Canadian Military History

Volume 21 | Issue 3 Article 8

2015

The Continuing Historical Legacy of Dominick "Toby" Graham

David Zimmerman

The Continuing Historical Legacy of Dominick "Toby" Graham

David Zimmerman

Abstract: Dominick Graham, the first Professor of Military History at the University of New Brunswick, had a comparatively brief academic career. His historiographical arguments and ideas remain valuable today, however, almost a quarter of a century after his retirement. Graham's most important study was his examination of the British Expeditionary Force contained in the book *Fire-power*. This paper will examine Graham's intellectual legacy, demonstrating how Graham's ideas can be applied to furthering our understanding of the role of science in the First World War.

Dominick Graham, the first Professor of Military History at the University of New Brunswick (UNB), had a comparatively brief academic career. His historiographical arguments and ideas remain valuable today, however, almost a quarter of a century after his retirement. This paper will briefly examine Graham's intellectual legacy, demonstrating how Graham's ideas can be applied to furthering our understanding of the role of science in the First World War.

Graham came to academe relatively late; he had already enjoyed a successful and highly distinguished career in the Royal Artillery. During the Second World War, Graham served in the Middle East where he took part in the first siege of Tobruk, and was eventually captured by the Afrika Korps during the Eighth Army's retreat into Egypt in August 1942. In 1943, after the Italian surrender, Graham escaped from a prisoner of war camp in Italy, made a daring journey down the spine of the peninsula, and rejoined the Allied forces after crossing German lines near Casino. When he had recovered from his Italian ordeal, he commanded an artillery battery in the Guards Armoured Division in Northwest Europe, 1944-45. He was twice wounded, mentioned in dispatches, and was awarded the Military Cross. After the war Graham commanded the Royal Artillery's first nuclear armed battery and also taught at the Royal Military Academy at Sandhurst. Graham was an accomplished athlete; in 1954 he was a member of Great Britain's Olympic cross-country ski team.

In 1959, after retiring from the army, Graham immigrated to Canada, taking up a position teaching math at Saint John High School in Saint John, New Brunswick. In 1961, Graham began his studies at UNB. He earned his BA in 1962 and a Master's degree in 1963. One year later Graham became a lecturer in history. In 1969, he entered the PhD program at King's College London, where he studied under Gerald Graham (no relation), the Canadian-born maritime and Imperial historian. After receiving his doctorate in 1970, Graham became an assistant professor at UNB.

Graham's academic legacy may be seen in the institutional foundations he laid for the military history program at UNB, a program which today is firmly established in the Gregg Centre for the Study of War and Society. Graham also educated a generation of scholars in his rigorous and masterfully run graduate seminars. He had few doctoral students, since UNB's graduate program was expanded to include a PhD just a few years before his retirement. Three of those doctoral students, if I dare say, have had rather successful careers. Marc Milner is Graham's successor at UNB and the director of the Gregg Centre. I am professor of Military History at the University of Victoria. Scott Robertson is a member of the History Department at the University of Alberta. Graham also supervised a large number of MA students, many of whom went on to complete doctorates elsewhere. Some of his former MA students hold positions at the Royal Military College of Canada and King's College London, among other institutions. The students of his students hold far too numerous academic and government appointments to mention.

While Graham's important contribution as an institutional builder and educator are well known by those in the field of Canadian military history, the value of his scholarly contribution to the field is less well understood. Graham did not have time to produce an extensive body of literature, and much of his work was traditional campaign narratives or biography.[1] Yet Graham did write several important intellectual works, and it is this legacy and how it can be used to further our understanding the First World War that I wish to explore in this article.

Those who experienced Professor Graham's graduate seminars know that there was no subject he was more passionate about than breaking the myths that dominated the writing on the First World War. I well remember being required to read much of Sir James Edmonds 14 volume official operational history of the British Army on the Western Front. Graham often began any seminar discussion of the Western Front by demanding: "What does Edmonds say?!" He did not believe Edmonds was infallible, far from it, but he insisted that students start from the basic fundamental body of knowledge found in the official history, and build from there. Graham was one of the first historians to challenge the established historical paradigm that the battles on the Western Front were all bloody and indecisive contests of attrition in which soldiers were senselessly slaughtered by generals who were uncaring buffoons. This dominant paradigm of the First World War was molded by books such as Alan Clark's, *The Donkeys*, and the musical and film Clark's work inspired, "Oh What a Lovely War."[2]

In 1982, Dominick Graham and Shelford Bidwell's book *Fire-Power: British Army Weapons and Theories of War, 1904-1945* was published.[3] Graham wrote the chapters on the First World War. Unlike Clark, whose book only examined the failed offensives of 1915, Graham looked at the entire campaign on the Western Front right through to the end of the war. Graham's theme was that the British Expeditionary Force (BEF) required time to educate itself about how to apply the new technology of war to the battlefield, particularly to restore effectiveness to the offensive. Graham showed the stark contrast between the early, failed breakthrough battles of Ypres and the Somme, with the masterly offensive of the Hundred Days in the summer and autumn of 1918, in which the BEF destroyed the fighting spirit of the German Army. *Fire-Power* was all about technology, not just the introduction of new technology, but principally, as it related to fully exploiting the potential of the most deadly weapon on the First World War battlefield – artillery, and its related weapon systems, including the machine gun. As Graham points out, almost all of the main weapons used to win in 1918 were available, albeit in small numbers, in 1914 – from heavy howitzers to light machine guns. The obvious exception to this was the tank, but Graham did not consider the tank a war winning weapon, but rather an important auxiliary to the infantry.

