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A Conceptual Framework for Knowledge Exchange in a Wildland Fire Research and Practice Context

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A Conceptual Framework for Knowledge Exchange in a Wildland Fire Research and Practice Context

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Introduction

The location, time, size, and intensity of wildland fires are highly variable, and the impacts of these fires can be complex. Wildland fire can be beneficial, playing a role in the natural functioning of many fire adapted and fire dependent ecosystems while also reducing hazardous fuels (Coogan et al., 2021). However, wildland fire can have catastrophic outcomes for human communities, including loss of life, evacuations, and socio-economic disruptions (Johnston et al., 2020). For example, a single fire in Fort McMurray, Alberta, Canada in 2016 resulted in billions of dollars in insured losses along with considerable but unquantified impacts on families and first responders (MNP, 2017).

Fire management is critically important for reducing negative impacts of wildland fire (Cumming, 2005; Martell and Sun, 2008). It commonly focuses on suppression but often includes prevention, mitigation, and recovery (Johnston et al., 2020; OMNRF, 2014; Tymstra et al., 2020). The objectives typically emphasize protection of people, property, infrastructure, forest resources and socio-economic activity (Tymstra et al., 2020).

Fire management is very expensive. Over $1B can be spent annually on fire management in Canada (Hope et al., 2016; Stocks and Martell, 2016). Fire management is also challenging and complex, involving decision-making across a wide range of spatial and temporal scales (Boychuk et al., 2020), high uncertainty, and multiple conflicting objectives. Operational fire management must deal with relatively infrequent but critical situations of extreme and quickly changing fire behavior and workloads, dangerous working conditions, and severe resource shortages.

The growing scientific effort to understand wildland fire has helped fire management in many ways for decades (Wright, 1933; Coogan et al., 2021). This work is crucial for effective, efficient, and robust fire management (Sankey, 2018). Wildland fire science is both a body of

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knowledge[1] and a systematic process to build and organize knowledge pertaining to questions and needs of fire management. It requires an interdisciplinary approach to address the physical, ecological, natural, cultural, economic, social and management aspects of wildland fire and their interactions. Fire science work occurs across a broad range of domains, approaches, and scales. Sankey's (2018) recent blueprint for wildland fire science outlined the need for both continued and new research to further the understanding of wildland fire in Canada.

An increasingly important area for fire science knowledge is wildland fire and climate change interactions. Existing research has shown how fire management in Canada may change under a range of possible future climates. For example, forest fuels are expected to be drier and, therefore, more receptive to ignition and vigorous fire spread. These factors are expected to result in having more and larger fires that exceed limits of direct suppression (Flannigan et al., 2005; Wotton et al., 2010; Wotton et al., 2017). Studies on the effect of these changes on fire management in Ontario, Canada have shown that increases in fire occurrence and behavior compound non-linearly to an even greater proportion of escaped fires (Wotton et al., 2005), requiring an even greater number of suppression resources (Wotton and Stocks, 2006).

Notwithstanding the many successful applications of science in fire management, developing and integrating science is not straightforward, nor without difficulties. The existence of knowledge itself is not sufficient to create a change in policies and practices (Levin, 2008; Reed et al., 2014). Science knowledge cannot be easily transferred and taken up by fire management agencies without addressing multiple factors that influence integration, including the relevance, credibility, and accessibility of the science and the operational, administrative, and cultural state of agencies (Hunter et al., 2020; Levin, 2008). How science is created and integrated into these fire management decision-making processes requires a conscious

[1] **Knowledge** can be classified into explicit (for example codified) and tacit knowledge (for example has a personal quality) (Nonaka, 1994). Knowledge and knowledge creation occur over a range of domains from fundamental research to local communities (Roux et al., 2006).

understanding of how the science is most useful. Focusing solely on identifying science gaps or improving communications between *researchers*[2] and *practitioners*[3] in disciplinary silos can be somewhat effective, but is limited if not done in an interdisciplinary, informed, collaborative, and iterative way (Tedim et al., 2021). This important design task can be aided using a *knowledge exchange* (KE) framework.

Effective KE in fire management helps ensure that real-world problems are understood by researchers, the research is relevant, and the results are integrated into fire management practices. This chapter outlines a conceptual KE framework to support the creation of application-oriented science outcomes and their successful adoption into operational fire management decision-making. We provide a review of the KE literature relevant to wildland fire management. Through developing a KE framework for the fire management context, we: (1) support the implementation of science *innovations*[4] into fire management agencies and (2) identify potential barriers and facilitators to KE in this context.

Knowledge Exchange (KE)

There is no universal framework for KE. Concepts and terminology vary depending on both the domain and the focus (e.g., see Gopalakrishnan and Santoro, 2004; Graham et al., 2006; Levin, 2008; Mitton et al., 2007; Roux et al., 2006; Rushmer et al., 2019; Walsh et al., 2019). In the literature, and in everyday use, there are terms that are used interchangeably or with different meanings.

