}$		$93\frac{1}{16}$	$93\frac{1}{5}$
14	$71\frac{5}{16}$		$100\frac{7}{16}$	$99\frac{6}{7}$
13	$78\frac{11}{16}$		$107\frac{13}{16}$	$107\frac{7}{13}$
12	$88\frac{7}{16}$		$117\frac{9}{16}$	$116\frac{4}{8}$

A. The number of equal spaces in the shorter leg, that contained the same parcel of air diversely extended.

B. The height of the mercurial cylinder in the longer leg, that compressed the air into those dimensions.

C. The height of the mercurial cylinder, that counterbalanced the pressure of the atmosphere.

D. The aggregate of the two last columns, *B* and *C*, exhibiting the pressure sustained by the included air.

E. What that pressure should be according to the hypothesis, that supposes the pressures and expansions to be in reciprocal proportion.

Figure 12. Use of Quantitative Data from Original Texts in *On Understanding Science*

Lastly, Conant incorporated quotes from original texts written by scientists in the case histories. The use of classic texts in general science education at the college level was also suggested in the Harvard Red Book, as shown in *Table 4*. This suggestion was accepted and applied in Conant's case-study approach in OUS and thus his course for general science education at Harvard as well. Almost the entirety of Boyle's concept of the elasticity of air in OUS was told through Boyle's voice. By utilizing direct quotations from *New Experiments Physico-Mechanicall Touching the Spring of the Air* (1660), Conant explained how Boyle was indecisive between two possible explanations for his idea that "there is a spring or elastical power in the air we live in" (p.55). One was "…by conceiving the air near the earth to be such a heap of little bodies, lying one upon another, as may be resembled to a fleece of wool" (p.57). The other was "…by supposing with that most ingenious gentleman, Monsieur *Des Cartes*, that the air is nothing but a congeries or heap of small and of flexible particles, of several sizes…" (p.57). Not only did the use of direct quotation increase the vividness of the incident, but it also demonstrated what subprinciple [A8] meant and how it occurred in real.

3.3.3 External Approach to Science

So far, the case-study approach had been presented in a confined manner, discussing only the science-related contents. However, Conant was fully aware that science was not an isolated knowledge disconnected from society and from the surrounding knowledge such as mathematics and philosophy. He justified his limited incorporation of contents external to science as he intended to focus on the progress of science in regard to the development of new concepts through experimentation and observations. Nonetheless, the OUS was not completely void of discussion on how society impacted science, and Conant also explicated how mathematics and philosophy should be embedded into the general science education at the college level. Thus, this section investigated this external approach to science.

■ Science and Society

Although not on the principles of the Tactics and Strategy of Science, Conant had a peripheral goal to convey how society interacted and impacted the activity of science. He stated, “I should want also to illustrate the interconnection between science and society” (p.32). This interaction could be interpreted in two perspectives: one was seeing science itself as a social activity, and the other was examining the relationship between science and the society encompassing it. For the former, any case histories from second half of the 17^{th} century and onwards would be appropriate as this was when the great scientific societies were formed. Conant added that this was also when the importance of publishing scientific results was raised. The aforementioned incident of Boyle learning about the Magdeburg hemispheres from Schott’s book could be an example. As for the latter, Conant found that a consideration of Boyle’s life almost exemplified how social, religious, and political forces influenced the early days of modern science. To have a glimpse of how society promoted science, Conant also encouraged the use of the Accademia del Cimento sponsored by the two Medici brothers where scientists collaborated and published together.

What Conant was concerned with was not that the instructor of the Tactics and Strategy of Science would misplace or exclude these historical backgrounds in the study of case histories, but that too much time might be expended on it. He stated:

> *After all, I am suggesting a course in the Tactics and Strategy of Science, not one on European cultural history as illustrated by episodes in science, though the latter might be of value in the education of future scientists and engineers. Therefore, the role of the scientific societies in forewarding the new philosophy and sponsoring the publication of books and journals…would be the matter of prime attention.* (p.71)

By the second sentence, Conant meant that the incorporation of society in general science education should be focused and compact. Only those episodes, which were considered to share a keen interconnection with science, say why neither Oxford nor Cambridge were the homes of early modern science, would be relevant. These would foster an understanding of the progress of science in regard to the role of scientific societies and amateur scientists.

■ Incorporation of Math and Philosophy

Conant explicitly stated that general science education at the college level should be prepared for students with relatively little knowledge of mathematics. Thus, another criterion for the selection of case histories was that they should be comprehensible without any advanced prerequisites in math. There was neither formula nor calculations that appeared in OUS, save for the quantitative data collected by Boyle as shown in *Figure 12* and the simple arithmetic operations on the atomic weights[54] of phosphorus, sulfur, oxygen, and tin in combustion by Lavoisier.

Conant further stated:

> *Progress in mathematics would of course be included in the course to the extent that the students were able to handle the material… since the development of mathematics is also the development of the language, I doubt if anyone will be inclined to argue this point against me… I suggest that the advances in mathematics be illustrated by examples closely connected with physics and astronomy.* (p.38)

The above examples of Boyle and Lavoisier would apply to mathematics as a language of science. However, Conant did not provide examples of progress in mathematics that fostered the progress of science or vice versa. This could be that while he acknowledged that the progress of mathematics and science was inextricably linked, it was perhaps difficult to find case histories with simple mathematics that could show this interconnection. It could also simply be that Conant did not prioritize the progress of mathematics in general science education and thus that it did not fall in the three case histories that he chose for the short book of OUS.