Graham shows that by 1917, new technology and techniques allowed artillery to fire accurate, brief, and devastating bombardments which could neutralize German artillery, and the carefully coordinated curtain of steel of the creeping barrage which allowed the infantry to move forward. The use of artillery in the last two years of the war stood in stark contrast to the ineffective, poorly aimed, and days-long mass bombardments of earlier battles.

These new technologies included aerial photographic mapping, which made possible the creation of highly accurate grid maps of the German rear areas, essential for accurate predicted fire. Radios made possible the correcting of shot by aerial or ground based observers. Graham also examined the importance of the introduction of better fuses with air bursts to destroy wire and kill defenders without churning up the ground. Other new types of shells, such as those filled with gas, were specifically designed to incapacitate German gunners. Counter battery fire could be directed by the development of gun sound ranging and flash spotting because these techniques provided a reasonably accurate way of detecting previously unobserved enemy gun positions.

While the artillery could make the initial assault possible, Graham realized that the infantry went through equally radical changes. After July 1916, German defensive tactics were transformed. Gone was the front line consisting of a continuous trench system; instead the German defences "were not linear but consisted of irregular and discontinuous positions unsuited to linear assaults."[4] Graham argued that progressive British officers realized that after assisting the infantry to capture their initial objectives, artillery was far less useful in maintaining positions from the inevitable German counterattacks. To hold their hard won gains and to expand their holdings, the infantry required their own fire-power. Graham went into great detail about the developments in the number and tactical deployment of infantry support weapons: heavy and light machine guns, mortars, grenades, and rifle grenades. The placement of these weapons in the army organization, whether under the control of brigade, battalion, company, platoon, or section, was crucial to understanding the transformation of infantry tactics from 1915 to 1918. (In general, weapons were pushed forward to make as much firepower as possible immediately available to the front line troops, with the most portable items (light machine guns, grenades and rifle grenades) ultimately being assigned to specially trained infantrymen in platoons and sections.)

Graham argued that there were several factors which slowed the pace of improvements. In many ways the British Expeditionary Force, most notably General Douglas Haig, commander-in-chief from 1915-1918, had to be dragged into the modern age which required a professional, technical-minded army. For instance, until the summer of 1918, Haig did not see the need for a central office in his command to gather and disseminate the lessons being learned on the battlefield.[5] Individual army, corps, divisional, and even battalion commands were left to cope with and adapt to the reality of war in the industrial age.

Graham linked the development and application of technology and techniques to the social structure of the British and Commonwealth armies. Graham pointed out that much of the delay in correctly applying artillery to the battlefield was caused by the class system which generally kept artillery officers from implementing new doctrine. Within the artillery, a distinct hierarchy existed; officers of the garrison artillery, the group with the most experience with heavy artillery and "scientific" methods, were considered socially inferior to members of the field and horse artillery. Some elements of the BEF overcame these social constraints, or like the Canadians and Australian Corps, never were hamstrung by them. Progressive officers learned by experience or by observing the French, particularly at Verdun. Those units that incorporated the lessons of the earlier battles into their doctrine became the elite units in the BEF in 1917 and 1918.