[2] A **researcher** is a person who studies a subject and carries out academic or scientific research especially in order to discover new information or reach a new understanding (for example, a fire research scientist).
[3] A **practitioner** is a person actively engaged in a discipline, or practices a profession for example, fire management staff, personnel, or managers (McGee et al., 2016).
[4] **Innovation** is the adoption of the products and related organizational, administrative or policies related to fire management agencies (adapted from Damanpour and Gopalakrishnan, 1998). In this way innovation is viewed as an outcome of knowledge exchange. Adoption is synonymous with implementation and integration.

We define KE as: (1) the collective overarching process where knowledge is collaboratively created, shared, and transformed as it is shared; and (2) the context in which people learn about new knowledge (Lavis et al., 2003; Reed et al., 2014; Roux et al., 2006). KE implies feedback within a network of researchers, intermediaries, and practitioners (Davis et al., 2013). Other similar terms have been used in the literature and are elaborated further in the cited references. These terms include knowledge translation (Straus et al., 2009); knowledge mobilization (Levin, 2008); knowledge transfer (Gilbert and Cordey-Hayes, 1996); and knowledge translation and exchange (Boyko et al., 2012).

KE has been described as a system where reciprocal learning to discover, create, or address something with mutual understanding and benefit can occur (Reed et al., 2014; Rushmer et al., 2019). Through this understanding of KE, outcomes tend to be more realistic, acceptable, and likely to produce more lasting change (Rushmer et al., 2019).

It is crucially important to emphasize that we consider KE systems as an iterative process with bi-directional flows (Davis et al., 2013; Reed et al., 2014) where researchers and practitioners are both knowledge producers and users. This contrasts with typical historical practice where researchers push and practitioners pull knowledge between the two groups. Based on our experience, we believe those one-way knowledge streams from producers to users have proven insufficient in the wildland fire community; rather, shared understanding and concerted efforts to create and diffuse knowledge are needed (Butler et al., 2017; Tedim et al., 2021). Early and continuous knowledge flow between the practitioners and researchers has been shown to be an essential approach for KE in wildland fire. For example, Woolford et al. (2021) note how instrumental this type of knowledge flow was in development and implementation of a province-wide, fine scale, spatially explicit human-caused wildland fire occurrence mode for Ontario, Canada.

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KE is a complex non-linear process, with interactions between sub-systems (Davis et al., 2013; Graham et al., 2006); KE can be conceptualized as a network or web. This is illustrated in Figure 1, which is an example with several networks of researchers or research groups and practitioners or practitioner groups in different domains, all working to identify and address a specific wildland fire management problem.

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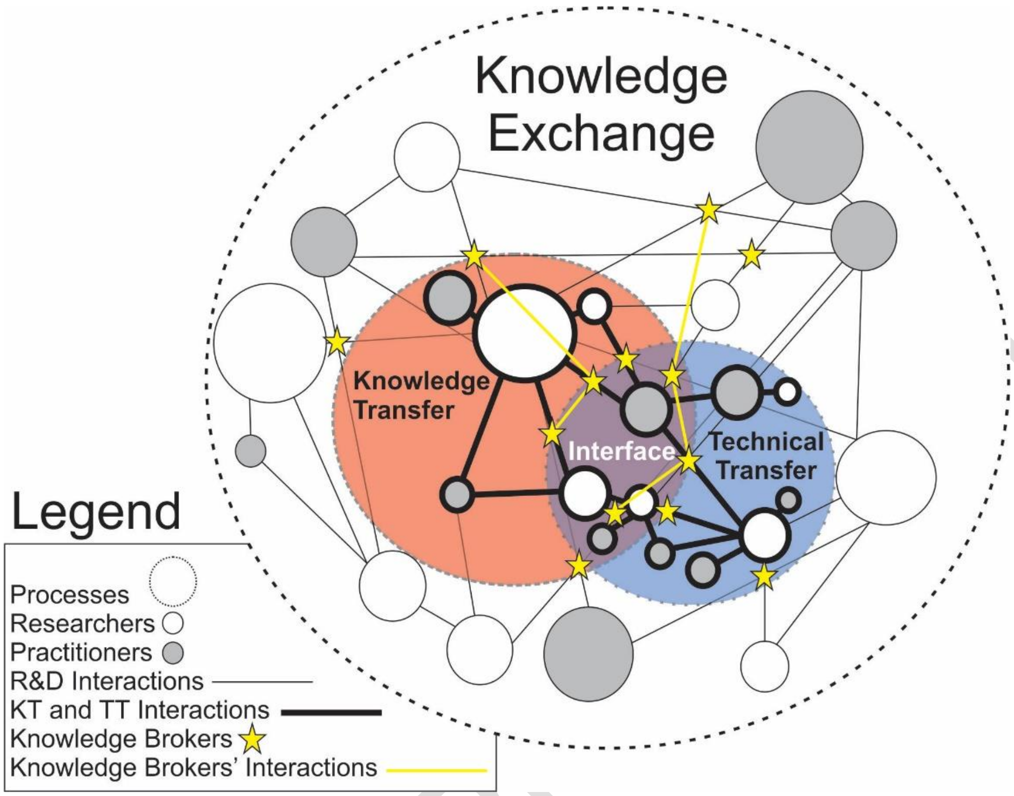