Likewise, Conant proposed that the extent to which philosophical problems should be taken into account, especially regarding metaphysics and epistemology, depended on the instructor and the students. In terms of metaphysics, he agreed that the formation of new scientific concepts had a definite influence on how men thought of the universe and nature – for instance, the evolving concept of the vacuum. Questions like "Is a vacuum really empty…? [Thus] Is action at a distance imaginable?" should be presented during the case-study approach for students to ponder upon (p.33). As for epistemological questions, Conant also suggested throwing out questions like the difference between the meaning of "establish" in the two statements "chemists have 'established' that chlorophyll is essential for photosynthesis" and "[chemists] also have 'established' the spatial arrangements of

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[54] Now, average atomic mass

the carbon, hydrogen, and oxygen atoms in cane sugar" (p.33). This would allow students to critically think about simple expositions on science taught in conventional science education. Nevertheless, Conant reminded that the case-study approach should still not deviate from its focus on science as progressive knowledge as well as its interaction with the practical arts.

Chapter 4. Discussions and Conclusion

At last, after all the investigations on Conant and his general science education, this research intended to take an attempt at some of the broader, controversial questions in science education. In sequence, these were: (1) Can Conant be considered a science educator? If so, what are the aspects that define a science educator? (2) Can Conant and his principles of the Tactics and Strategy of Science be considered a precursor to the Nature of Science? How was Conant able to tackle issues in science education that still irritate science educators today? (3) If Conant is truly a science educator, where is he in the larger context of science education? After the discussion over these questions, this research was brought to its closure.

4.1 Conant as a Science Educator

This research began with grandiose plans to reappraise Conant as a science educator by examining his works on science education. Beginning from scratch, it first reviewed prior biographical research in science education to seek hints to achieving this aim. From Song (2006) and Matthews (2015), it learned that science educators possessed specific views on science which were transferred to their views and methods in science education. It additionally learned that science educators sensitively read the sociocultural contexts they were in, in order to customize science education to the current and future needs of society. In both studies, science educators produced speeches or written texts on science education and carried these over to practice. These findings laid the foundation of this research, which proceeded onto repeating similar procedures on Conant.

So, could Conant be evaluated as a science educator? He saw science as a continuous development of new and fruitful concepts born from interactions with experimentations, observations, and the practical arts. Thus, he taught general science at Harvard with case histories that demonstrated this cyclical development of theoretical concepts and practical works. Conant addressed verbally and in written forms the need for a better understanding of science amongst the general public now that science and technology were embedded in all areas of life. He stressed the importance of a proper understanding of science, not of its theories and concepts but of the process through which it developed, for the nonscientists in order for them to make reasoned decisions on science-related issues. He delivered his ideas through speeches at science societies and through publications such as *OUS* and personally taught a course on general science at Harvard. Therefore, this research daringly concluded that Conant was a science educator who set apart general science from an elementary version of specialized science, granting it new aims and pedagogy that involved a historical approach to learning and teaching science.

4.1.1 From an Administrator to an Educator

At this point, this research was determined to confess a concern that it once suffered. While working on Chapter 2, the question of whether the Harvard Red Book, especially the parts on science education, could be seen as the works of Conant. Without access to archival records, this research only confirmed that the subcommittee on science consisted of Hoadley and Wald, among which Wald contributed a larger pie in the subchapters on general science education. It was unclear if Conant had participated in the meetings of the subcommittee and if his ideas on science were included in the final report. Both the Harvard Committee and its subcommittees were constituted under the commands of president Conant but his name was not included in the list of authors. Aforementioned, he did write the foreword in which he boasted the consensus on general education that the committee was able to reach. Therefore, this research settled on a feeble conclusion that Conant could not be assessed as a science educator to the extent of the Harvard Red Book.

However, as the title of this subchapter sneakily implied, this research nonetheless found significant congruency between the report and the ideas and methods of Conant. This finding allowed this research to extend Conant's identity as an administrator or policy maker of science education to a science educator. On a side note, the previous statement also entailed that at least this research did not regard an administrator as equal to an educator. Anyways, this finding of high congruence was supported by Hamlin (2016), although he did not elaborate on how so. Hence, it was for this subchapter to present how well Conant's ideas on general science education mirrored those in the Harvard Red Book. The table below compared the Conantian general science education to that of Harvard Red Book, using its suggestions on physical science as a checklist. In order to do so, some sentences in *Table 4* were rephrased while the entire section of "Methods and Tools" was omitted as it was considered redundant for this sake. It was already confirmed that the course was taught mainly with lectures supplemented by special lectures and involved the study of annotated classic texts in the history of science. It was likely void of individual laboratory work but students enrolled in the course were likely supported with group meetings or tutoring.