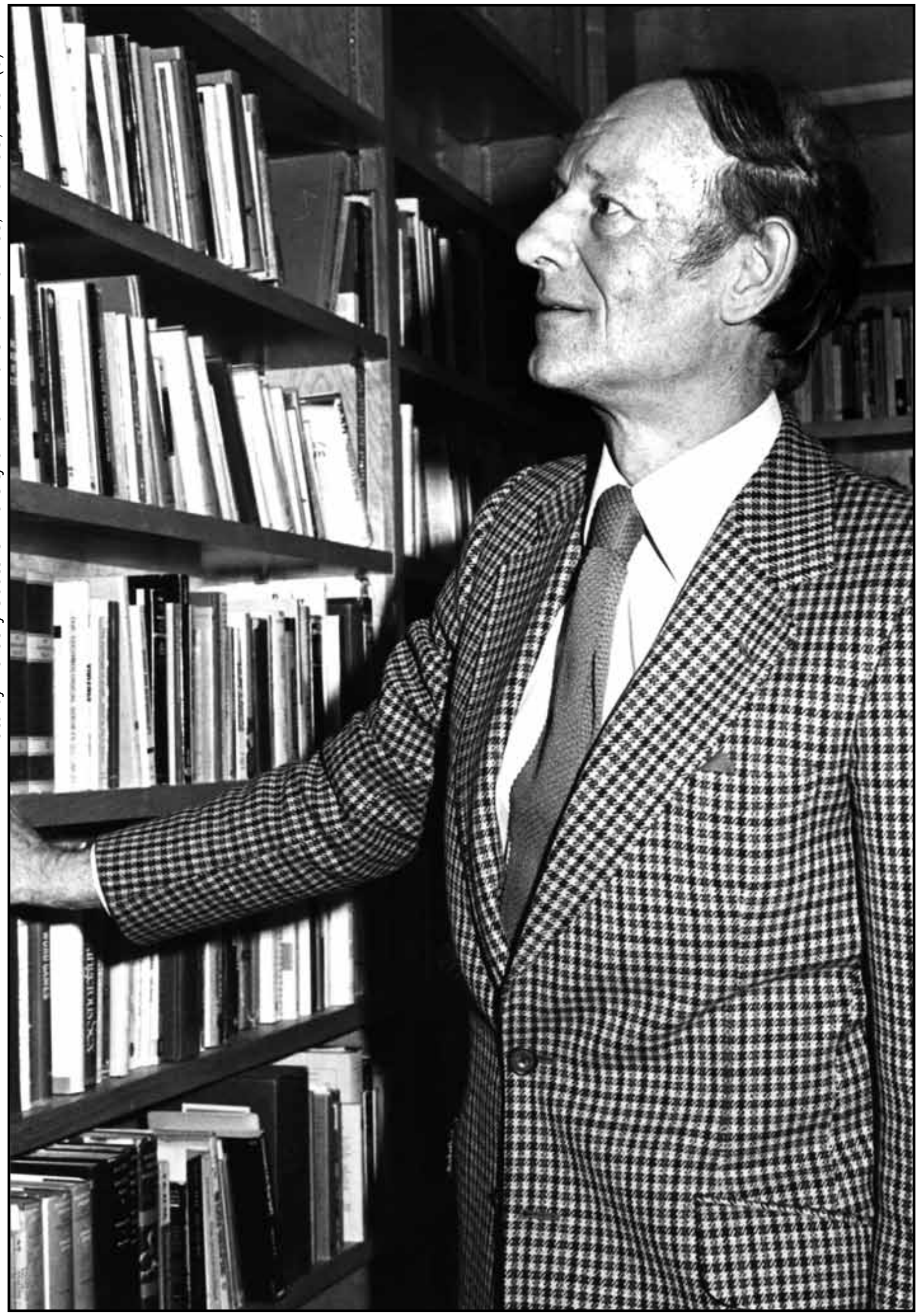
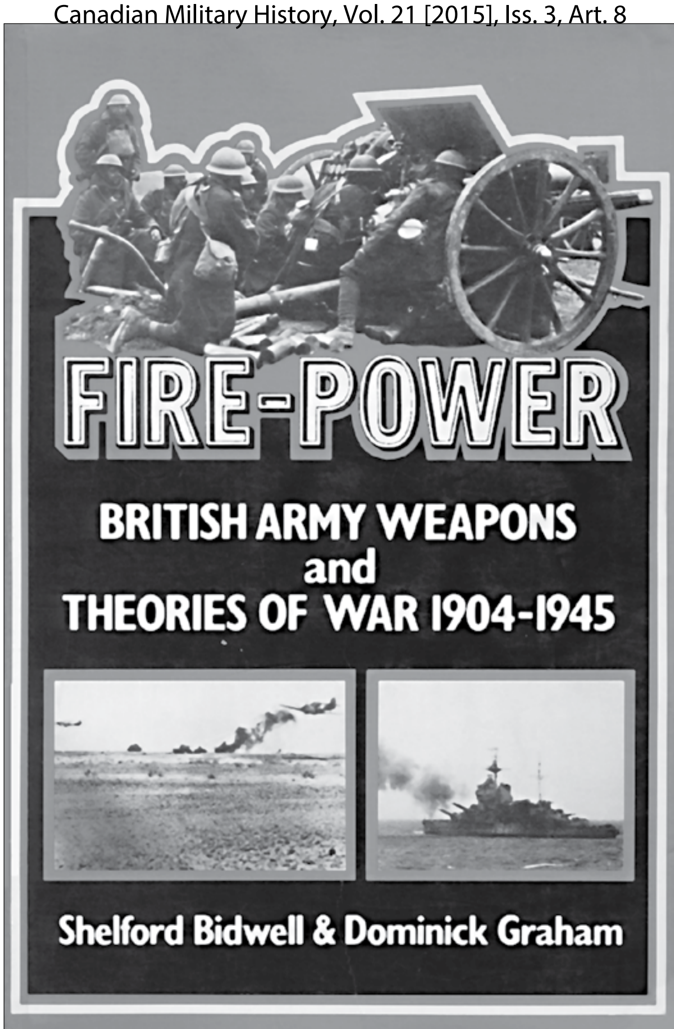


Photo by Dorothy Scott. University of New Brunswick Archives, File 403, x-852(b).

Professor Dominick "Toby" Graham.

Whatever the cause of earlier failures, Graham argued that by the summer of 1918 the BEF had successfully learned how to conduct modern offensive warfare. The brilliant but flawed plan for the Battle of Cambrai in November 1917 was the archetype for future success. By building on the lessons of Cambrai, the BEF's infantry, supported by tanks, artillery and ground attack aircraft, achieved a "technical knockout" against the German Army in the Hundred Days offensive in 1918. "For the British response to the challenges of 1918 was a milestone in the history of land warfare of more significance than Haig indicated in his last dispatch, as it marked the first successful use of high performance teams in using high performance machines in the attack."[6]

For Graham, the Hundred Days was Haig's great triumphant while the tragedy was that most of the lessons, so painfully learned by the BEF in war, were not incorporated into peacetime doctrine. The Army had "no historical sense" and, "in truth, the Army directors did not look further than the infantry to determine the meaning of the Hundred Days."[7] All other arms were auxiliaries, and the post-1919 Army actually reverted back to the tactics of the pre-First World War infantry.



Even worse, because of postwar inter-service rivalry, the techniques of close air support had to be completely relearned in the Second World War.