Figure 1. Conceptual illustration of knowledge exchange (KE) and its Knowledge Transfer (KT) and Technical Transfer (TT) sub-processes for a specific, hypothetical case of science research and development (R&D) and integration. KE is an overarching process among researchers and practitioners. The sizes of the researchers' and practitioners' circles represent their respective levels of expertise for this specific case. The black lines represent connections among people during the R&D and integration (KT, TT) work. The thick circles identify the people involved in the KT and TT sub-processes. The thick black lines represent connections between people for the KT and TT work. The yellow stars represent knowledge brokers, who facilitate connections among various people and groups. The yellow lines represent connections between knowledge brokers. The interface of KT and TT represents the interactions between researchers and practitioners that seek to increase their respective and mutual understanding. Defined boundaries are shown for the interface between KT and TT, but the actual boundaries are a fuzzy continuum.

Once an applied outcome becomes clearer, the efforts transition to *knowledge*[5] *and technical transfer*[6] processes. *Knowledge brokers*[7] facilitate this exchange at all stages, facilitating collaboration and bridging knowledge between researchers, practitioners and facilitating collaboration. The interface between knowledge and technical transfer conceptually has the highest concentration of knowledge brokers because this is where 'the water hits the fire' so to speak and innovation and implementation take place. The outcome of KE in this context is some evidence-informed application of science aimed at achieving a specific outcome for fire management policies or practices.

Gopalakrishnan and Santoro (2004) proposed that knowledge and technology transfer are different in scope and facilitated by different organizational factors. Knowledge transfer is broader and concerned with the 'why,' whereas technology transfer is more focused on the tools. We contend that these two sub-processes of KE work together in many cases, especially in novel or unfamiliar situations. The attributes and activities needed to carry out knowledge transfer or technology transfer are like those needed for KE in general. Reed et al. (2014) identified five directives to guide KE in environmental management: 1) design, 2) engage, 3) represent, 4) impact, and 5) reflect and sustain. Many of these principles included consideration

[5] **Knowledge transfer** is a sub-process of KE for disseminating broader learning aimed at changes in strategic thinking, culture and providing inputs to decision-making (Gopalakrishnan and Santoro 2004). This embodies the underlying principles which may include considering aspects such as organizational design and culture. This is a systematic approach to collect and share knowledge so ideas, research results and skills enable innovative new products to be developed (Graham et al., 2006).

[6] **Technical Transfer** is a sub-process of KE for disseminating knowledge with a more narrow-in-focus than knowledge transfer and aimed at processes, products, tools, data or models (Gopalakrishnan and Santoro 2004). This may include considering aspects such as policy, procedures for acquisition, application and archive of information (Zimmerman, 2012).

[7] **Knowledge brokers** (data translators; opinion leaders, boundary organizations) are the intermediaries between the knowledge producers and those who use it. They are the human force behind finding, assessing and interpreting evidence, facilitating interaction and identifying emerging research questions (Nonaka, 1994; Nutley et al., 2007; Ward et al., 2009). Knowledge brokers may be specialized to certain domains such as a data translators who bridge the expertise gaps between technical teams in data science (Maynard-Atem and Ludford, 2020). Knowledge brokers may also be opinion leaders who are trusted information sources (Butler et al., 2017). There are also boundary organizations which are coordinated groups that are intermediaries that develop long-term relationships and collaboration to increase the impact of science in fire management (Hunter et al., 2020).

that would be useful to knowledge transfer or technology transfer; for example, well-timed implementation and creating networks suitable to the scope of the transfer.

A critical characteristic of KE is mutual benefit. This place where mutual understanding, communications, sharing, and knowledge creation occurs is called the knowledge interface (Roux et al., 2006). Loosely described, the *knowledge and technical interface*[8] is the place for collaboration – a critical aspect of KE. Roux et al. (2006) further describe the values of shared understanding, where participants move beyond the typical role of knowledge producer and user and negotiate what is achievable and relevant. This interface (or collaboration) provides for a robustness based on trust and aligned incentive systems.