Table 9. Congruency of Conantian General Science Education to Harvard Red Book

General Science in Harvard Red Book	Conantian General Science	
		JUSTIFICATION
Conveys some integrative viewpoint, scientific method, or the development of scientific concepts, or the scientific world-view	✓	Conant's view of science as a dynamic process was reflected in his general science education.
Gives insight into the fundamental principles of the subject and the nature of the scientific enterprise	✓	Although the variety of principles introduced was limited, Conant's case-study approach provided some sociocultural contexts surrounding the selected case histories.
Provides the clearest, simplest, and most rigorous examples of scientific analysis and approach	✓	Simplicity was demonstrated by the succinct list of principles while rigor was conveyed through the of trials and errors of scientists.
Includes general principles and concepts of science	△	Conant's criteria for choosing case histories limited the number of principles and concepts but those introduced (e.g., atmosphere) were general and important.
Demonstrates conceptual interrelations, world-view, and view of the nature of man and knowledge	✓	In the selected case histories, scientists interacted with their surroundings to be affected by the works of others. Case histories showed the complexities in knowledge formation.
Demonstrates the methods by which principles and concepts have been developed	✓	The entire Principles of the Tactics and Strategy of Science and the case-study approach supported this.
Demonstrates different modes of scientific approach to scientific problems	△	It was ambiguous how "modes" differed from "methods" but assuming the two were different, Conant did not demonstrate how to actually solve scientific problems.
Integrates philosophy and history of science to: • Discuss outdated scientific topics that were matters of concern and controversy in the past • As parts of science and not to simply add humanistic garnish	✓	Conant's case histories began off from outdated scientific topics (e.g., phlogiston theory) to demonstrate how scientists progressed onto newer concepts. History was not a temporary feature but foundational to Conant's approach.
Demonstrates various means by which science progresses (e.g., the evolution of fundamental concepts or the introduction of new instruments and procedures)	✓	Conant emphasized throughout *OUS* that science was a progressive activity where concepts were developed via interactions with experiments, observations, and the introduction of new procedures and tools.
Sets physics as the core with only pertinent matters from other sciences: • Such as basic chemical concepts • To demonstrate patterns in the development of basic physical principles and concepts	△	The three case studies selected in *OUS* were not solely on physics, but they did demonstrate some patterns of how principles and concepts developed.

*The symbols ✓ and △ respectively stood for congruence and partial congruence or indecisive.

This comparison verified that at the least, Conant was influenced *by* the suggestions on general science education in the Harvard Red Book. Optimistically, Conant's ideas on general science education were included – thus influenced the suggestions – in the report. He abided by seven out of ten suggestions made in the report. Thus, on a personal level, he was not quite wrong in stating that there was a "unanimity" of opinions in his preface: either he was thrilled to find that the suggestions written by the subcommittee coincidently suited his or his voice was heard. Now, in order to find out the extent of his influence on the report in terms of science education, further study on archival records would be necessary.

Anyhow, either way, Conant transferred ideas on science education at the administrative level to actual practice. This was what this research valued as an aspect of a true science educator. Already, the title of this section "From an Administrator to an Educator" entailed two underlying assumptions: one was that Conant fulfilled the identity of an educational administrator; two was that an educational administrator is inequivalent to an educator. To elaborate on this idea, some preliminary research was conducted in the field of education policy and policy implementation. The following discussions were the researcher's basic ideas on how a science educator could be demarcated from an administrator in science education.

According to the OECD, an educational program implemented to affect an educational system could be seen as a type of education policy (Viennet & Pont, 2017). Adams et al. (2001) and Viennet and Pont (2017) recognized that the details of a policy could change depending on the stage of implementation it is at. Naming education policy according to its stage, a rhetorical policy usually takes the form of broad aims and goals addressed openly by someone in a senior leadership position. An enacted policy refers to authoritative instructions (e.g., decrees or laws) given to an education sector on specific standards and procedures to follow. An implemented policy is this enacted policy applied to the education system with necessary modifications.

Extending this concept of education policy to Conant from the Harvard Red Book to *OUS*, the instructions that Conant addressed to Dean Buck on behalf of the Harvard Committee were the rhetorical policy. These were elaborated to take the form of explicit instructions that schools, especially Harvard College, could follow. The compiled statements and instructions published in the Harvard Red Book were the enacted policy. Finally, professors who were offered to teach a course in the new general education program interpreted the report to develop individual courses. Conant who volunteered to teach Natural Science 4 actualized the statements in the report, modifying them with his own views on general science. The course he personally taught and the book he published under the same title, i.e., *OUS*, were the implemented policy. This research considered education policy, unrealized and remaining at the rhetorical level, solely the work of an educational administrator. On the other hand, this research defined implemented policy carried out by someone who did not participate in either the rhetorical or enacted levels as the work of an educator alone. Enacted policy, in between rhetorical and implemented, was interpreted as the work of an administrator and educator combined. Hence, Conant who had clearly participated in the rhetorical and implemented level of the education policy on general science education could be defined as an administrator as well as an educator in the field of science education.

The above clarification between the roles of an administrator and those of an educator was necessary for persuading how this research landed on the conclusion that despite Conant was not one of the authors of the Harvard Red Book, he could be seen as both a science administrator and educator. That is, he had fulfilled both roles, administrative and educational, during the general science education movement.

Wrapping up the subchapter, this research daringly attempted to provide a draft list of some aspects of a science educator. A science educator is someone who:

- Possess specific views on science to translate them into his or her views on science education.
- Is sensitive to the sociocultural contexts (e.g., societal, environmental, racial, religious, national, and international contexts) surrounding the education system.
- Set goals and aims in consideration of these contexts for the learners of the education system.
- Not only visualize the goals and aims but also actualize them – i.e., does not remain at the rhetorical level but actually enact them, giving the goals and aims explicit forms (e.g., standards and instructions).
- Develop teaching and learning materials that can be applied in actual educational scenes.

