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Knowledge, innovation and the race to the South Pole

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Research Article

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Abstract

The present article extends recent studies that ask what might else have been considered by Scott and Amundsen in planning their sledging operations to reach the South Pole during the southern summer of 1911/12. Both were on the cusp of changes in exploration methods and had at hand significant knowledge from past expeditions. Scott's preparations were based on British Arctic experiences using several haulage methods including the recent innovation, motor sledges. He had little success with them although more research and experimentation might have made them valuable. Amundsen's integrated program was based on previous American and Norwegian exploration in the Arctic and Antarctica. The race was between two men with very different backgrounds. Scott and Amundsen belonged to the same generation, Scott followed the romantic tradition of heroism as suffering; whereas Amundsen came from a culture that did not value unnecessary risk to life and limb. He won the race with a different organizational type and a different approach to gathering and using knowledge. Evolutionary economics with its focus on organizational structure and its impact on the use of knowledge and innovation is used to evaluate the plans and results of Scott and Amundsen.

Introduction

Recent research about the race to the South Pole asks specific questions about knowledge and innovation: What did the participants seek? What did they learn, and how did they apply what they learned? (Alp, 2018; May, 2013, 2018; May & Airless, 2015; May & Lewis, 2015; Schultz et al., 2015; Tahan, 2019; Turney, 2018). Although previous research has examined elements of expedition management, the present analysis extends that to innovation in sledging (Karpoff, 2001; Stuster, 1996, 2000; Savitt, 2004, 2008; Savitt & Lüdecke, 2007). This is based on the proposition that Scott looked backwards to the British in their search for the Northwest Passage and ignored much of Antarctic experiences before his first expedition on the *Discovery* (1901–1904). A year after volunteering for command he was still astonishingly ignorant of polar exploration and had done very little reading on the subject (Huntford, 1999, p. 129). Amundsen drew upon knowledge gained from the recent past including his personal Antarctic experiences on the *Belgica (1897–1899)* and looked for new solutions for improving his equipment. Both expedition leaders represented two distinct views of polar exploration with the sense of times colliding. "Scott seemed to live in 1911 which is only forty years from the 1870s, Amundsen's 1911 seems only forty years in advance of the 1950s" (Spufford, 1997, p. 267). Scott relied on the traditional British approach but disregarded recent developments on Antarctic expeditions. Amundsen's program of continual innovation contributed to successfully reaching the South Pole; he perfected the integrated, dog-based sledging system. The analysis focuses on innovation, the changes in routine operations which arises by employing available knowledge or through experimentation. These are viewed in the context of the organisational models that each used and how they affected the search for knowledge and innovation.

Polar exploration came to prominence in the nineteenth and early twentieth centuries. Expeditions were sponsored by commercial enterprises, governments, religious organisations such as the Moravians, scientific societies and private donors. They were driven by three inextricably intertwined goals, economic exploitation, national prestige and science. Nations were in competition with one another mainly in the search for the magnetic pole of the southern hemisphere and the passages to Asia, the Northwest Passage in the western hemisphere and the Northeast Passage in the eastern hemisphere. There was little direct competition between specific expeditions being in the same area at the same time with the same goals. However, there were two exceptions, the competition between Frederick Cook and Robert Peary in searching for the North Pole and the race to the South Pole in the Antarctic (Cook, 1919; Huntford, 2010; Peary, 2001). Sixteen major expeditions took place in the area of Antarctica between 1892 and 1913 starting with the Dundee Whaling Expedition (1892–1893) and concluding with

Table 1. Major sources of Antarctic expedition knowledge in the heroic age including the race to the South Pole, 1892–1913.

Dates	Expedition Name	Captain	Commander	Personnel	Name of Ship
1892–1893	British Whaling Exploration	Thomas Robertson		William Speirs Bruce	Active
		Alexander Fairweather			Balaena
		Robert Davidson			Diana
		James Davidson			Polar Star
1893–1894	Norwegian sealing and whaling exploration	Carl Anton Larsen			Jason
		Morten Pedersen			Castor
		Carl Julius Evensen			Hertha
1893–1895	Norwegian sealing and whaling exploration	Leonard Kristensen	Hernyk Bull	Carsten E. Borchgrevink	Antarctic
1897–1899	Belgian Antarctic Expedition	Adrian de Gerlache de Gomery		Roald Amundsen	Belgica
				Frederick Albert Cook	
				Henryk Arctowski	
1898–1900	British Antarctic Expedition	Bernhard Jensen	Carsten E. Borchgrevink	Louis Bernacchi	Southern Cross
1901–1903	German South Polar Expedition	Hans Ruser	Erich von Drygalski	Paul Björvig	Gauss
1901–1903	Swedish South Polar Expedition	Carl Anton Larsen	Nils Otto Nordenskjold		Antarctic
1901–1904	British National Antarctic Expedition	Robert Falcon Scott		Ernest H. Shackleton	Discovery
				Louis Bernacchi	
				Edward Wilson	
				Albert Armitage	
				Reginald Koettlitz	
1902–1904	Scottish National Antarctic Expedition	Thomas Robertson	William Spears Bruce		Scotia
1903–1905	French Antarctic Expedition	Jean-Baptiste Charcot			Française
1907–1909	British Antarctic Expedition	Rupert George England	Ernest Shackleton		Nimrod
		Frederick Pryce Evans			
1908–1910	French Antarctic Expedition	Ernest Chollet	Jean-Baptiste Charcot		Pourquoi Pas?
1910–1912	Norwegian Antarctic Expedition	Thorvald Nielsen	Roald Amundsen	Helmer Han(s)sen	Fram
				Adolf Lindstrøm	
1910–1912	Japanese Antarctic Expedition	Naokichi Nomura	Nobu Shirase		Kainan Maru
1910–1913	British Antarctic Expedition	Robert Falcon Scott (only on outward voyage)		Henry Bowers	Terra Nova
				Edgar Evans	
				Lawrence Grace Oates	
				Edward Wilson	
1911–1912	2nd German Antarctic Expedition	Richard Vahsel, after his death:	Wilhelm Filchner	Paul Björvig	Deutschland
		Wilhelm Lorenz			

Source: Headland (2009).

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Scott's British Antarctic Expedition (1910–1913). These expeditions contributed to an understanding of the Antarctic and were a source of knowledge for further exploration, see Table 1.