Knowledge, Researchers and Practitioners

Research is investigation in a planned and systematic fashion for the purpose of increasing the sum of knowledge (Nutley et al., 2007), typically done by a researcher or research team. Within a fire management agency context, a *community of practice* can refer to those who manage an aspect of fire, such as a cadre of Fire Behaviour Analysts or firefighters. We can refer to these people as practitioners, as suggested by McGee et al. (2016). The creation and holding of knowledge occur across five generalized domains, which have different degrees of the explicitness of knowledge. Table 1 summarizes this continuum with examples pertaining to fire behaviour. Although presented as distinct and separate, we recognize the boundaries between knowledge domains are fuzzy, and there are individuals whose expertise span multiple domains (such as a researcher who is also a practitioner). We also recognize that

[8] **Knowledge and technical interface** is where concerted bi-directional flow of collaborative learning, shared understanding of key concepts and co-evolution towards common purpose, intent and action takes place (Roux et al., 2006). We contend this is where tacit and explicit knowledge exchange can be the most impactful and therefore important for the positioning of knowledge brokers.

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knowledge comes in many forms from *Indigenous Knowledge*[9] to experiential and operational knowledge (Tedum et al., 2021).

The knowledge being exchanged can range from more formal knowledge, known as "explicit knowledge", to knowledge that is more subjective and based on ideas, perceptions, or experience, known as "tacit knowledge" (Bolisani and Scarso, 1999). Explicit knowledge is more easily expressed and codified, whereas tacit knowledge is more subtle and often difficult to convey. The assumption is that shared contexts and understanding in respective knowledge domains results in arguably better outcomes for both parties (Rushmer et al., 2019). This facilitates acceptance, sustained use, and growth of the knowledge (Roux et al., 2006).

Table 1. Examples of wildland fire knowledge domains

More theoretically based ⟵			**⟶ More applied and experientially based**	
Fundamental research	Applied research	Policy and strategy development	Operational management	Indigenous Knowledge
Physical fire processes	Fire weather and behaviour system development	Risk mitigation policy	Best practices to assess and reduce hazards such as fuel loading	Cultural burning practices for ecological sustainability
Fire ignition processes	Fire occurrence system development	Preparedness policy	General rules for fire occurrence	Place-based knowledge of fire occurrence and cultural fire management
More codified ⟵				**⟶ More tacit**

[9] **Indigenous Knowledge.** It is important to recognize that the knowledge systems described here are derived from Western perspectives. Authors acknowledge the value of Indigenous and traditional ways of knowing and of knowledge exchange that are not represented in this paper. Indigenous ways of knowing celebrate the intimate connections between humans and the biophysical world. Fire has been used as an important tool for Indigenous Peoples for a variety of reasons, including in hunting and gathering activities, to regenerate land and safeguard resources, for cooking, heating, and ceremony, and for communication (McKemey et al., 2021). Indigenous Peoples hold important place-based knowledge about fire and fire management and have played a key role in wildland fire management through time.

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The Role of Knowledge Exchange from Problem Identification to Implementation

Having established context and elements of KE as an overarching system, the focus turns to the sub-processes that bridge knowledge creation through to implementation. Graham et al. (2006) visualized this as a cycle. We build on these ideas (Figure 2) and place the cycle in a fire management context. It is important first to note that knowledge and technical transfer occur at varying times and with varying complexity in the journey from problem identification through knowledge creation to implementation.

How does KE happen? These processes are aided by knowledge brokers to encourage and facilitate positive interactions at the knowledge interface (as visualized conceptually in Figure 1). It starts with having the right people in that knowledge interface space who recognize a problem or research need. The remainder of this section describes the system and processes underlying KE are illustrated in Figure 2. We describe the application of KE to wildland fire management, although the system and process are more widely applicable.