Fire-Power was one of the early works which began the historiographical re-evaluation of the Western Front that has transformed our understanding of the conflict in the years since its publication. Since 1982, there has been an explosion of academic studies concerning British and Commonwealth armies in France.[8] Not all of Graham's arguments have withstood scholarly scrutiny, but *Fire-Power* remains an essential read on the BEF.[9]

While the BEF has been extensively studied, much of the rest of the First World War remains "an undiscovered country." Graham addressed the failure of military historians to move beyond the battlefield in his article "Stress Lines and Gray Areas: The Utility of the Historical Method to the Military Profession."[10] Graham explained that "within military history, certain aspects tend to be overlooked when the focus of attention is fixed on the last 400 metres of the battlefield."[11] Graham argued that historians do their most important work examining the stress lines and gray areas that "occur at the junctions of the functional and dialectical planes of military planning and action and in the discontinuities between policy, military strategy, operations, and tactics." Stress lines are particularly acute in the "overlapping boundaries" between different organizations. It is in these gray areas that Clausewitz found the sources of friction which often undermine even the most carefully planned strategy.[12]

The ideas and concepts contained in *Fire-Power* and "Stress-lines and Gray Areas" were used by Graham to direct his students' historical research. His influence can be seen in Marc Milner's ground breaking work on the Royal Canadian Navy and the Battle of the Atlantic.[13] Milner rewrote the history of the RCN by challenging orthodoxy that Canada's naval war was a magnificent triumph. Instead, Milner wrote a narrative that wove together a new operational narrative, with a sophisticated study of Canadian and Allied naval, political, and industrial policy. Like Graham's study of the British army, Milner focused on the Canadian navy's struggle to learn the technological and tactical lessons of the increasingly complex campaign.

While Graham's argument focused on the conflict within military organizations, he understood that the stress lines and the friction that result from them are even more intense when military professionals must interact with other professional groups and their institutions. His guidance of my own doctoral work on science and technology and the Royal Canadian Navy helped me to understand how institutional, linguistic, and cultural barriers often make cooperation between disparate groups remarkably difficult, even when these groups share a common goal.[14] My recent work continues to draw heavily on Graham's intellectual legacy, particularly as I have adopted Graham's view that major developments in the Second World War can only be understood if one traces their origins to the First World War. What follows is an examination of the use of science in the First World War to illustrate the continuing legacy of Graham's historical ideas.

The First World War eventually involved the mobilization of entire societies, and because of the technological nature of the conflict, no group was more important than the technical experts – inventors, engineers, and scientists – who were instrumental in developing or improving weapons systems and techniques. Yet just as Graham discovered in his pioneering study of the British Army, many aspects of the war remain poorly understood, including military-scientific interaction.[15] Guy Hartcup, who wrote one general study of science and technology in the First World War reveals the extensive work undertaken by scientists, but he provides little analysis of the nature the of scientific war effort.[16] It seems certain, however, that science was not anywhere near as influential as it would be in the next world conflict Barton Hacker recently summarized the current historiography on technology and war since 1850. He concluded:

> From the standpoint of military technology, the 20th century divides between two eras. The first half of the century saw the culmination of the mechanization of armed forces that had begun midway through the previous century. During most of this period, European innovations dictated the pace and direction of change. World War II changed all that. Europeans became followers of military change driven by the arms race between the USA and the Soviet Union. Two innovations, both largely products of World War II, dominated the second half of the century but proceeded with surprisingly little interaction. One was the elaboration of nuclear arsenals and their delivery systems. The other was the radical reconstruction of conventional warfare through applied electronics, especially from the 1960s onward.[17]

Like most historians who have discussed the ways in which new technologies have been developed, Hacker argues that until the Second World War, innovation was primarily driven by empirical research. During the Second World War, military technology proliferated, while applied science became ever less distinct from scientific engineering.

Hacker's broad outlines appear sound, but his argument tends to obscure the actual origins of the major shift in military innovation to applied science. On this point, Hacker offers us little guidance because the First World War remains the unknown country. After listing some of the important technological and tactical developments, Hacker states that in the First World War:

> Technology and science took their places among the activities the state sought to control, with varying success. None of these achievements came cheaply. The war clearly eroded Europe's world hegemony, sapping the vitality of Europe's overseas empires and diverting international trade into new and less favorable channels. Scholars still struggle to assess the full range of the war's social and psychological costs, at home as well as abroad.[18]

Hacker offers no real claims to how science was mobilized by the state, or whether or not this mobilization had any effect on the outcome of the war. In this I do not criticize his work, for in such a sweeping summary, one should not expect that he would do anything more than report on the existing historiography.

Graham's thesis that the First World War was a great educational experience for the army can be applied more broadly. The war was not just about learning how to harness the weapons produced by empirical invention of the late 19th and early 20th centuries, but also about understanding how to harness all the new tools provided by the related scientific innovations that occurred in this same period. Scientists have written that it was during the First World War that the break between 19th century empirical innovation and the application of applied science to war began.[19] The difference between empirical innovation and applied science is extremely difficult to define in absolute terms, and any definition can only be given in terms that those who participated in the scientific war effort would have understood.[20] Leading scientists, like Ernest Rutherford, viewed empiricists as researchers who emphasized tediously exact experimentation over experimental work guided by theory. This "old-fashioned" approach was eclipsed by applied science, in which the research was guided by the latest theoretical knowledge.[21]