The research includes a wide assortment of original and secondary materials including biographies, public records and scientific publications. It concentrated on documenting what knowledge was available at the time to advance haulage and sledging activities, the origin of the new methods, how they were evaluated, and how the new knowledge was applied. A substantial body of formal, written knowledge developed in the late nineteenth century, however, less is known about the knowledge of individuals who participated in previous expeditions. Few participants offer some insights about what had been directly learned from previous explorers; some reported their efforts, others said nothing and hence in some cases inferences were drawn from the records. Individual explorers accentuated their adventures with the hope of paying off debts and providing income for further activities rather than illuminate the contributions of others. Recent studies provide new insights, although several are hagiographic (Borkan & Hirzel, 2017; Capparell & Morrell 2001; Huntford, 2010; Monatersky, 2001; Perkins et al., 2000; Solomon, 2001; Stuster, 1996; Useem et al., 2003). This article begins by defining the organisational models used in the Antarctic, continues with a description of knowledge available to Amundsen and Scott, and concludes with an analysis of how these factors affected their propensity to engage in innovation, the process of creating useable improvements by changing the activities required to complete a task; it is either spontaneous or continual and always involves taking risks (Yezersky, 2007, pp. 44–45).

Expeditions as organisations

As with all organisations, polar expeditions were organised and managed by past knowledge and new knowledge. This is the knowledge management process consisting of three elements: First is making "sense of changes and developments in the external environment" (Choo, 1998, p. 1). Second is improving operations, and, third is making decisions based on what was learned (Choo, 1998, p. 2). Organisations are defined by the individuals who create them and the social and political cultures in which they exist. They function most effectively when basic values are shared among all the members of the organisation (Schein, 1991, p. 247). Organisations differ in size, complexity and purpose. Each influences how knowledge is managed. "Like chess players organizations have a memory, a capacity to learn, and a mode of knowing" (Baumard, 1999, p. 17).

Three expedition models were used in the Antarctic in the late nineteenth and early twentieth centuries. They are the hierarchical model, the autocracy model and the scientific model. Each has unique features and strategies, none is pure, each often contains elements of the others. A priori one may appear more appropriate for exploration than another, however, each has limitations in application. Success or failure stems is not predetermined by the model but they influence how an expedition operates. The defining features are formality, complexity, risk taking, adaptability, knowledge management and leadership. Formality represents the organisation's structure both vertically and horizontally and the specificity of responsibility for activities; complexity describes the number of divisions in the structure and the nature of communications among divisions; risk taking is the willingness to make decisions with limited knowledge of the outcome often without access to support; adaptability is the degree to which changes are made; knowledge management is the degree to which learning and knowledge influence success. Organizations succeed when they capture, use, and reuse the "best practices and intellectual assets" (Davenport & Klar, 1998, p. 195). Finally, leadership and management are the skills which inspire participants to follow the organisations goals, on the one hand, and on the other, follow the specific directions of the leader (Sternberg et. al., 2000: 167). Beyond honesty and integrity, the "leader as manager" is required to assemble and allocate resources and gain respect for decisions even when unpopular (Capparrell & Morrell, 2001, p. 45).

The hierarchical model is the most formal; it consists of a set of vertical structures representing various functions and horizontal levels with several layers within each carrying out the basic activities of an expedition. It can be visualised as pyramid with the ultimate authority at the apex. The vertical structures, often referred to as silos, each have a specific function. These include the ship's operations consisting of the captain, a navigational staff of officers, a scientific staff and the exploration organisation. This model is found in several expeditions listed in Table 1 (Borchgrevink, 1901, pp. 13–22: Charcot, 1911, pp. 22–23; Cook, 1900; Speak, 2003, pp. 77–79). Among these are the *Antarctica, Belgica, Southern Cross, Discovery and Terra Nova* expeditions. The two latter represent versions of the British naval model used in the Arctic between 1818–1916 (Savitt, 2004, p. 2). Authority is at the top of the vertical structure, communications move downward to intermediate and lower levels and little moves upwards. Communications among horizontal levels is limited. Individuals are rewarded based on adherence to commands and risk taking is limited. There is little incentive to innovate except where contingencies demand it. The *Discovery* and partly the *Terra Nova* differed from naval expeditions because the authority came from the Royal Society and the Royal Geographical Society, known as the "Societies Antarctic Expedition" (Markham, 1921, pp. 448). "Elaborate instructions were drawn up for the guidance of the offers and men, and these were given to Captain Scott by Clements Markham, president of the Royal Geographical Society, himself; it contained discretionary power vested in the leader of the organization in the event of the instruction conflicting any way with local circumstances, or unexpected discovery of new territory or seas, that would constitute a change of plans" (Markham, 1917, p. 329). This structure minimised conflict between the commander of the ship and the leader of the expedition in contrast to the *Belgica* where there was wide spread conflict among the captain, the commander of the expedition and the ship's officers (Cook, 1900). A recent popular treatise *Madhouse at the End of the Earth* illustrates describes what took place on the *Belgica* (Sancton, 2021). While used for exploration, the many of the personnel were not part of an exploration ethic. "Officers and men, ambitiously minded, volunteered for polar work not as 'explorers' in the twentieth-century idiom but as part of an ordinary naval career and they sailed for an unknown world of ice full of the robust confidence of the Victorian age" (Wallace, 1980, p. 79). The Royal Navy was the agent of authority. "It was the product of hierarchical service establishment based on discipline and its purpose was war and the keeping of peace and order" (Wallace, 1980, p. 5). The *Discovery* expedition (1901–1904) and the *Terra Nova* expedition (1911–1913) followed the hierarchical model in which "the planners repeated the mistakes of fifty years and condemned British Antarctic expeditions to tragedy in the second decade of the twentieth century" (Baughman, 1999, p. 4). The Admiralty and the Royal Societies provided orders allowing little discretion to the officers who were expected to obey them (Ellis,

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1986, pp. 100–101). Rewards were based on how well individuals followed instructions. Risk taking except in dire circumstances was not encouraged. Discipline and courage defined what it meant to be a "good explorer," and they were greatly favoured over self-reliance and initiative. Military command and control principles, known as the "heavy" approach to Arctic exploration, defined operations. Expeditions often included several ships and sailed as an armada. Vessel design paid attention to the "comfort and accommodations of both officers and men and to the greatest formal planning that human foresight could suggest, or a liberal Government provide" (Wallace, 1980, p. 10).