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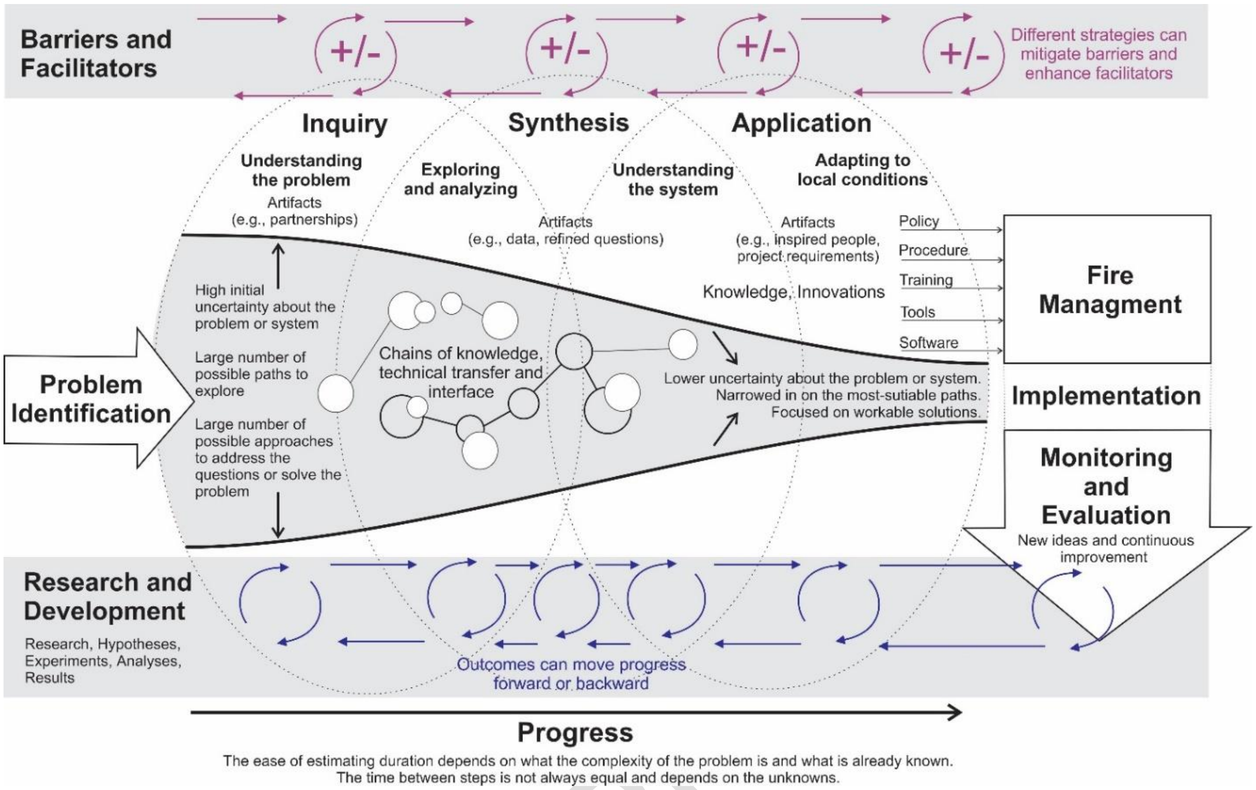

Figure 2. Illustration of the systems and processes of knowledge exchange towards addressing problems and advancing innovation for fire management.

Problem Identification

There is not a single person, group, or path to achieve science-informed policies and practices for fire management; however, a key requirement for effective and efficient development of relevant, practical, and useful science is to have some individuals who have deep expertise in both science and fire management. This is essential for (1) understanding problems correctly and identifying opportunities where currently feasible research may help, and (2) ensuring effective communication among people from different domains. Problem identification spans domains and can be facilitated through different avenues; examples include formal collaboration agreements, memorandum of understandings, and informal professional relationships and participation.

The process

Once a problem or research need has been identified, work can commence to address it. This process is illustrated by a funnel that starts wide and becomes narrow over time. The funnel width represents the relative uncertainty and complexity to address the problem. There are many possible paths and approaches (for example, knowledge domains and methods). Technical transfer and interfacing with varying degrees of complexity happen between groups throughout this process. The funnel narrows with progress as uncertainty is reduced through knowledge creation and access; the most-suitable path becomes more apparent and the focus changes to workable solutions. Along this funnel there are the interacting phases of 1) inquiry, 2) synthesis and 3) application (Graham et al., 2006). These phases interact, have fuzzy boundaries, and overlap depending on specific situations as illustrated using hashed lines in Figure 2.

Inquiry

The inquiry phase is characterized by the many options available and by exploration, uncertainty, creation of desired or necessary skillsets, and building partnerships. Process artifacts of this phase may include partnerships, agreements, brainstorming, and exploratory data.

Synthesis

As progress continues to the synthesis phase, the focus shifts to making sense of the relevant knowledge leading to a general understanding of the problem and system. Artifacts of this phase may include data, refined questions, and discrete work. As clarity improves, and more workable outcomes are produced, the focus moves to the application phase.

Application

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In this phase, some innovation or knowledge is suitable for application in fire management. There may be efforts to adapt outcomes to local conditions for a variety of potential audiences or purposes across the fire management field. Artifacts in this stage include inspired people, codified knowledge, requirements for other implementation processes, a new or amended policy, an improved procedure, a new tool, or prototype software.

The fire management decision-making space is complex (Boychuk et al., 2020; Taylor et al., 2013; Taylor, 2020; Thompson and Calkin, 2011; Zimmerman, 2012). In addition, fire management is very user focused. The specifics of how a new idea or product is developed should be aligned to the end user needs and the decision-making environment (Lavis et al., 2003). This is not always straightforward because there are many complex challenges for fire management that occur at different scales and scopes, from real-time decisions on a single fire to longer-term, national-level policy setting (Taylor, 2017; Tymstra et al., 2020).

Successful application requires the effective interaction between researchers and practitioners for translation, support, and delivery of the necessary knowledge (McGee et al., 2016; Mitton et al., 2007; Ryan and Cerveny, 2011). Within the wildland fire community, early and ongoing close engagement between researchers and practitioners is critical to successful decision support system development and implementation because of the need for shared understanding (Martell, 2011; Noble and Paveglio, 2020; Woolford et al., 2021).