While the first attempts to bring applied science into solving the perplexing problems faced by armies and navies occurred between 1914 and 1918, there were no scientific-technical breakthroughs similar to the cavity magnetron or the atomic bomb in the Second World War. Even where new approaches in applied science were used, such as in the development of chemical weapons, the lack of cooperation between scientists and the military limited their effectiveness. When first deployed in 1915, poison gas failed to achieve the hoped for breakthrough of the allied lines because insufficient planning went into a way to deliver it on target. As Graham outlined, only much later in the war, with the introduction of the new techniques for accurately aiming gas-filled shells, did chemical weapons achieve a crucial role in bringing decisiveness back to the battlefield. There are certainly areas where applied science was influential in determining the course of the war. The most important application of science to military problems is in chemistry, not chemical weaponry, but in the developments which satisfied the huge increases in demand for explosives.[22] Another example of a scientific breakthrough was the almost accidental discovery by German scientists of the science of aeronautics and the subsequent development of the superior aerodynamic qualities of aircraft like the thick wing Fokker D VII, a weapon that entered service just a little too late in too small numbers to swing the air battle in favor of the Germans.[23]

In order to understand the reasons for the limited success of science in the First World War, it is necessary to look at Graham's "stress lines" both within science and in its relationship with the armed forces. Like the military, academic science, particularly in physics and chemistry, was undergoing revolutionary changes in the early part of the twentieth century. Distinctions between physicists, chemists, and engineering were not as clear as they are today. Scientists' understanding of basic universal laws of physics, for instance, was in a state of extraordinary flux. Einstein's theories, after all, had not yet been accepted or proved. Newtonian mechanics remained the dominant way to understand the universe, with the first experimental evidence supporting Einstein's theories being made only during the conflict. Methods for applying scientific theory to practical problems were not broadly accepted either in the academy or industry.[24]

Graham's external "stress lines" between science and the military were even more crucial. In a situation strikingly similar to what Graham analyzed in the BEF, social barriers delayed and then hampered the mobilization of scientists. Initially, scientists were specifically excluded from involvement in military research by military technical experts, who considered scientists as impractical theoreticians. At the start of the war, scientists enlisted in the armed forces and, with the military seeing no need for their special skills, they served, and a number died, in front-line combat units. The death of experimental physicist Henry Moseley during the Dardanelles campaign in August 1915, prompted an outcry by British scientists. Rutherford bemoaned that Moseley's "services would have been far more useful to his country in one of the numerous fields of scientific inquiry rendered necessary by the war than by the exposure to the chances of a Turkish bullet."[25]

The difficult learning process which Graham described occurring in the BEF as it struggled with modern warfare, was even more tortuous in the scientific war. It was not until late 1915 that Allied forces began to utilize scientists to solve military technical problems and weapon systems development. Even then, scientists were often excluded from collaborative work with "more practical" inventors and engineers. One of the salient features of military research during the conflict was the time it took time for scientists to win the confidence of military and political leaders that their skills were applicable to solving practical war-related problems. On 16 July 1917, Horace Darwin and A.V. Hill, leading Cambridge University scientists, heavily involved in British military research, wrote to prominent American scientists including George Ellery Hale, director of the Wilson Observatory and head of the new National Research Council. The Cambridge scientists wished to warn their colleagues not to repeat their own country's "mistake of allowing men with engineering and scientific knowledge to be employed in capacities (military or civil) where their particular abilities were useless. The military authorities, as well as the public," they lamented, "did not (and to some extent do not still) realize the extreme value of a training in science and engineering to men called upon to build up, in many cases out of nothing, some means of dealing quickly and effectively with a difficulty, a menace, or an opportunity, that had suddenly presented itself."[26]

The skills of scientists would only be recognized by the military when specific technical problems proved unsolvable by military technical experts. The military had little interest in long-term fundamental research; generals and admirals believed that to win the war they required immediate practical answers which were directly applicable to the battlefield. Within these limits, scientists did make useful contributions to the war effort, but primarily by pursuing empirical innovation, and not by applied science.

The full shortcomings of the use of science in the First World War can be most clearly seen in the largest of all military research programs of the conflict, which was directed at developing techniques to detect and destroy U-boats. In the First World War, anti-submarine research was hampered by the absence of a close working relationship between scientists, engineers, and naval technical experts. In both the United States and Great Britain, scientists had to fight a protracted bureaucratic struggle to win recognition that their skills could aid the war effort. Although scientists had made some important contributions, naval technical experts and engineers remained unwilling to work with university-based scientists. In both countries, it was necessary to create separate research laboratories for the two groups.[27]

In early 1915 in Great Britain, Commander (later, acting Captain) C.P. Ryan was placed in charge of the Hawkcraig Admiralty Experimental Station. Ryan was an innovator in early naval wireless technology; he had left the navy in 1911 to pursue his career as an inventor with the Marconi Company. Ryan had rejoined the service at the start of hostilities and had begun experimenting with the use of hydrophones. Only when the submarine threat was well established was Ryan's work given official sanction, and the Hawkcraig Station established. While Ryan's team made important strides forward in the development of practical directional hydrophones, efforts to supplement his team with academic scientists floundered. In September 1915, when the first scientists and engineers arrived at Hawkcraig, Ryan viewed them as imposed outsiders, and was unwilling to cooperate with them. Only at the end of 1916, after months of competitive rather than complementary research, was it decided to move the scientists to a separate facility. In 1917 a

Photo by Allain Sallard. University of New Brunswick Archives, File 403, 88-10-13a.