4.1.2 From the Principles of the Tactics and Strategy of Science to the Nature of Science

This research was fascinated by the resemblance of the principles of the Tactics and Strategy of Science to the Nature of Science (NOS) when it first came across them in *OUS*. Obviously, this was not a personal finding as it turned out to be that Conant's ideas on general science education influenced those of the later generation. Though it was unclear if such accreditation was made in hindsight by scholars in the present time, tracking back to the roots of NOS, there were Conant and his general science education. For instance, the Next Generation Science Standards recognized the new Conantian understanding of science for the general public as one of the early-on efforts to expand the contents of science education from scientific concepts and practices to include NOS (NGSS Lead States, 2013). Also, Wilson (1954), which was known for one of the earliest attempts to measure student understanding of the nature of science, credited Conant for his definition of understanding science and applied it in the questionnaire.

Before moving on to the explication of how the principles resembled the NOS, this research intended to provide a brief explanation of this NOS. NOS is indisputably one of the most popular concepts in science education. It is still being greatly advocated in science instruction; however, the compartments of NOS are nebulous and there has also been pouring research suggesting a family resemblance approach to defining NOS (e.g., Dagher & Erduran, 2016; Erduran et al., 2019; Irzik & Nola, 2011). A contrasting viewpoint argues that nonetheless some consensus could be reached on the components for the sake of science instruction – among these is Lederman et al. (2013). For the sake of comparison, this research adopted the consensus view, with explicit statements of NOS. Plus, the principles of the Tactics and Strategy of Science did demonstrate exceptional resemblance with the NOS as proposed by the consensus group.

According to Lederman (2006) and Lederman et al. (2013), some crucial aspects of NOS that students should learn are the distinction between observation and inference; the distinction between scientific hypotheses, laws, and theories; the formation of scientific knowledge being partially empirical (i.e., based on observation) and partially imaginative and creative; scientific knowledge being subjective or theory-laden; science as a human enterprise; the subjectivity of science (i.e., the possibility of multiple explanations to a natural phenomenon); the tentativeness of science. These aspects provided by the Lederman group were matched with the subprinciples of the Tactics and Strategy of Science presented in *Table 7*. For that purpose, the aspects were condensed into keywords and phrases based on the researcher's interpretations of Lederman (2006) – eight in total, which was slightly different from the customary Lederman seven.

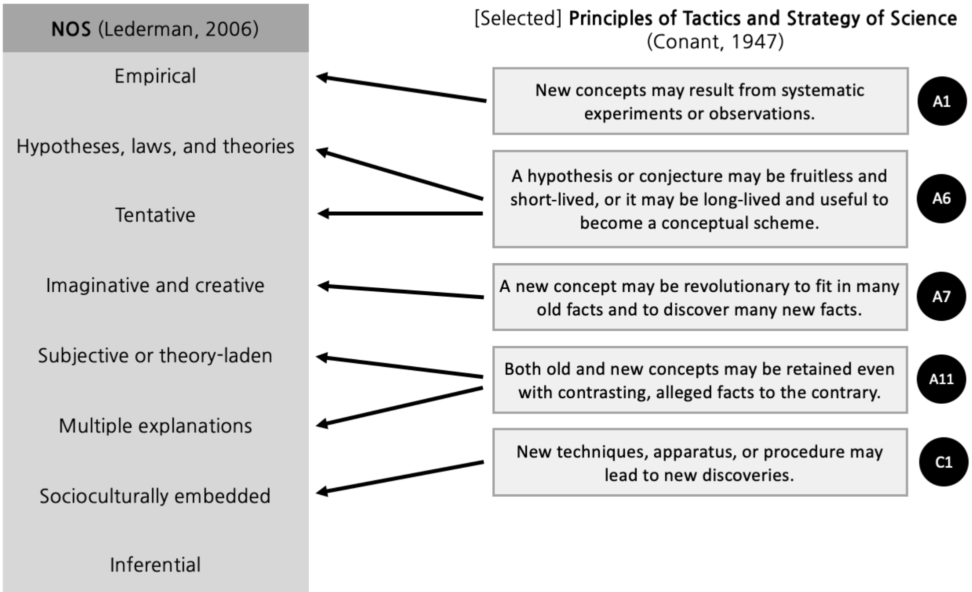

Figure 13. Example of How the Principles of Tactics and Strategy of Science Correspond with Lederman NOS

The principles were too extensive to individually be matched with the list of eight components of NOS; thus, only a few selected subprinciples were matched as to demonstrate how the Conantian principles of the Tactics and Strategy of Science could be a predecessor of the NOS. The subprinciple [A7] was matched with an aspect of NOS stating science is imaginative and creative. According to Lederman (2006), science does not always operate in an orderly, rational fashion but sometimes it is the imagination and creativity of the scientist that helps him or her ‘leap’ forward. Lavoisier’s discovery of the role of oxygen in combustion, contrasted with Priestley’s persistence of the phlogiston theory, in Conant’s case histories could be regarded as such a ‘leap.’