The adhocracy model is characterised by a flat structure with usually no more than two levels and without competition among the functions. While there is a clearly defined leader, the structure appears more like a box including a peak to indicate the leader. It includes the demarcation of specialized areas such as science and expedition operations, however, members "share common knowledge and responsibility" for the operations (Mintzberg et al., 2002, pp. 223–224). The organisation is made up by a small group of individual volunteers and by a leader responsible for the expedition. Each member specialises in one area but has the knowledge to work in other areas. Expedition leadership and management are lodged in one individual; however, decision-making is shared among the various members as much as possible. Amundsen adopted this model based on the Arctic tradition of Fridtjof Nansen and Robert Peary and his *Belgica* experiences. He also attempted to ensure homogeneity among the crew (Amundsen, 1927, p. 20). The model requires the concentration of resources with overlapping skills. The adhocracy model depends upon knowledge of past activities, the ability to apply direct experience and continual learning. Peary's and Nansen's expeditions are classic examples (Nansen, 1890; Peary, 2001; Savitt, 2008). Members were carefully selected so as to ensure their commitment to the expedition goals and not as "an escape from civilised existence" (Huntford, 1999, p. 248). Size required a commitment to "systematic simulation, testing and evaluation of every item of equipment and the meticulous attention to detail as well as recognizing the importance of the crew's well being" (Stuster, 2000, p. 54). Amundsen described this as the "essentials which brought success" (Amundsen, 1927, p. 19–20).

The scientific model is the "scientific method" in action, observation, experimentation, revision and more experimentation. It approaches the hierarchical model except that the focus of the expedition is scientific rather than geographic discovery. In this model, there is a clear demarcation between the operation of the ship and the scientific activities with the latter having greater influence in organisation and operation of the expedition. In this way, it is more complex than the adhocracy model with several horizontal layers and less complex than the hierarchical models although it may contain elements of it. William Bruce wrote "The scientific side of the ship should be separate from the nautical, and the leader must be the intermediary and guiding hand for both" (Bruce, 1911, p. 241). Bruce organised the expedition around scientific areas, like biology, botany, geology, meteorology, and zoology in the British manner as described in the Royal Society instructions for scientific discovery in 1839 (Royal Society, 1840). The scientific orientation is seen in the *Scotia's* structure, "two well-equipped laboratories, a dark room, and a Lucas sounding machine with two drums of 6000 cable each" (Speak, 2003, p. 77). Bruce also delineated the roles of the various members. "The master of the ship must be subject to the leader, and the crew entirely responsible to the master, the leader strongly supporting the master in this position." (Bruce, 1911, pp. 241–242). The Scottish National Expedition of 1902 and the French Antarctic Expeditions of 1903–1905 and 1908–1910 led by Bruce and Jean Charcot are examples (Bruce, 1902; Charcot, 1906; Charcot, 1911). Bruce applied Erich von Drygalski's ideas (Hayes, 1928). Bruce's crew was expected to know as much of the equipment as possible, and each became a scientist participating in a large experiment—as he saw his expedition. Bruce went a step further in "purity" and solicited funds only from those who understood his model. It "was the only Polar expedition to have been organized, supported and led wholly by . . . the people of Scotland" (Speak, 1992, p. 138). Although successful in scientific achievements, Bruce and the *Scotia* expedition did not receive significant recognition outside of the scientific community, a matter attributed to Clements Markham (Speak, 2003, p. 96). His expedition was never intended for extensive land exploration as were the other two models, but mostly for oceanographic investigations of the Antarctic waters.

Knowing and planning

Expedition planning begins with a search for what is known from the past and the search for additional knowledge both from current developments and from outside fields. Organizations that undertake this process are known as "the knowledge creating company" (Nonaka & Takeesuchi, 1995, p. 8). Amundsen and Scott had the luxury of not having to begin *de nova*. What knowledge existed did not mean they were fully aware of it, knew where it was located nor appreciate how useful it might be. Beyond the exploration literature, there were potential advances and discoveries from other fields. Core concepts for knowledge acquisition are exploration and exploitation. The former is "learning through discovery or experimentation" that leads to new ways of operating; exploitation is expansion of known concepts as a means of making improvements (Choo, 1998, pp. 251–252). Regardless of what was known they did not have what was necessary to predict accurately the risks that they would face considering the various states of nature they might face. Searching for knowledge determines what is available so as to define uncertainty and establish alternatives and their probabilities. Some of what might be important may be outside of the realm of those searching and that is not often obvious (Nelson & Winter, 1982, p. 171). The advantage of external search, exploration, is the discovery of new methods, technologies and innovations as was the case of motor sledges. This requires risk taking beyond the comfort of what is familiar and the curiosity of asking whether "it can be employed in practice" (Nelson & Winter, 1982, p. 249). Changes can also be evolutionary over time and appear without much fanfare simply as "part of operations." This is more likely to take place in organisations where individuals have high degrees of specialisation and are working together to solve a problem such as with Bruce and Amundsen. In those cases, knowledge is introduced to foster change (Leonard-Barton, 1995, p. 10).

Search focuses on limiting or reducing uncertainty and reaches to discover identifiable "alternatives" that can be explored, a process which should bring to light alternatives. "Real search processes take place in specific historical contexts, and their outcomes clearly depend in part on what those contain in the way of problem solution that are available to be 'found'" (Nelson & Winter, 1982, p. 172). The organisations involved in the search have an important impact on the process. It is influenced by those who request it, those who conduct it and those who require it. Success is measured by how valuable the knowledge is and how well it can be used

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rather than how much of it is gathered. Planning matches what is known to assumptions about what is not known. Plans contend with "partial ignorance" when not all of the alternatives, methods and programs are known, for example. In spite of not being able to evaluate in advance, assumptions and plans can be made using "what if" (Ansoff, 1987, pp. 39–44). The goal of planning is to reduce partial ignorance and minimise possible risk; however, they are always present. "The fact that the future can never be known with accuracy means that the planning of business firms [expeditions] is based on expectations about the future which are held with varying degrees of confidence; furthermore the expectations themselves are themselves essentially estimates of various possible outcomes in the future or a given action or series of actions" (Penrose, 1959, p. 56). The plan incorporates past knowledge, develops means for gaining new knowledge and applies these to the conditions which are expected and unexpected. Not everything will be known in advance and establishing contingency plans when the "unknown become known." The plan establishes the goals and objectives, the resources necessary for undertaking the expedition and the means for allocating them, and alternatives in case the original plan has to be changed. The final step is to estimate the resources necessary to meet those conditions. Wilhelm Filchner, leader of the 2nd German Antarctic Expedition, wrote "Von der Vorbereitung einer Expedition und ganz besonders einer Polarexpedition hängt viel, mitunter vielleicht alles ab." ("A great deal, sometimes perhaps everything, depends on the preparation for an expedition, and especially a polar expedition.") (Filchner, 1922, p. 12). A point that Scott did not appreciate when he was quoted saying "that the worst part of the expedition was over when the preparations were finished" (Cherry-Garrard, 1922, p. 1).