Implementation

The implementation often requires a tailored solution. There are specific ways that the outcomes of the KE process can be implemented, such as a policy review cycle, procedure task team, or project plan. However, given the context of the public sector where most fire management agencies in Canada are positioned (Canadian Interagency Forest Fire Centre, 2022), innovation is often challenging because it can be seen as unknown in an organizational structure that discourages risk (OECD 2017). Adoption by practitioners through passive dissemination can sometimes be ineffective (Ward et al., 2009). We view knowledge and technical transfer as a sub-process as distinct from project planning or software development methods. The latter are commonly used as mechanisms to manage the creation of initially relatively well-defined projects or products such as training courses or software (e.g., Varajão et al., 2017). Project planning approaches are appropriate for the application phase of Figure 2 when the when problem and solution are well understood. It is very important to understand which implementation method is needed based on the fire management agency institutional requirement. After implementation, monitoring and continued evaluation should occur and may result in new ideas for future work. This is a practice of continuous improvement.

Processes of Progression and Retrogression

There are two parallel considerations that are pervasive throughout KE and influence progress at all phases. These are (1) the research and development process and (2) barriers and facilitators (BF). These are illustrated above and below the funnel in Figure 2.

Research and Development Cycle

The research and development process includes exploration, discovery, trial and error, hypothesis testing, confirmation, prototyping, and field testing. This necessarily involves advancing and retreating as tentative results emerge. This cycling tends to occur earlier but can happen at any point. This moves us forward and back in the funnel in larger or smaller steps.

Barriers and Facilitators

Identifying and understanding the significance of barriers to and facilitators of progress are critical within fire management agencies This is true for both KE, where the focus is between researchers and practitioners, and knowledge and technical transfer, where the focus is on the needs of the adopter. Other areas such as health sciences and conservation are further along with KE research and the identification of BFs (Mitton et al., 2007; Walsh et al., 2019). and recently conversations associated with KE have arisen in the wildland fire management literature (Hunter et al., 2020; Tedim et al., 2021).

There are many potential categories of BFs, and we need a tractable way to understand them. We compared BFs identified from wildland fire science centric KE papers (Davis et al., 2013; McGee et al., 2016; Ryan and Cerveny, 2011) and three recent perspectives on the adoption of wildland fire decision support (Martell, 2011; Noble and Paveglio, 2020; Rapp et al., 2020). We organized the comparison using a framework that was adapted from the summary by Mitton et al. (2007) wherein BFs were classified for policy decision-making for health studies. Figure 3 is a summary of the BFs pulled and organized from the six wildland fire papers and organized by the themes from Mitton et al. (2007). The nine themes of BFs are capacity, clear objectives and alignment, collaboration and networking, communication, ownership and authority, readiness for innovation, research motivation, timing, and trust. BFs identified by the majority of authors (at least 3 of 6 papers noted above) include: limited time to make decisions; collaborative research partnerships; networks (user relationships); culture and degree of collaboration; suitability for task; sufficient resources (money, technology); provision of support and training; attitude towards change; collaborative research partnerships; face-to-face exchanges, in person support; tailored to a specific audience; and workshop engagement; knowledge sharing between researchers and practitioners.

Strategies are required to mitigate the barriers and enhance the performance of facilitators. Specific strategies must align with types of decisions practitioners face and the environments in which they work. This requires an understanding of the both the organization and the people within it.