It must be taken into consideration that the principles of the Tactics and Strategy of Science were only one of the major components of the Conantian general science. Therefore, despite that, there was no subprinciple that seemed to correspond with the aspect of NOS stating ‘science is inferential,’ the case histories had it covered. To provide an example, based on Lederman (2006)’s explanation, inferences are statements in science that can only be observed or measured through their manifestations. In one of Conant’s case histories, Torricelli measured the atmospheric pressure – an inferential concept – indirectly by the height change of the mercury column in his tube-shaped barometer.

This research was aware that the discussion above could cause some misunderstanding. Describing the principles as extensive over the Lederman NOS could impress the idea that the Conantian principles are superior to the Lederman NOS. However, it was not of interest to this research to compare the superiority of the two lists. The same logic could apply to the Lederman NOS that these aspects that Lederman cataloged were only a portion of what students would learn in science. Nonetheless, further analysis of their differences must proceed.

A major difference that this research found was while Conant included subprinciples stating what is *not* science, Lederman focused on what is science. That is, Conant was concerned with the demarcation of science while Lederman aimed to demonstrate these aspects of science that sometimes are invisible in conventional school science. For instance, subprinciple [A12] stated, "Advances in practical arts are not the same as advances in science…" The entire principle C was aimed towards distinguishing the development of techniques, procedures, and apparatus due to improvements in the practical arts from actual science. Demarcation of science from nonscience was an intentional choice of Conant as he aimed in his general science education for students to appreciate science as a progressive knowledge in contrast to all the handy products it helped to create. As a science educator, Conant was considerate of distorted value judgments on science in his society and wanted especially those not pursuing science as a career to form a better understanding of the true science. On the other hand, the more recent opinions on science education regarding the demarcation problem varied but overall, the field seemed to call for flexibility in the boundary (e.g., Cobern & Loving, 2000; Smith & Scharmann, 1998) – some science educators acknowledged the field now resting in a wider, multicultural context while others pointed out the need for NOS to become less dogmatic.

This research intended to explicate one more difference that it found particularly intriguing. The principles were more detailed and longer in length than the Lederman NOS. This was likely due to the two serving different education systems – principles for undergraduate general science education and NOS most likely for secondary education – and being at different stages of policy implementation. While the principles of the Tactics and Strategy of Science were recorded based on the course that Conant taught, thus at the implemented level, the Lederman NOS seemed to be at the enacted level. Conant was able to create an explicit list because he was in the midst of teaching the principles to his students and because the list was not utilized as content that students had to memorize for exams. They were embedded in the case histories implicitly and discussed in class. One common criticism over the Lederman NOS was the list being "yet another something to be learnt" and to come down like a "mantra" (Matthews, 2012). This could possibly be due to the Lederman NOS being suggested top-down through academic journals – thus, not necessarily ready to be implemented. More discussions over how NOS should be presented ready-for-use could happen elsewhere.

Returning to the explicitness of Conant's principles, this research intended to leave two final comments. One, his principles were clear and unambiguous because he tactically aimed for some understanding of science. He was aware that he would not be able to demonstrate all aspects of science. This idea was quite in line with the underlying assumption for the features of science in Matthews (2012). Two, the strength of his principles came from Conant being able to criticize issues in science education that are still relevant today. For instance, Conant wanted general students to learn the complexity of scientific experimentation and observations. In subprinciple [B1], he warned that the failure to identify and control significant variables in an experiment could vitiate the results. This alluded to a relatively-recent criticism over hands-on experiments that students perform in science classes that began in the 90s. Students, on most occasions, only perform simplified versions of experiments with preselected variables, procedures, and instruments. As a result, they were not given the opportunity to construct knowledge of science in their own (e.g., Tobin, 1990; Hofstein & Mamlok-Naaman, 2007). This research questioned whether laboratory activities have changed much since then.

It was intriguing to realize how discussions and critical thinking on the principles of the Tactics and Strategy of Science could be connected to recent issues in science education. The concerns around science education that Conant suffered from could be different in their historical contexts but in essence, they could also be quite similar to those of today. For that reason, this research argued that ideas and methods of science education could persevere. For the same reason, this explained exactly why historical research on science education should be conducted.

4.1.3 Dissemination of the Historical Approach

Reviewing the ideas and methods of Conant on general science education, this subchapter had so far reappraised him as a science educator and argued that his principles of the Tactics and Strategy of Science could be a precursor of the Nature of Science. Now, this section was dedicated to situating Conant in a larger science educational context. As conducting background research on the history of science in science education, this research compiled the following:

- Matthews (2015) also stated that the Conantian case studies at Harvard and the historical text-based science course taught by Joseph Schwab at the University of Chicago prompted Klopfer also at the University of Chicago to apply the historical approach to high schools.
- Matthews (2015) added that the *Teachers' Handbook* (1963) of the Biological Sciences Curriculum Study (BSCS) written by Schwab greatly advocated the historical approach.
- Lederman (2006) recognized the *History of Science Cases for High*

Schools (abb. HOSC; 1957) by Klopfer and Watson and the *Harvard Project Physics* (1970) by Rutherford, Holton, and Watson as the two most significant curriculum development that implemented a historical approach in high school science.

- Klopfer and Cooley (1963), from University of Chicago and Harvard respectively, developed the "Test on Understanding Science" to evaluate the effectiveness of HOSC in developing student understanding of science and scientists.
- Holton (2003) recalled James Rutherford, then a high school physics teacher who received his doctorate under Watson and was long ago persuaded by Conant, visiting his office as the beginning of the Harvard Project Physics.