Professor Graham relaxes in his office at the University of New Brunswick. On the wall behind him is a poster from the 1956 Winter Olympics in Cortina d'Ampezzo, Italy where he competed in cross country skiing for Great Britain. The bottoms of his skis can be seen at the top middle of the photo.

laboratory was opened for them at Parkeston Quay at Harwich.[28] Communication between the two laboratories remained "not very intimate" for the rest of the war.[29]

In the United States, it also took some time before the merits of the scientific approach were appreciated. In June 1916, the National Academy of Science formed the National Research Council to manage war research. The NRC was not a government agency, nor did have direct access to government funding; initially, much of its money came from private donations. A competing organization, the Naval Consulting Board, had been established somewhat earlier by the United States Navy under the leadership of Thomas Edison. This board deliberately limited the influence of academic scientists, viewing them as impractical theoreticians. By spring 1917, the consulting board established a research station at Nahant, Massachusetts, in an effort to convert a device originally designed to send Morse code through water into a submarine detector. As a reflection of the board's discrimination against university-based scientists, the Nahant group deliberately excluded them, ostensibly to avoid complications regarding the ownership of any patents which might develop from their research. Instead, the staff at Nahant was made up of industrial engineers and inventors. Academic scientists were given their own research facility at New London, Connecticut.[30]

The competition between inventors and academic scientists never fully disappeared. This led to much duplication and administrative confusion. In Great Britain and the United States, privately financed anti-submarine research ventures added to the confusion. The Manchester, or Lancashire, Anti-Submarine Committee was formed in 1917 by local "manufacturers, business men (sic), and engineers, with some professors from the university."[31] In the United States, Vannevar Bush developed a device in which the presence of a submerged submarine created an imbalance in an electromagnetic field suspended under the hull of a submarine chaser. His work was privately financed by AMRAD corporation, owned by

Library and Archives Canada PA 30314; courtesy of RCN History & Heritage

The campaign to defeat German submarines in the First World War is a good example of how friction made the application of science to war less successful than it might have been. Here the German submarine SM *UC-97* is tied up in Toronto during a Victory Bond tour in 1919.

J.P. Morgan. Bush later recalled one of the consequences of the lack of a coordinated research program:

> Toward the end of the first war there were several other groups, about whom I knew nothing, working on the same problem. One group was trying by trailing a wire which had some nonpolarizing electrodes on it, to pick up stray currents from the submarine resulting from the electrolytic effects produced, for instance, between a bronze propeller and a steel hull. I did not even know they were working on it until one day down at New London I went aboard a craft and saw the gear. I asked them what they were doing and they told me. I asked what trouble they were having and they said, "The stabilizing of the galvanometer on shipboard sufficiently so that we can get proper sensitivity. " I said, "Why don't you use a pivot instrument? Weston Instruments has just gotten out a very sensitive microampere meter of this form." They had never heard of it. They got one and put it on deck, and it promptly proceeded to work all right.[32]

In reality, the duplication of effort did not matter, since neither group had any theoretical scientific basis to develop a submarine detection device. There was no attempt to conduct wide-ranging systematic investigations into ocean acoustics.[33]

This lack of fundamental knowledge meant that First World War anti-submarine warfare research was far more convoluted than the scientific wartime emergency program that would develop just two decades later. For instance, at the New London laboratory, "at first the work naturally took the form of testing out abstract ideas evolved from the whole range of possibilities presented by the fields of sound, light, heat and electricity."[34] The number of projects undertaken expanded exponentially. It was difficult to reduce the number of devices being developed since leading researchers often defended their approach vigorously. Most of these research projects had some basis in fundamental scientific knowledge, but with little or no understanding of how such devices might work in the ocean environment. It was not even possible to concentrate efforts in acoustics since several other types of detection apparatus appeared to have equal promise.

Empirical innovation could not solve the mysteries of detecting the unseen, submerged U-boat. A huge array of technologies for submarine detection was experimented with during the conflict, but the majority of the research was in passive listening, or hydrophone technology. The best indicator of the overall performance of these devices is their comparative lack of operational success. Almost 10,000 hydrophones were delivered to the Royal Navy during the war, but only three or four German submarines were sunk in actions where ship-borne hydrophone detection played a key role. One, or possibly two, other U-boats were sunk by mines after being detected by fixed-mounted harbour defence hydrophones. This compares poorly to the number of U-boats sunk by another new military technology, aeroplanes, which sent at least nine submarines to the bottom.[35]

One anti-submarine research team, led by the French astrophysicist Professor Paul Langevin, did work in a fashion that was much more similar to Second World War research projects. Langevin was an early supporter of the theory of relativity and an expert on paramagnetism, diamagnetism, secondary x-rays, and the behaviour of ions. Langevin's research methodology stood in stark contrast to other anti-submarine investigation. Rather than employing empirical experimentation that dominated most First World War anti-submarine research, a British scientist later commented, "Professor Langevin did it the other way, a more creditable way; he envisioned it, looked for it, calculated for it and built his apparatus to perform it."[36] Specifically, Langevin realized that the best hope to detect submerged U-boats was in developing a means to deflect a pulse of high frequency sound off its hull. Langevin took his knowledge of the piezo-electric properties of quartz to generate a suitable sound, and, in turn, to transform that reflected sound into an electrical signal that could be amplified sufficiently for an operator to hear. By the end of the war, Langevin had invented active sonar. Sonar, however, was not ready for operational use before the Armistice. The defeat of the U-boat was mainly achieved by the introduction of convoys, and scientists had only a marginal influence on the outcome of the campaign.