There are two sources of knowledge, formal and tacit. Explicit or formal knowledge in the form of articles, books and records is visible in expedition plans and documents where experiential/tacit knowledge can only be inferred. One of the most comprehensive sources at the time was "The Antarctic Manual" of 1901; it contains 491 references of articles, books, manuscripts and other printed materials for the 1700–1890 period; most were about scientific matters although a few offered insights about expeditions activities (Murray, 1901, pp. 521–576). "The Antarctic Bibliography, compiled by Dr. Mill, is the first so far published which makes any claim to completeness, and though no doubt a certain amount of Antarctic literature exist which is not included, it is believed that no paper of any importance has been admitted." (Royal Geographic & Royal Society, 1901, p. 160). There were reports on scientific materials whose categories came from previous Arctic manuals whose purpose was served "by giving easy access to information, otherwise inaccessible, which was required by the officers in their scientific investigations." (Markham, 1901, p. vii). There is no similar volume in the Norwegian literature although there are extensive reports and the writings by Nansen (Nansen, 1890; Tahan, 2019). Reports in English based on Nansen's experiences were available; however, it is difficult to judge how widely they were circulated. Amundsen's knowledge of the Norwegian experiences are well documented in the first chapter of his travel account of his Antarctic expedition (Amundsen, 1912a, pp. 1–41; Bain, 1897).

In contrast, "storehouses" of experiential or tacit knowledge do not exist. They reside with individual expedition participants, some of whom are well known, others who are not and still others who are not participants in a specific expedition. There are important examples in the literature describing individual contributions that were made at a specific time but much of these are lost and must be assumed. Tacit knowledge is difficult to document because "what we know" requires personal contact (Polanyi, 1983, p. 4). "It can not be articulated fast enough" because of how it develops (Nelson & Winter, 1982, pp. 81–82). Individuals who experience and learn from events carry it with them. Tacit knowledge has the "function of producing fundamental innovations" if can be identified and used (Polanyi, 1983, p. 55). That is why Amundsen relied on experienced members of his former expeditions. They could apply tacit knowledge when necessary. Experiential knowledge from experiences can be codified although they are not always available or useful as they might be (Sternberg et al., 2000, p. 107). Amundsen made an interesting point about the relationship between explicit knowledge and tacit knowledge. "Secondhand experience out of books is often as good as first-hand, if the reader has had enough practical experience in the same field to understand and apply what he reads" (Amundsen, 1927, p. 239). Antarctic explorers had to accept partial ignorance. They "did not have what was necessary to predict accurately the risks that they would face. By their very nature they were concerned with how to confront the unknown" (Dunn, 1992, p. 17). Their challenge was to develop a process to gather and apply knowledge for their operations similar to "dead reckoning", informed guess work applied in navigation (Gurney, 1977, p. 25). Julius von Payer, member of the Austro-Hungarian North Pole Expedition (1872–1874) made this point "Every Arctic [Antarctic] expedition should be guided by the experiences of its predecessors, both in its plan and its equipment; hence, we have often to deplore the negligence of almost all polar navigators in failing to inform those who follow them of what they actually saw, of their modes of procedure, or of the mistakes which they committed. It will not, therefore, be labour thrown away, if we state our own experience and record our own observations for the guidance of others, in order to show, with the utmost possible clearness, what future explorers have before them, and how best to meet it." (Payer, 1876 (1), p. 62).

The British approach to knowledge and innovation

The British history of publishing exploration instructions began with James Clark Ross's expeditions in 1839–1840 (Ross, 1982). The *Instructions to be Prepared for the Scientific Expedition to the Antarctic Regions* provided recommendations for carrying out scientific work, although little was written about exploration methods (Royal Society, 1840, p. iii). Similar instructions were prepared for the Arctic expedition of 1875 (King, 1876). In 1901, the Executive Committee of the Royal Geographical Society commissioned "Instructions to the Commander" as noted previously. Markham applied the format from the Manuals of 1875 and 1876 (Anonymous, 1875; King, 1876: Markham, 1921, p. 451). "The Antarctic Manual" contains materials from voyages to the Antarctic in a section titled "Geography." Essays by John Biscoe, John Balley, Charles Wilkes, and M. J. Dumont d'Urville are included (Murray, 1901, pp. 305–497). Henryk Arctowski and Louis Bernacchi offer first-person knowledge from the *Belgica* and the *Southern Cross* expeditions (Arctowski, 1901, pp. 465–496; Bernacchi, 1901, pp. 497–514). Bernacchi served with Borchgrevink on the *Southern Cross* and a year after his return with Scott on the *Discovery* (Bernacchi, 2001). Only one article discussed exploration methods; it was M'Clintock's "On Arctic Sledge-travelling" which describes preparations for sledge journeys including clothing, food, haulage methods, and the use of dogs (M'Clintock, 1901, pp. 293–304). The volume represented a major contribution so much so that Nansen "thought enough to ask for a

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copy of it" (Baughman, 1999, p 27). Interestingly and considering the extensive Arctic activities by the British it contained no references to the Arctic Blue Books, the British Parliamentary Papers documenting British experiences in the Canadian Arctic (Arctic/Subarctic Research Group, 2003). Yet both Royal Societies and the Royal Navy used knowledge from the Arctic to develop plans for the *Discovery* and the *Terra Nova* expeditions. A major source was Markham's report on *The Arctic Expedition of 1875–1876* in which he provides a detailed examination of the role of sledging activities. He states that it is necessary to spend one winter in the Arctic and "to look for sledge-traveling as the main instrument of discovery and exploration" (Markham, 1876–1877, p. 542). Little was said about the methods and equipment except for references to "they laying-out of depots by autumn sledge traveling" (Markham, (1876–1877), p. 545).

Planning efforts were narrowly focused and gave little recognition to the previous Antarctic expeditions, noted in Table 1. Markham drew upon what he was most familiar, the Royal Navy. He was an officer of the Royal Navy himself; his appointed came from personal contacts with the Countess of Mansfield; he was awarded the "exalted rank of Naval Cadet" (Markham, 1917, p. 18). His support was unwavering; however, he had difficulty with those outside of his social context such as Bruce who represented different views of how to organise expeditions (Markham, 1921, pp. 437–438). Markham was less than helpful and supportive of Bruce's attempts to develop a "rival enterprise" and basically rejected any aid based on the view that it was competition to the British expedition (Speak, 2003, pp. 73–74). Markham did not give great value to non-British expeditions. (Baughman, 1999, pp. 10–34). He made light of the contributions of the *Belgica* and *Southern Cross* expeditions (Markham, 1921, pp. 28–30). The latter was the British Antarctic Expedition; however, he did not regard it as British because Borchgrevink, the expedition leader, was Norwegian and it had a mixed crew from Britain and Norway, even though it was and financed by the English publisher Sir George Newnes (Borchgrevink, 1901, p. 9). Markham held the *Southern Cross* up to ridicule "claiming everything but the money was Norwegian" which meant that "virtually everyone was urged to shun Borchgrevink", and "the valuable experiences gained by this rogue; the refusal only increased to ignore the realities of modern polar travel (the suitability of dogs, the value of taking the nature of native Arctic people to the Antarctic for their experiences, the necessity of skis) and to rely on out-moded mid-century nineteenth century British Arctic Experience" (Baughman, 1999, p. 8).