These were not all that was found but samples that were extracted to appeal to the fascination that this researcher experienced. Explanations need a little more waiting, as it also found some historical connections between the historical approach, Conant, and scientific literacy.

- Hetherington (1982), upon reviewing the history of science education, unearthed Conant's ideas and methods on science education to argue that the historical approach must be employed in order for the American public to gain civic and cultural scientific literacy.
- Hinman (1998) in a *Science* magazine article highlighted the definition of scientific literacy that Conant provided in 1950 – "the ability to choose one's experts wisely, being able to 'communicate intelligently with men who were advancing science and applying it'" – to compare it with the definition of scientific literacy of the National Science Education Standards.

Although there were worries that the following chart, *Figure 14*, could be skewed to overly emphasize Conant, this research dared to take the challenge. The chart was made largely based on Atkin and Black (2007), Matthews (2015), Lederman (2007), and DeBoer (2014). Other sources that were mentioned in the early parts of this research were also taken into reference. Events directly related to the historical approach in science education were presented in white boxes in the middle column. This research assumed that all events in the history of science education had a mutual impact on each other, and only events within the first degree of connection to the events in the historical approach were selected and presented in grey boxes in the right column. As all timelines do, this research was not able to include every event in the history of historical approach, scientific literacy, or the nature of science. Some precautions were considered while creating the chart. First, it strived to even out the credit of the historical approach in science education between Harvard and the University of Chicago (abb. UChicago) as indicated in numerous literature. Nonetheless, it deliberately chose events that could demonstrate the lasting impact of Conant's ideas and methods in science education. In addition, although only the HOSC and the BSCS were confirmed to advocate the historical approach, the Physical Science Study Committee (PSSC) program was also inserted as all three curriculum developments were significant in relation to the science-educational response to the Sputnik shock. Likewise, it attempted to include alternative explanations of science such as those of Kuhn and Schwab that arose to exert influence on science education. Furthermore, while most events were confined within two decades after the end of WWII, the birth of *Science & Education* and the Project 2061 of the AAAS were included as indications that neither the historical approach nor scientific literacy and the nature of science had withered into history – they still breathed in this field of science education.

At the top of the chart were events on general science education programs at Harvard and UChicago. These sparked the historical approach to science education. Both programs also produced massive books that translated classic texts in the history of science. The *Harvard Case Histories* annotated classic texts to bind them in sets of case histories like those in *OUS*. The Great Books Program of UChicago, on the other hand, only focused on translation, with the intention to preserve the original texts. This program was independent of the general education program but Schwab's involvement in it likely influenced his historical text-based general science education (DeBoer, 2014). Translation of historical texts was a valuable accomplishment in the history of science education; as of November 20, 1946, Conant had complained in the preface of *OUS* about the lack of ready-for-use historical material (Conant, 1947). Hence, they were included in the timeline.