While Langevin's active sonar was a key instrument in effective anti-submarine warfare during the Second World War, his applied scientific methodology had little influence on shaping the nature of military-scientific research that occurred in the later conflict. Soon after the armistice of November 1918, a cloak of secrecy was thrown over sonar research, and work was confined to government establishments, which on the whole reverted to old style empirical research. Without external scientific guidance, navies pursued their own empirical research into improving sonar technology, with little regard to fundamental research into ocean acoustics.[37]

The primary influence of the First World War on shaping the military-scientific revolution of the Second World War was, I would argue, in two major developments. First, for most junior or middle-level scientists, who were the front-line scientific workers in the First World War, their experiences were mainly unhappy ones. Poor organization, bureaucratic obstacles, and outright hostility to these scientists' efforts to apply their knowledge to war, left them with a determination that things must be different if they were called again into the service of their nation. By the 1930s, these junior scientists, like Vannevar Bush and Henry Tizard, were the scientific leaders.

Second, certain research programs continued to promote cooperation between academic and government scientists, the military, and industry, particularly in the field of aviation. Aviation was viewed as a strategic industry of the future, and money was provided to undertake fundamental research and to allow industry to use the results of this research in the latest model of aircraft. The extraordinary transformation of aviation in the interwar period was the result. It is no coincidence that both Bush and Tizard acted as chairs of their country`s aviation research boards, and then became heads of major military-scientific organizations. The highly successful development in Great Britain of the radar-based air defence system in the late 1930s, shows how much military-scientific cooperation had changed since 1918. The development of radar, and its incorporation into the Royal Air Force's Fighter Command, was a model for Second World War applied scientific research projects in Great Britain and the United States.[38]

It was through their efforts that science became better applied to war. In the summer of 1940, a group of senior American scientists led by Bush successfully lobbied the Roosevelt administration to establish the National Defense Research Committee, which would supervise the mobilization of civilian scientists. Bush explained the scientists' motivation for forming the NDRC:

> We were all drawn together early in 1940 by one thing we deeply shared – worry. It was during the period of the "phony" war. We were agreed that the war was bound to break out into an intense struggle, that America was sure to get into it in one way or another, sooner or later, that it would be a highly technical struggle, that we were by no means prepared in this regard, and finally and most importantly, that the military system as it existed, and as it had **operated during the first world war [sic], which we all remembered,** would never fully produce the new instrumentalities which we would certainly had need, and which were possible because of the state of science as it then stood.[39]

Graham presented the BEF of 1914-18 as learning how to fight modern war and ultimately achieving the great triumph of the Hundred Days. Graham argued that from this success came the failure of the interwar period. Graham would not have been surprised to discover that scientists learned better from failure than the British Army learned from success. He might point out the obvious parallel of the Weimar Republic's army, which laid the ground for the Wehrmacht's early successes in the Second World War by their careful study of the causes for German defeat in 1918.

Graham's view that the First World War was an educational experience for the British Army, once it had been confronted by failure, is more broadly applicable to the entire conflict. Scientific-military cooperation evolved during the war, but there was insufficient time for the lessons to be applied effectively to the battlefield. Graham's focus on the stress lines in military organizations remains an invaluable approach to the study of institutions in war. The gray areas, within science itself and between science and the military, produced the stress lines or friction that made the application of science to war less successful than it might have been. Graham may no longer promulgate and develop his insights by leading stimulating and challenging seminars, but his historical methods and arguments continue to have a profound influence among military historians.