Markham's contributions to Antarctic exploration were substantial especially developing the support for such expeditions and providing the organisational context for their management (Markham, 1921, pp. 444–465). As important as these were at the aggregate level, Markham did not appear to involve himself in operations. He did not consider the importance of dogs in the *Southern Cross* expedition: "Seventy-five dogs were landed, the first time dogs were used in Antarctica" (Mills, 2003, p. 93). Borchgrevink discussed the trials and tribulations of the dogs on the voyage south but also attributes the expedition's winter sledge journey success to them (Borchgrevink, 1901, pp. 39–44 and p. 155, ff.) Such knowledge would have helped Scott. "It must be remembered that in making long sledge journeys in the South we had no previous experience to go on except that which had been gained in the North; **we were forced** [emphasis added] to assume that Southern conditions were more or less similar to those of the North" (Scott, 1905 (1), p. 413). The contributions from the *Southern Cross* with its first ascent of the Barrier thought inaccessible since Ross's time was not given much importance. Amundsen did and wrote "We must acknowledge that by ascending the Barrier, Borchgrevink opened a way to the south, and threw aside the greatest obstacle to the expeditions that followed." (Amundsen, 1912a, pp. 25–26). Also Cook's experience on the *Belgica* expedition were not considered. He wrote "My story ... is a record of the first expedition to pass through the ordeal of the long antarctic night and its gloomy winter storms. It is, I hope, a contribution of new human experience in a new, inhuman world of ice." (Cook, 1894, 1900, p. xv). Cook, originally a physician was "an experienced and respected polar traveler, who had been an anthropologist on Peary's Greenland expedition of 1892" and had much to contribute (Bryce, 1997; Kirwan, 1962, p. 282). He understood the Peary system and its "light traveling" methods used by Frederick Schwatka during the last search for the disappeared Franklin expedition (1878–1880) (Savitt, 2008; Wamsely 2017, p. 208).

The details about the Peary system were well known at the time of the *Discovery*. Donald B. MacMillan, Peary's companion on several expeditions wrote in retrospect about Peary's various expeditions in the Arctic and Greenland in the late nineteenth century. He described it as combining dogs, sledge design, personal equipment and the use of a "task force composed of five sledges" (MacMillan, 1934, p. 160). Peary also contributed elements in a precise method for calculating the loading of sledge (Kaplan & LaMoine, 2019, p. 54). He was not the traditional naval officer, but an "engineer and a technologist, a military planner concerned with strategy, tactics and logistics of his polar campaign" and his strategy included "the dispatch of small advance parties to blaze the trail and set up camps and depots ... thereby saving the strength of the men and of the dogs reserved for the final dash" (Kirwan, 1960, pp. 254, 258). Peary experimented with sledges using "native patterns" and studied sledge traction on different types of ice surfaces. He analysed the abilities and strengths of dogs including how much they could pull and how much food they required in order to determine the ideal size of a dog team. He began with the design of equipment, all of which had to be light weight and robust. The two attributes—"weight and durability"—had to be balanced including specifications for how sledges were to be loaded with food, tea and pemmican on top, above tools. Peary's contributions to exploration methods were substantial. "He understood that expeditions could fail due to inattention to detail, and his men would also be more comfortable and work most efficiently if things were planned as well" (Kaplan & LaMoine, 2019, p. 54). Markham acknowledged Peary but none of Peary's books were found in the *Discovery*'s Library "Whoever selected the Polar Library for the *Discovery* was determined that members of the expedition should not greatly counteract their inexperience by reading. Scott regretted the deficiency of their shelves in the works of the only two polar travellers, Nansen and Peary, who had anything to teach; *The First Crossing of Greenland* was the only book either of these explorers that they possessed" (Hayes, 1928, p. 151). Peary's detailed discussions of what led to his success were adopted by Amundsen. They came from a "carefully planned system ... Every thing that could be controlled ... was taken into consideration in the percentages of the probabilities provided as far as possible" (Peary, 2001, p. 201).

Motor sledges as British innovation

Motor sledges were a significant innovation for exploration in Antarctica. They represented a quantum leap in haulage as a

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supplement to man and dogs as well as a possible singular mode of transportation. "The precise nature of the innovation actually arrived at is usually not predictable at the start of the endeavor that culminates in the innovation" (Nelson & Winter, 1982, p. 128–129). Innovation regardless of how practical the innovation might appear requires experimentation and testing especially in the environment in which it is to be used. Motorised transport would revolutionise exploration if it worked. Much needed to be known including answers to the following questions: Were they a supplement or a replacement? What skills were needed to drive them? How should they be maintained? Would they require specialised mechanics and stores of replacement parts? What type of petrol would work in cold climates? And how much testing should be undertaken before using them? The "consequences of employing an innovation—changing the routine—in general will not be closely predictable until a reasonable amount of operating experience has been accumulated" (Nelson & Winter, 1982, p. 129).