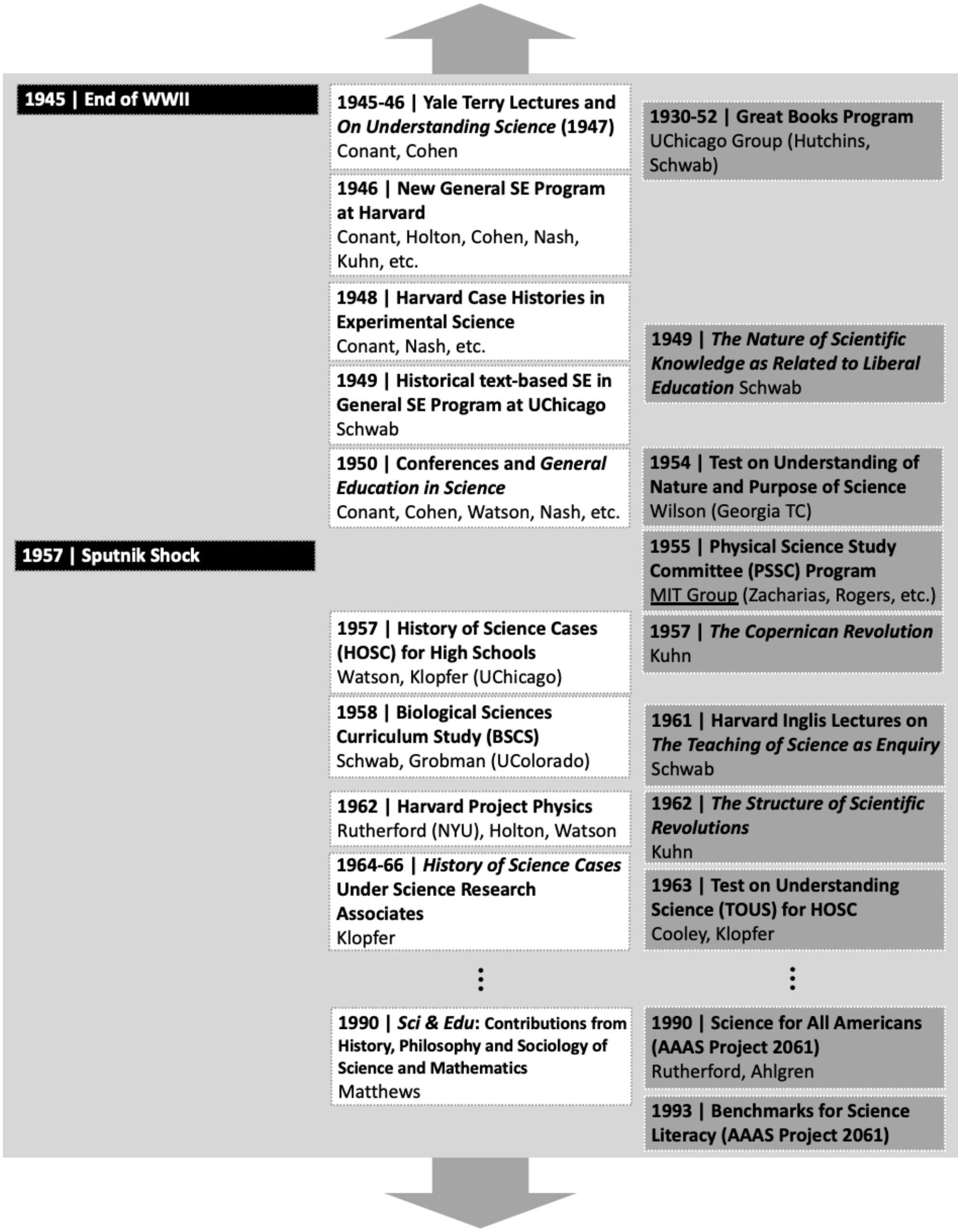

Figure 14. Dissemination of the Historical Approach in Science Education

Some early assessments of students' understanding of science, namely the Science Attitude Questionnaire of Wilson (1954) and the Test on Understanding Science (TOUS) of Klopfer and Cooley (1963), were also recognized as early NOS instruments (Lederman, 2007). Of the two, Wilson (1954) explicitly credited Conant and his book *Science and Common Sense* (1951), the expanded version of *OUS*, as one of the two references to developing the questionnaire. Thus, this research saw Conant as one of whom laid the foundation for NOS research in science education. As for Klopfer and Cooley (1963), their TOUS was developed to assess the effectiveness of the HOSC, which Klopfer and Watson coauthored. Klopfer and Watson (1957) shared their process of creating the HOSC to acknowledge Conant for his editorship of the *Harvard Case Histories*. While Watson was the teaching assistant to Conant's general science course, Klopfer, then at the University of Chicago, was likely influenced by Schwab's works on the historical approach (Matthews, 2015). The TOUS was also inserted in *Figure 14* because of its name. Though not specified in Klopfer and Cooley (1963), the name of the test was identical to Conant's *OUS*. The three subscales of the test, which were the understanding of the scientific enterprise, scientists, and the methods and aims of science, resembled the aims and contents of the Harvard Red Book as well as those in Conant's *OUS*. Therefore, this research saw a chain of influence from the Conantian science education, HOSC, TOUS, all the way to NOS.

While methods or approaches waned, ideas of great science educators had lasting impacts on the field. As shown in *Figure 14* and stated in Hamlin (2016), after the early 1950s, Conant passed his works on science education to the hands of younger science educators. He no longer made direct contributions to the historical approach. However, this research agreed with Hamlin (2016) that his ideas and jargon persisted. This was confirmed by the example of the Science Attitude Questionnaire and the TOUS.

This research also found in the process of tracking the dissemination of the historical approach that the experience of selecting and annotating historical materials in science changed and shaped science educators' views on science. Kuhn, who supported Conant in gathering historical materials for the course on general science, acknowledged Conant in his book *The Copernican Revolution* (1957) for the influence he had over his views on science (Matthews, 2015). Although later research comparing their views on science revealed that the two did not share one science (e.g., Wray, 2016; Hamlin, 2016; Reisch, 2019), clearly the extensive reviews and analyses of historical texts had formed some understanding of science in Kuhn's mind. Likewise, it was this experience that allowed other science educators as well to individually develop precursory ideas to the nature of science. These ideas, combined with the perspectives on the science education that all citizens should receive, became the components of scientific literacy.

4.2 Conclusion

This research concluded that James B. Conant was one of the protagonists of the general science education movement at the college level that occurred in the mid-20th century US. After the end of WWII, Conant at Harvard was faced with changes in views on science and an expansion of the student body. With the assignment of reforming the general education program at Harvard passed onto his hands, he diagnosed and prescribed a new understanding of science. With the help of the Harvard Committee and their report *General Education in a Free Society*, he diagnosed that in the era of science, general science education was necessary for the public to make better decisions on issues related to science. He prescribed the case-study approach, as described in *On Understanding Science*, to emphasize the progressive aspect of science where concepts and ideas interact with experimentations and observations. These aspects that defined science were named the principles of the Tactics and Strategy of Science. The case-study approach traced the development process of a few scientific concepts over a short period of time in the history of science.

Clearly, there were gaps in this research that needed to be filled in. Each of the discussions in the previous subchapter – the definition of a science educator, the value of historical research in science education, and the history of the historical approach and its relation to scientific literacy and the nature of science – are topics worthy of individual attention. Yet, this research yearned to bring one last attention to the following question. After an extensive research on Conant, it still tickled how science educators in the past were able to address questions that are pertinent up to the present time. Was it perhaps, for instance, because Conant had a unique life experience? Or simply, because problems in education like those of any other field are deemed to resurface?