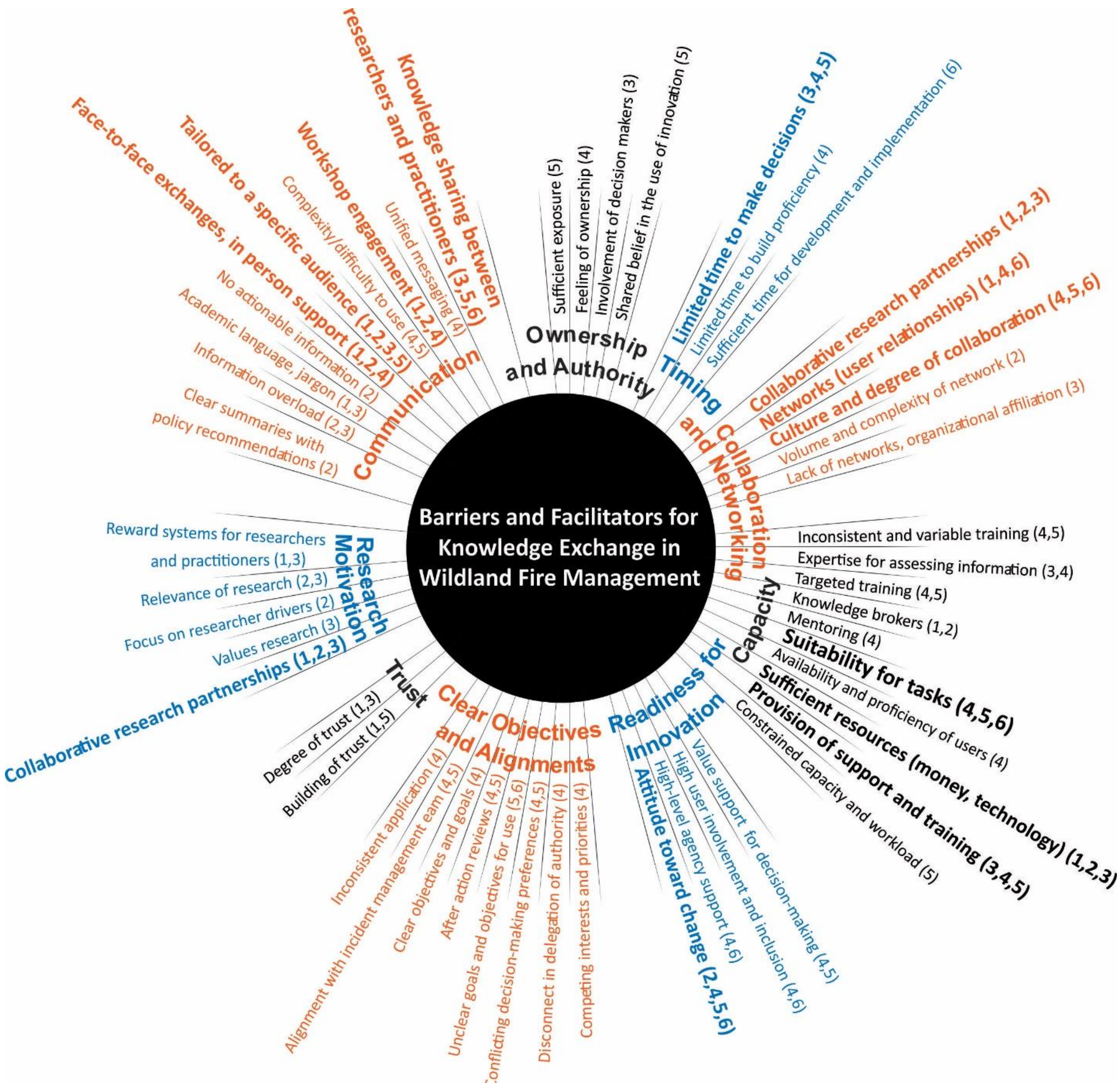

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Figure 3. Barriers and facilitators (BFs) for knowledge exchange in wildland fire management. Nine central themes for the barriers and facilitators were identified in selected literature. Each BF identified in the literature is listed under a specific theme. BF that were in at least half (≥3) of the papers are shown in a bold and larger font. The BFs identified in the papers are numbered as follows: (1) McGee et al. 2016; (2) Davis et al. 2013; (3) Ryan and Cerveny, 2011; (4) Noble and Paveglio 2020; (5) Rapp et al, 2020; (6) Martell 2011. Papers from the literature were selected from two general scopes: papers 1-3 describe knowledge exchange (researcher and practitioner); and papers 4-6 discuss knowledge and technical transfer (innovation and adopters).

Training the Next Generation in Knowledge Exchange

The overarching principle of KE as a mutual exchange between researchers and practitioners is perhaps best learned through experience. In the classroom, this can be achieved using active learning techniques, which have been found to lead to a deeper understanding when compared to traditional lecturing (Waldrop, 2015). This holds true in the data science domain—the importance of active learning techniques was endorsed by the statistical science community in the American Statistical Association's (ASA) Guidelines for Assessment and Instruction in Statistics Education (GAISE) College Report (GAISE, 2016).

We have explored the KE principles outlined in this chapter using an active learning approach in the context of a post-secondary course, "Data Analytics Consulting", which is taught in the Department of Statistical and Actuarial Sciences at the University of Western Ontario (https://www.uwo.ca/stats/). This course is offered to 4th-year students in the honours Statistical or Data Science undergraduate programs and graduate students (Masters and PhD) in that department, as well as graduate students pursuing the Master of Data Analytics program, a one-year professional science master's program.

Although those students will have received advanced training in data science and analytics theory, techniques, and applications through data modelling, nearly all their preceding training would have been technical in nature. Consequently, rather than teaching new data modelling theory or techniques, the course's learning objectives focus on fostering the development of key skills to be a successful data science and analytics professional. A variety of topics are covered, such as: the iterative flow through the data analytics consulting process; meetings and project management; intellectual property, compensation, and negotiation; robust and ethical data analyses. These are all grounded in the development of effective communication skills, needed for KE, which is threaded throughout the course content and its assessments.