Scott saw the potential of motor sledges; however, he viewed sledging as a set of relatively independent components such as dogs, men and ponies and not as an integrated activity. He needed to know a great deal more than he knew before departure. What resulted was "on the job learning" which is "dangerous and wasteful of resources" (Savitt, 2004, p. 7). Scott admitted as much in his visit to Christiana (today: Oslo) that sledging was not a prime concern and certainly not the centre of his expedition prior to the *Discovery* expedition, when he wrote: "I should have liked to linger and increase my knowledge in this province [sledges] … However, I had learnt enough to give me a practical idea of the basis on which our equipment should be collected" (Scott, 1905 (1), p. 411). But as we will see it was not simply his limited knowledge that mattered but the extent of knowledge of those who were involved in the development of these vehicles as well as those who were to use them. In an unattributed article in the *South Polar Times*, Scott reflects on what might have undertaken "to secure a better result on the 'Southern Sledge Journey' including matters that could have been foreseen" such as starfish for the dogs and the "unspeakable tedious of relay work" (Scott [attributed to 1903], p. 28). His limited focus continued when he prepared for the *Terra Nova* and his almost off handed manner in which he decided to take motor sledges. If he "had concentrated solely on dogs and had trained his people thoroughly in their management, he would have got comfortably to the Pole and back" (Huxley, 1977, p. 190). Instead of research, he extolled the English role in sledging "it is the direct outcome of that feverish energy in exploration which has distinguished our race for so many centuries and has led them to the performance within the Arctic Circle" (Scott, 1905 (1), p. 403). He apparently disregarded Albert Armitage's article in the first edition of the *South Polar Times*, where he described his disastrous experiences with ponies in Frederick Jackson's expedition to Franz Joseph Land (1894–1897). Armitage wrote about how "[e]ach sledge-journey teaches something new; and although the discomforts of sledging can never be entirely done away with, much may be done to prevent them becoming hardships, if due care, attention and common sense, are brought to bear" and how the only one pony remained, the others being "very good 'beef'" (Armitage, 1902, p. 2). Apparently little attention was paid to sledging in spite of Armitage who "came to the conclusion based on experience with Jackson that "dogs are the best animals for all-round purposes on these expeditions" and to the success of dogs in *Southern Cross* where Borchgrevink wrote "The dogs were invaluable to us on these journeys" (Armitage, 1925, p. 112; Borchgrevink 1901, p. 170). Yet Scott settled on a series of haulage methods including dogs, men, ponies and motor sledges. Skis were regarded as entertainment (Scott, 1905 (1), p. 125). He noted "Skis are the thing, and hence are my tiresome fellow-country men too prejudiced to have prepared themselves for the event" (Scott, 2005, p. 345). One might ask "Why did not Scott better prepare his compatriots for the totality of haulage?" Bernacchi used Norwegian skis from the Arctic, but they were not included as part of haulage (Bernacchi, 2001, pp. 31–32). Scott "pinned his fate finally—[to] a number of Shetland ponies" (Amundsen, 1927, p. 67).

With knowledge of the *Nimrod* expedition (1907–1909), Scott did not draw on Ernest Shackleton's experiences in sledging with ponies and the viability of the motor car. Shackleton's interest in motor vehicles came from the desire to support Arrol-Johnston in Paisley, Scotland, who was attempting to establish the Scottish automobile industry (Huntford, 1985, pp. 171–172). The vehicle was basically a modified automobile; little was known about how the petrol engine would behave in extreme cold and whether it had a suitable traction system for the snow. Shackleton "optimistically proposed taking it south without testing it first under working conditions" (Huntford, 1985, p. 173). There was no financial risk, because he received a vehicle for free, "partly for advertisement." (Huntford, 1985, p. 173). It "will be of a special type, taking into consideration the temperatures and the surface to be travelled over. … As long as the car continued to remain satisfactory, it alone would be used to drag out equipment and provisions" (Shackleton, 1907, p. 330). His knowledge from the *Discovery* provided scepticism as to whether the Barrier could be breached with the motor car. "I knew that it would not do to place much reliance on the machine in view of the uncertainty of the conditions." (Shackleton, 1909a (1), p. 21). He noted there were no difficulties at starting the car at 10 degrees below zero; however, "the driving-wheels were a great source of trouble, and the weight of the car its self-made it almost impossible to travel over the snow; the heavy rear wheels sunk into even the hardest snow and then spun around in the hole they had made for themselves." (Shackleton, 1909a (1), p. 166). Eventually he concluded "The motor car had not proved a success" (Shackleton, 1909b, p. 484). Scott's interest in motor sledges was substantial, however, and in spite of testing did not evaluate them with regard to Antarctic conditions. He "put his faith in a technological panacea. In this he was following history and times. The Royal Navy was in the hand of materialists: that school of thought which saw in bigger and better gadgetry, by its mere possession of superiority and success putting machine before men." (Huntford, 1999, p. 222). In spite of what was known, Scott went ahead adding motor sledges without evaluating their compatibility, reliability or sustainability. Their success depended on understanding ice conditions, snow and land features as well as wind and temperature. These had to be seen in terms of the vehicles' operating capacities.

Scott selected a British chain traction vehicle instead of Shackleton's modified automobile. The decision came after testing a French vehicle. In 1908, Charcot and Scott including Reginald Skelton and Michael Barne, engineer and officer respectively of the *Discovery,* tested two motor sledges developed by the French Ministry of War at Lautaret in the French Alps (Crane, 2006, pp. 350–352). Charcot and Scott differed about them. Charcot wrote "We had the assistance of Lieutenant de La Besse, who had long given attention to motor-sledges" and "during eight days of the trial …. The results seemed most encouraging … Unluckily, we never came across, in the region we visited, any surface on which we could use them" including several attempts on January 11, 1909 (Charcot, 1911, pp. 17–18; p. 345). In

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Antarctica he realised "the whole [thing] will not be in working order until after numerous trials and changes, which will be made during our winter season. Besides I look at these automobile sledges in the light of a first experiment for future expeditions." (Charcot, 1911, p. 111). In 1910, Scott went to Norway to test a British model, but in a forest rather on a nearby glacier (Huntford, 2010, p. 255). These experiences gave him hope. Scott abandoned the French design and adopted vehicles patented by Major B. T. Hamilton that were built by Worsley in Britain (Ellis, 1969, pp. 101–102). After initial experiences, he concluded the propulsion system was satisfactory "but their use had to be abandoned owing to the over-heating of the air-cooled engines, a defect, which could undoubtedly be remedied" with more investigation before leaving for the south (Markham, 1921, p. 490). Scott maintained confidence "of the possibility of motor traction, whilst realizing that reliance cannot be placed on it in its present untried evolutionary state" (Scott, 2005, p. 284). An important finding but all too late. Other matters which should have been considered before departure included the air cooling system, lubricant gaskets, and the quality of the operating cylinder. "I am secretly convinced that we shall not get much help from the motors, yet nothing has ever happened to them that was unavoidable. A little more care and foresight would make them splendid allies. The trouble is that if they fail, no one will ever believe this" (Scott, 2005, p. 300). Whatever the case, Scott did not know how to use or maintain them (Huntford, 2010, p. 108). A recent study looked at the role of petroleum and concluded it "was probably suitable for the power of powering the motor sledges . . . but [results] support the explanation that inadequate engine design was the primary cause of the failings" (McIntyre et al., 2008, p. 277). Scott tested the French sledges in the Alps (1908 and 1909) and the British ones in Norway (1910). "After each trial the sledges were brought back and improved," but he did not test if the improvements were satisfactory on snow (Scott, 2005, p. 308 footnote). He took three motor sledges with him, the first was lost in the water as it was being unloaded (Scott, 2005, pp. 71, 81). The two remaining motor sledges pulling three loaded sledges failed within a week and had to be abandoned on the Barrier (Scott, 2005, p. 315). "If their collapse was not unexpected, it must have been an uncomfortable reminder to Scott of the fallibility of his judgement, for it was by his long persistence that they appeared on the scene" (Pound, 1967, p. 268). Scott did not understand the technology he was embracing and did not rely on Reginald Skelton's extensive knowledge, who accompanied him on the test of the French motor sledges (Preston, 1999, p. 218). Skelton had served on the *Discovery* and had acted "for Scott in supervising "the design and construction of the latest motor sledges." (Pound, 1967, p. 185). It is difficult to conclude that if there had been more research and testing Scott might have had different results. By 1942, motor sledges were fully useable when "the Eliason motor sledge was patented and working in Sweden" (Swithbank, 1962, p. 265). The choice of motor sledges was limited as were vehicle trials. Both Shackleton and Scott did not search enough for knowledge to understand their risks, but. "both Scott and Shackleton were innovators and made significant contributions to the technology of polar exploration, but innovating they forfeited reliability" (Sullivan, 1962, p. 177).