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국문 초록

누가 과학교육을 배워야 하며, 그랬을 때 무엇을, 어떻게 배워야 하는지는 과학교육의 핵심을 관통하는 세 가지 질문이다. 이 질문들에 대해 오래 전부터 수많은 과학교육자들이 숙고했으나, 아직까지도 완전한 해결책이 나오지 않았다. 과학교육의 역사를 거슬러 올라가면 약 70년 전에 이 질문들을 답하기 위한 대학 수준의 운동, 그리고 개인의 시도가 있었다. 이 연구는 1940-50년대 미국 하버드 대학에서 일어난 대학교양과학교육의 개편, 그리고 그 중심이 있었던 당시의 총장 제임스 코난트(1893-1978)를 살펴봤다.

코난트는 과학, 정치, 그리고 교육의 세 단어로 묘사될 수 있다. 하버드의 총장으로서 코난트는 대학에 새로운 장학금 제도와 교수 임용 및 승진 정책을 시행했다. 제2차 세계 대전에서 코난트는 미국의 국방연구위원회장, 원자폭탄 사용에 대한 임시위원회원 등을 맡았다. 즉, 하버드 대학 총장은 코난트의 정치적, 교육적 측면을 상징하고, 2차 대전 중의 활동은 그의 과학적, 정치적 측면을 대표한다. 그리고 코난트의 과학적, 교육적 측면에 대한 연구가 부족하여 다음과 같은 연구질문을 확립했다. (1) 코난트는 제2차 세계 대전 이후 하버드의 대학교양과학교육 개편에 어떤 역할과 기여를 했는가? (2) 그의 과학교육 저서인 [On Understanding Science]를 통해 확인할 수 있는 코난트의 대학교양과학교육에 대한 생각과 방법에는 무엇이 있는가?

2차 대전 이후 하버드로 돌아온 코난트는 증가한 학생 인구, 다양화된 학생 유형, 그리고 과학에 대해 양면적인 대중 인식을 국면했다. 그는 하버드의 교육을 정상화하기 위해 교양교육에 주목했고, 이에 '하버드교양교육개편위원회'를 추진했다. 1945년에 개편위는 이후 널리 배포된 [General Education in a Free Society]라는 보고서를 출판했다. 해당 보고서는 대학교양교육에서의 과학을 단순히 개념적 사실의 축적이 아닌 더 큰 역사적 맥락의 일부로 정의했고, 이에 과학적 방법, 과학 개념의 발전, 그리고 과학적 세계관에 대한 통합적 이해를 대학교양과학교육의 목표로 설정했다. 코난트는 하버드의 교양교육 프로그램에서 직접 'On Understanding Science'라는 교양과학 강의를 가르쳤으며, 해당 강의는 그의 대학교양과학교육에 대한 견해를 담은 과학사례적 접근을 사용했다. 그는 강의 자료를 제작하기 위해 저명한 과학사학자, 과학철학자, 그리고 과학교육자(예: Cohen, Holten, Nash, Kuhn)와 협력했다. 이밖에 코난트는 대학교양과학교육의 방향성을 논의하기 위해 과학교육자를 모아 수차례의 회의를 주최하였다.

[On Understanding Science (1947)]는 코난트가 직접 가르친

교양과학 강의와 동명으로, 그의 대학교양과학교육에 대한 생각이 담겨 있는 책이다. 이 책에서 그는 'Understanding science'와 'Tactics and strategy of science'라는 두 용어를 새로 정의하여 자신의 대학교양과학교육과 관련된 철학을 담았다. 'Understanding science', 즉 '과학을 이해한다는 것'은 과학의 시대에서 과학과 관련된 의사결정을 위해 과학이 할 수 있는 것과 하지 못하는 것에 대한 감각을 의미한다. 'Tactics and strategy of science'는 과학의 복잡한 발전 양상을 상징하는데, 군사 전술과 전략으로부터 착안하여 과학이 발전하기 위해 복잡한 전술과 전략이 필요하다는 것을 의미한다. 더 나아가 'Tactics and strategy of science'는 세 가지의 큰 'principle'로 나눠진다: (A) 과학은 개념과 실험 및 관찰 간의 상호작용으로 발전한다. (B) 과학의 실험 및 관찰은 복잡하다. (C) 과학은 기술과 동일하지 않으나 기술과의 상호작용을 통해 발전한다. 코난트의 과학사례적 접근은 과학에 대한 이해를 형성하기 위해 이러한 'Tactics and strategy of science'를 다시 세분화하여 근대과학 속 개념의 변천사와 엮었다. 그는 비연대기적, 사건 중심의 전개를 따라 적은 수의 변천 사례에 다양하고 광범위한 'principle'를 적용하는 '일반화 학습(generalization)'을 사용했다.

본 연구는 코난트를 20세기 중반 미국에서 일어난 대학교양과학교육 운동의 주역으로 봤다. 그는 과학교육에 대한 행정적 차원의 생각을 실천에 옮기며 과학교육 행정가 이상의, 과학교육자적 면모를 보여줬다. 또한 코난트의 'principle'은 오늘날 과학교육의 주요 키워드인 과학의 본성(NOS)과 매우 유사할 뿐만 아니라, 그 유사성 덕분에 NOS, 과학적 소양 등 오늘날 과학교육의 여러 주제에 대해 다양한 시사점을 제공했다.

키워드: 대학교양과학교육, 제임스 코난트, 과학사, 과학교육사, 과학사례적 접근

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