Active learning is incorporated through a community engaged learning approach, where an external "client" (not the instructor or a teaching assistant) interacts with the class throughout the term. Students are grouped into teams and, through a series of interactions with the client that take place over the course of the term, they practice and develop their KE skills. Those interactions mimic typical engagement settings, including synchronous and asynchronous learning opportunities. Examples of synchronous engagement include an initial meeting, phone/video meetings, interim presentation(s) and discussions, as well as an in-person meeting (when feasible). Asynchronous activities include communicating via email, providing, and receiving feedback on interim progress report(s). In all such interactions, the instructor acts as a knowledge broker, facilitating interactions between the students and the client while also having separate interactions with the client to help guide the KE process. A final report to the client, written in appropriate format and language for that target audience is used as a final summative assessment. All of this occurs using a directed learning approach where both the client and the instructor act as knowledge brokers to guide the students through this process. Informal peer assessments are also included for some engagement pieces so that the students can observed and learn from their fellow classmates while also providing constructive criticism. A sample schedule of activities for a 4-month term appears in Table 2.

In essence, this active learning using a community engaged learning approach for the Data Analytics Consulting course both teaches and applies KE principles. The classroom is a place for knowledge interface where fire management practitioners (one of the clients for the past few years) data scientist and the students interact for mutual benefit. The students learn from the practitioners about their domain and gain a deeper understanding of the meaning of the data . The practitioners learn new ways data can be informative in their business. These interactions lead to better understanding, new initiatives, and importantly inspired people, improving both the fire practitioner's knowledge of data science and its application and the student's knowledge of fire management.

Table 2. Sample schedule of knowledge exchange activities in the Data Analytics Consulting class

Week(s)	Topic	Activities
1	Initial meeting (virtual) and problem description	Web presentation by client
2	Data, data governance and project overview	Data sharing agreements signed Data Released Teams identified
3	Exploratory data analysis presentations and discussion	5 min presentations by each team Planning for next touchpoint with client
4	Client meeting (virtual)	Remote synchronous meeting to discuss results of exploratory data analysis and ask any questions
5	Preliminary modelling	Planning for client's visit the following week
6	Client meetings (in person)	Teams present and discuss summaries of work to date with client. Debriefing after meetings, led by instructor with peer discussions and feedback.
7 - 13	Ongoing project work and client engagement	Team presentations Class discussions with peer feedback. Client meetings (virtual; approx. bi-weekly) Final presentations
14 - 16	Community engaged learning project ends	Final written reports submitted Client provides feedback, which is incorporated into each team's grade

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This is one approach that can help meet that bi-directional flow of KE while also recognizing in the academic environment there is a need to develop those communication, business, and soft skills to become a knowledge broker. That is, to become an effective data translator, working in the wildland fire science and management domain. The outcomes of these efforts were presented at Wildland Fire Canada 2019, which is part of a biennial series of conferences (https://wildlandfirecanada.com/) that bring together a wide variety of people working in wildland fire, both fire management practitioners and wildland fire science researchers.

Finally, it is important to note that similar approaches can be applied to effectively train students outside of a classroom setting when they are conducting thesis-based research guided by a supervisor. In this context, regular engagement between the student, other researchers, and practitioners is crucial to foster the development of effective KE skills. Supervisors can act as knowledge brokers, encouraging the student to not only attend and participate in such interactions, but to also have them witness the interactions of other trainees in the research lab to learn from their peers. These interactions also help the trainees expand their professional network.

Closing

Fire management is challenging and will become even more so in future. Globally, a large and growing amount of wildland fire science work is being done to aid fire management. The integration of ongoing advances remains difficult and occurs slowly, which can leave fire management understanding and practices short of the best available science and necessary innovation. Research efforts continue to fall short of effective implementation and typically end with traditional, impersonal approaches such as publications and reports (Levin, 2008). This

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issue is not exclusive to fire management; many studies have identified barriers in the public service's use of research (Nutley et al., 2007).

Ultimately, people and relationships are a crucial vehicle for overcoming barriers to successfully integrating science into practice. KE is not about processes and checklists. People are at the heart of KE, and effective KE depends on networks of diverse people and teams in which individuals can play one or more roles. These individuals need not only technical skills, but also creativity and soft social skills (OECD, 2017). It takes significant effort on the part of agencies to engender and successfully integrate new science into operational fire management practices and decision-making. Similarly, it takes extra effort for researchers to maintain strong working relationships with practitioners. Our repeated experience suggests that these efforts are exceptionally beneficial for fire management and rewarding for all concerned.

While fire management agencies have practiced some elements of KE for years, adoption of holistic KE thinking is relatively recent and continues to improve. There is no single, authoritative KE system and process. In this chapter, we attempted to organize KE components into a framework to support the implementation of science innovations in the wildland fire management context; although, the framework offers value to other contexts. Our ongoing KE work involves developing more detailed, practical guidance for KE and application of KE for fire management innovations.

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