The Norwegian approach to knowledge and innovation

With Amundsen's conquest of the Northwest Passage, Norwegian explorers established their preeminence in Arctic exploration. Their ships were designed for sailing in polar waters. Their captains had extensive experiences in navigating in ice-chocked waters of the northern seas and Greenland served them well, for example, Carl Anton Larsen, the captain of the *Antarctic* in the Swedish Antarctic Expedition (1901–1904) (Kirwan, 1962, pp. 240–241). Norway's environment required travel over difficult terrain and through rough seas in harsh weathers. On land skiing was part of life. As a small tight-knit community adaptation and innovation were critical values. Norwegian commercial activities were focused on the sea including the hunting of seals, walrus, and whales. As a small nation in union with Sweden until its dissolution in the year 1905, they extended themselves to the larger world; cooperation with foreigners was commonplace. An important example is Eivind Astrup, a member of Peary's Greenland Expedition (1891–1892), who knew much about dogs, sledges, and sleeping bags (Astrup, 1898, 2014). The experience of others was important to Amundsen who wrote "there are many useful things which you learn from an experienced polar explorer like Cook" who by chance participated in the same expedition as Astrup (Declair, 1999, p. 141). Amundsen selected his crew based on what they would bring to the expedition from their tacit knowledge. "What I have in mind, rather, is the specialised mental equipment, which is informed regarding the experiences of all proceeding expeditions." (Amundsen, 1927, p. 239). He knew what others had contributed by others such as Peary's calculations of resources and used them. "That my estimate of the time it would take was not so very far out is proved by the final sentence of the plan: 'Thus we shall be back on the Polar journey on January 25.'" and it was on that date that they returned to Framheim (Amundsen, 1912a, 53).

Four experienced Norwegians contributed to Amundsen's expedition planning. These were Fridtjof Nansen, Otto Sverdrup, Eivind Astrup and Carsten Borchgrevink (Amundsen 1912a). Their contributions were in ship design, ice navigation, sledging equipment and methods. Nansen's contributions included the *Fram* with its special hull which was built in 1892 by Colin Archer, a Scot who had extensive experience in ship building (Huntford, 1997, pp. 151–152). The *Fram* was a "highly adapted machine. Her engines, specially designed, were the latest thing in triple expansion—the apex of steam power before the advent of the steam turbine" (Huntford, 1997, p. 167). This is in contrast to the *Discovery* which was built 1901 and resembled "mid-century—British vessels that had plied the Arctic waters, than it did to the designs of Collin Archer, whose creations such the *Fram* incorporated the more modern features of polar ships" (Baughman, 1999, pp. 49–50). Nansen's use of dogs haulage and using dogs to feed other dogs reduced the amount of food required for expeditions (Nansen, 1897, p. 87). Discussions of Amundsen and Scott's "use and abuse of dogs" are found elsewhere (Lüdecke, 2011; Murray, 2008; Tahan, 2019). Sverdrup's experience came from Nansen's Greenland Expedition (1888–1889) and as captain of two *Fram* expeditions (1893–1896, 1899–1902) (Huntford, 1997, pp. 227–229). Astrup's participation in the Peary's second Expedition (1893–1894) provided Amundsen with examples to apply to sledging practices (Astrup, 1898, 2014, 144–149). Astrup was honoured before his untimely death at the age of 25 by the Norwegians with The Order of Saint Olav at the age of 21 and by The Royal Geographical Society with The Murchison Grant in 1895 "for his journeys with Lieut. Peary across Greenland, and his journey along the shores of Melville Bay" (Anonymous, 1895, p. 592). He also provided important insights about the "Eskimos [Inuit], their homes, their belief, their games and hunting exploits." (Anonymous, 1899, p 83). Astrup, who never travelled with Amundsen, was an inspiration for him

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(Huntford, 1999, pp. 210–211). Amundsen used Borchgrevink's knowledge about the ice barrier at the Bay of Whales in the Ross Ice Shelf as a winter base and the starting point for his race to the South Pole (Amundsen, 1912a, pp. 25, 46).

When Scott arrived in Melbourne on 12 October 1910, he received a warning in a telegram from Amundsen written in Madeira and sent by his brother Leon from Christiania (today Oslo), which informed Scott about his plan to proceed to Antarctica (Gran 1984: 14, Scott 2005: 483). The British suspicion that Amundsen would race to the South Pole was underlined by the meeting of "*Terra Nova*" and "*Fram*" in the Bay of Whales on 5 February 1911. Scott realised that Amundsen's route was 60 miles shorter than his own and that "[h]is plan for running them [dogs pulling sledges] seems excellent." (Scott, 2005: 135). Above all he could start earlier than Scott because the ponies needed better weather conditions. Scott knew that "Amundsen's plan is a very serious menace to ours." (Scott, 2005: 135). However, he did not want to change anything in his own plan, but "to proceed exactly as though this had not happened. To go forward and do our best for the honour of the country without fear or panic." (Scott, 2005: 135).