Notes

1. Graham's books include *Cassino* (New York: Ballantine Books, 1971); *The Price of Command: A Biography of General Guy Simonds* (Toronto: Stoddart, 1994); *Coalitions, Politicians & Generals: Some Aspects of Command in Two World Wars* (with Shelford Bidwell), (London: Brassey's, 1993); *Tug of War: The Battle for Italy, 1943-1945* (with Shelford Bidwell) (London: Hodder and Stoughton, 1986).
2. Alan Clark, *The Donkeys* (London: Hutchinson, 1961). "Oh! What a Lovely War," was created by Joan Littlewood and the Theatre Workshop in 1963. In 1969, it was made into a movie directed by Richard Attenborough
3. Shelford Bidwell and Dominick Graham, *Fire-Power: British Army Weapons and Theories of War, 1904-1945* (London: George Allen & Unwin, 1982).
4. Ibid., p.114.
5. Ibid., pp.125-30.
6. Ibid., p.133.
7. Ibid., pp.145-6.
8. See, for example: Tim Travers, *The Killing Ground: the British Army, the Western Front, and the Emergence of Modern Warfare, 1900-1918* (London: Allen & Unwin, 1987); Bill Rawling, *Surviving Trench Warfare: Technology and the Canadian Corps, 1914-1918* (Toronto: University of Toronto Press, 1992); Tim Travers, *How the War Was Won: Command and Technology in the British Army on the Western Front, 1917-1918* (London: New York: Routledge, 2003); Tim Cook, *At the Sharp End: Canadians Fighting the Great War, 1914-1916* (Toronto: Viking Canada, 2008); Tim Cook, *Shock Troops: Canadians Fighting the Great War, 1917-1918* (Toronto: Viking Canada, 2008).
9. For instance there are several re-interpretations of BEF tactics in the Hundred Days. See for example, Ian M. Brown, "Not Glamorous, but Effective: The Canadian Corps and the Set-piece Attack, 1917-1918," *Journal of Military History* 58, no.3 (July 1994), pp.421-44; and Tim Travers, "The Evolution of British Strategy and Tactics on the Western Front in 1918: GHQ, Manpower, and Technology," *Journal of Military History* 54, no. 2 (April 1990), pp.173-200.
10. Dominick Graham, "Stress Lines and Gray Areas: The Utility of the Historical Method to the Military Profession," in David Charters, Marc Milner, J. Brent Wilson, eds., *Military History and the Military Profession* (Westport: Praeger, 1992), pp.147-59.
11. Ibid., p.156.
12. Ibid., p.157.
13. Marc Milner, *North Atlantic Run* (Toronto: University of Toronto Press, 1985); *The U-boat Hunters* (Toronto: University of Toronto Press, 1994).
14. David Zimmerman, *The Great Naval Battle of Ottawa* (Toronto: University of Toronto Press, 1989).
15. General surveys of technology and war tend to have very limited discussions of the conflict. See for example, Martin van Creveld, *Technology and War: From 2000 BC to the Present* (New York: Free Press 1989); and Max Boot, *War Made New: Technology, Warfare, and the Course of History, 1500 to Today* (New York: Gotham Books, 2006).
16. Guy Hartcup, *The War of Invention: Scientific Developments, 1914-18* (London: Brassey's, 1988).
17. Barton C. Hacker, "The Machines of War: Western Military Technology 1850–2000," *History and Technology* 21, no.3 (September 2005), pp.255–56.
18. Ibid., p.260.
19. See for instance: Sir Solly Zuckerman, *Scientists and War* (London: Scientific Book Club, 1966), pp.13-14; Bernard Katz, "A.V. Hill," *Biographical Memoirs of the Royal Society* 24 (1978), pp.87-88.
20. Discussions of the terms science, technology, applied science, and empirical innovation are numerous and highly contentious. See for example: Otto Mayr, "The Science-Technology Relationship as a Historiographic Problem," *Technology and Culture* 17, no.4 (October 1976), pp.663-73; Ronald Kline, "Construing 'Technology' as 'Applied Science': Public Rhetoric of Scientists and Engineers in the United States, 1880-1945," *Isis* 86 (June 1995), pp.194-221.
21. Ernest Rutherford to Mary Newton, 11 August 1898, as quoted by John Heilbron, "Physics at McGill in Rutherford's Time," *Rutherford and Physics at the Turn of the Century* (New York: Dawson and Science History Publications, 1979), p.45.
22. Hartcup, pp.44-56.
23. Peter Garrison, "What the Red Baron Never Knew: Computer analysis of World War I aircraft shows precisely why some were deadly and others, death traps," *Air & Space Magazine* (January 2008).
24. For an examination of the extraordinary transformation in science in the two decades leading up to the war see, Daniel Kevles, *The Physicists* (New York: Vintage, 1979), pp.75-116.
25. Ernest Rutherford, "Obituary of Henry Gwyn Jeffreys Moseley," *Nature* 96 (9 September 1915), p.33.
26. Scientific Liaison with America, 8 July 1917. Names of the authors were not provided, but one was certainly Horace Darwin, the other may have been A.V. Hill. Darwin to Hale, etc., 16 July 1917, Kew, United Kingdom, The National Archives [TNA], AVIA 8/3.
27. Willem Hackmann, *Seek and Strike* (London: HMSO, 1984), pp.21-27; David Zimmerman, *Top Secret Exchange* (Montreal: McGill-Queen's University press, 1996), p.9.
28. Hackmann, pp.21-27.
29. Scientific Attache, London to the Chairman, National Research Council, 9 March 1918, College Park, Maryland, National Archives and Records Administration [NARA], RG 189, Records of the National Academy of Sciences Research Information Office, Entry 4, Records of the London Office, box 1/3.
30. Zimmerman, *Top Secret Exchange* , p.9.
31. Scientific Attache, London to the Chairman, National Research Council, 9 March 1918.
32. Vannever Bush, *Pieces of the Action* (New York: William Morrow, 1970), p.74.
33. Ernest Esclangon, "Concerning Submarine detection and the scientific questions connected with it," translation of French pamphlet, Paris, 28 July 1919, NARA, RG 189, Records of the National Academy of Sciences, Research Information Office, Entry 2, Paris Office box 10/152.
34. Bureau of Steam Engineering to Secretary of the Navy, Requisitions covering expenditures of Special Board on Anti-Submarine Devices and Naval District, New London, Connecticut, 3 May 1919, NARA, RG45, Naval Record Collection of the Office of Naval Records and Library, Subject Files, 1911-27, box 337/1.
35. A full account of U-boat losses can be found in Dwight R. Messimer, *Find and Destroy* (Annapolis: Naval Institute Press, 2001).
36. Minutes of the Proceedings before the Royal Commission on Awards to Inventors held on Monday, 19th July, 1926: Claim of Professor Langevin and Monsieur Chilowsky, TNA, T 173/686 pt., p.88.
37. For a discussion on the lack of basic oceanographic research during the interwar period see Gary Weir, *An Ocean in Common* (College Station: Texas A&M Press, 2001), pp.3-98.
38. David Zimmerman, *Radar and the Defeat of the Luftwaffe* (Stroud: Amberley 2010).
39. Bush, p.33. Emphasis added.

David Zimmerman is the Professor of Military History at the University of Victoria. Zimmerman was educated at the University of Toronto and the University of New Brunswick, and has been a member of the faculty of the University of Victoria since 1988. His books include: *The Great Naval Battle of Ottawa*, *Top Secret Exchange: The Tizard Mission and the Scientific War*; and *Britain`s Shield: Radar and the Defeat of the Luftwaffe*. He has published over twenty scholarly articles and book chapters. He is an expert on the history of anti-submarine warfare, radar, the Royal Canadian Navy, science and technology in war, and the rescue of academic refugees from Germany in the 1930s.