Dog sledges and the Norwegian sledging system

In *The First Crossing of Greenland* (1890), Nansen presented a brief history of sledges used in the Arctic. He documented the experiences and shortcomings of the Americans, the British, the Germans and the Austro-Hungarians. He was particularly critical of the English, "one would suppose that the experience thus gained would have led to a high development of the sledge", but they "set out with such large, clumsy, and impractical sledges". (Nansen, 1890, pp. 31–32). Nansen's influence on the development of sledges and sledging techniques was extensive and it was carried forward by Jackson who first relied on McClintock's heavy approach but then changed to Nansen sledges. He described McClintock as "practically the Father of Sledging, and his sledges were as great an advance upon those of his predecessors" (Jackson, 1899 (1), p. 206). However, Jackson turned to Nansen sledges because of their light weight and the use of rawhide for lashing a practice drawn from the Inuit, this gave "greater spring and elasticity" which was based on experience in the field (Jackson, 1899 (1), p. 206). Nansen's design reduced the weight to minimise the effort of the man pulling it and became the reason for restructuring sledging parties. It was based on the premise that several smaller sledges were better than a few larger ones (Nansen, 1890, p. 27).

Both Scott and Amundsen purchased sledges from Hagen's in Christiana; however, Amundsen observed that the workmanship was defective and the lashings were not suitable (Huntford, 1999, p. 293). There is no evidence that Scott recognised the problems of the prefabricated sledges or was told by others of the problem; it is assumed that he used them without modifications. Amundsen engaged Olav Bjaaland, one of Norway's best skiers and a skilled carpenter, who working with Helmer Hanssen, someone with familiarity of Inuit sledges, to remodel the *Fram* sledges adapting them to meet the need for speed on snow in the Antarctic. "While the heavy Nansen sledge would be more adequate on the glacial ice sheets similar in some part to those of the Arctic, they would not serve well on the snow as Bjaaland's lighter sledges" (Huntford, 1999, p. 367). On his return, Amundsen wrote "We had to improve our equipment and make it lighter. We discarded all our sleds, for they were too heavy and unwieldily for the smooth surfaces of the Ice Barrier. Our sleds weighed 165 pounds each", but the Bjaaland sledges "weighed only one-third as much as the old ones" (Amundsen, 1912b, p. 828). Continual experimentation provided alternatives and those that prevailed provided "greater strengths and infinitely less weight. By this invention, he easily doubled the travelling radius of men and dogs" (Amundsen, 1927, p. 241). This was based on several questions: "What will be the nature of the regions we have to cross? How will the sleds behave? Will our equipment meet the requirements of the situation? Have we the proper hauling power?" (Amundsen, 1912b, p. 826). This came from Astrup who saw the need "to make everything as light as possible, where we could be accomplished without sacrificing too much strength", a recognition after extensive trials with sledges of different sizes (Astrup, 1898, pp. 177–179).

Amundsen's integrated sledging system was the core strategy of his expedition. As in contemporary modern logistics and supply-chain management he included replacement parts and knowledge to maintain operations in order to prevent breakdowns (Sivakumar & Roy, 2004). Redundant parts for each "element that would serve as a 'replacement' in the event of the first element's demise, a trained understudy dog standing in the wings for each active dog," for example (Tahan, 2019, p. 19). Peary provided a detailed discussion of the basis of his success which were found in Amundsen's approach. It was a "carefully planned system ... Every thing that could be controlled ... was taken into consideration in the percentages of the probabilities provided as far as possible" (Peary, 2001, p. 201) There was a "back up;" planning recognised the need for "redundant elements." Sledges would carry only provisions guided by experienced skiers. The expedition made precise calculations for resources based on Peary's depot system for resupply (Kirwan, 1960, p. 258). Each element related to these principles "sledges, skis, sleeping-bags, and skin clothes, we had manufactured ourselves ... with materials brought from America, and were the outcome of rather extensive experience and practical trial" (Astrup, 1898, p. 177). This was the culmination of Nansen's ideas (Bain, 1897, p. 164). Amundsen provided specific details of his calculations for the South Pole noting how they were first made on paper and then verified when materials were loaded on to sledges. "This work was done with as much care as if we were counting gold in a bank vault" (Amundsen, 1927, p. 267). Scott used several almost independent haulage methods and only one experienced skier, a Norwegian at that. With irony Amundsen noted the differences: "We placed our whole trust on Eskimo [Inuit] dogs and skis, while the English, as a result of their own experience, had abandoned dogs as well as skis, but, on the other hand were well equipped with motor sleds and ponies" (Amundsen, 1912b, p. 826).

Summary and conclusion

Both Amundsen and Scott engaged in innovative practices, the former brought past haulage methods to a new level through continual innovation, the latter used spontaneous innovation in the choice of the motor sledge to support his sledging based on man haulage and ponies. Amundsen created an innovative haulage system which in spite of its success to reach the South Pole came to an abrupt end although the principle of redundancy planning remains. In contrast, motor sledges dominated Antarctic expeditions in spite of the failures of Shackleton and Scott. Both were constrained by organisational values and the naval heritage which accepted mechanical innovations such as steam engines but not to sledging. Neither engaged in the extensive research and testing which was necessary. The adhocracy model employed by

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Amundsen focused on continual learning and innovation. The irony of these two different experiences is that the one for which little research and testing failed in the early attempts became the dominant and accepted haulage system in Antarctica to the present, not ignoring the use of air haulage. The concept of continual innovation brought forward by Amundsen remains viable. Later, Amundsen fell victim to the use of aircraft in his pursuit of the North Pole. When the drift of the *Maud* towards the North Pole failed, a venture similar to Nansen's drift in the *Fram*, Amundsen reverted to aircraft; he and Lincoln Ellsworth used two Dornier flying boats starting from Spitsbergen (Amundsen & Ellsworth, 1925). This time Amundsen did not check the use of the new sun compass in advance and the expedition failed. For his next successful flight crossing the North Pole on the way from Spitsbergen to Alaska with a dirigible in 1926, Amundsen relied on the experience of its constructor the Italian Colonel Umberto Nobile and his crew (Amundsen & Ellsworth, 1927). This is the ironical twist of the story. In the end it was Amundsen who performed the development from land based dog sledging to flying in the air and who paved the way for the transition of the heroic era to modern polar research which is governed by technique (Lüdecke, 2011, pp. 198–201). He was experienced with the use of dogs and did not entertain motor sledges; they were a quantum innovation not compatible with his focused strategy. Yet later he did innovate with aircraft although that was because of the differences between Arctic and Antarctic geography.

Scott's efforts with motor sledges did not succeed as he had hoped but their presence turned the heads of those who followed. Both Amundsen and Scott engaged in innovation in order to achieve their individual goals. Individual success is less important than the contributions which have lasted. Scott stimulated attention to motor sledges in spite of their failure and Amundsen's innovations solidified the integrated planning model. Innovation is risky even when extensive research and experimentation is undertaken. It is a value which does not always guarantee success for innovators.

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