Article:

Thumbumrung, T., Vasconcelos, A. and Cox, A. (2022) Complexity and evolution of knowledge boundaries in an interdisciplinary research project. Knowledge and Process Management, 29 (3). pp. 296-306. ISSN 1092-4604

https://doi.org/10.1002/kpm.1727

Received: 18 December 2020 | Accepted: 7 July 2022
DOI: 10.1002/kpm.1727

RESEARCH ARTICLE

WILEY

Complexity and evolution of knowledge boundaries in an interdisciplinary research project

Titima Thumbumrung[1] | Ana Vasconcelos[2] | Andrew Cox[2]

[1]Science and Technology Knowledge Services, National Science and Technology Development Agency, Pathum Thani, Thailand

[2]Information School, University of Sheffield, Sheffield, UK

Correspondence
Ana Vasconcelos, Information School, University of Sheffield, UK.
Email: a.c.vasconcelos@sheffield.ac.uk

Abstract

This paper aims to understand how and why knowledge boundaries occur, change, and evolve throughout the life-cycle of interdisciplinary research projects, how they are experienced by different actors, and what strategies they deploy to overcome these boundaries. The study took a case study approach focusing on an interdisciplinary research project for the development of computerised tomography and digital X-ray scanners in a governmental research organisation in Thailand. A multi-method qualitative approach, involving semi-structured interviews, participative observation, and artefact and document analysis, was adopted. Data was analysed through thematic analysis. The findings suggest that knowledge management is more complex and difficult than portrayed in previous studies because of the following: (1) knowledge boundaries evolve and exhibit different emphases at distinct stages of the project; (2) boundaries do not stem only from differences in knowledge across different organisational actors, but, equally importantly, due to the lack of awareness that these differences exist; (3) different organisational actors experience diverse types of knowledge boundary types when faced within the same situation; and (4) context, in terms of external pressures driving the project and influencing its direction, plays an important role in boundary construction and boundary-spanning mechanisms. This paper presents a novel framework for conceptualising how and why knowledge boundaries evolve throughout an interdisciplinary research project, how these changes are experienced by different participating actors, and what boundary-spanning mechanisms for bridging them are developed by them. It demonstrates that these changes are often shaped by external drivers that shape the development of the project.

1 | INTRODUCTION

Most societies are faced with complex, dynamic, and interconnected challenges which cannot be solved by a single actor, organisation, or discipline (Bronstein, 2003). The integration of perspectives from different disciplines is required to develop a fuller understanding of these challenges and to develop more comprehensive solutions to cope with them (Bronstein, 2003; Cummings & Kiesler, 2005). Consequently, research policies and funding structures have been developed to support interdisciplinary collaboration both inside and outside academia (Noorden, 2015). However, cross-community collaboration is difficult because disciplines have fundamentally different knowledge bases and perceptions, which create discontinuities and boundaries in collaboration (Carlile, 2004; Hislop, 2013; Kotlarsky et al., 2015;

Lindberg et al., 2017; Rosenlund et al., 2017; Smith, 2016; Wenger, 2000).

Carlile (2002, 2004) developed an influential three-tier model for managing knowledge across boundaries. According to Carlile's model, variations in degrees of difference, dependency, and novelty in knowledge between diverse knowledge communities create three progressively more complex knowledge boundaries: syntactic, semantic, and pragmatic boundaries. Empirical studies have shown that Carlile's model provides useful insights into how knowledge is managed across boundaries and why this is difficult (e.g. Edenius et al., 2010; Kotlarsky et al., 2015; Maaninen-Olsson et al., 2008; Smith, 2016). However, recent work suggests that there is more to discover about the dynamics of knowledge boundaries, particularly in diverse contexts marked by fluidity and change (Edmondson & Harvey, 2018; Kellogg et al., 2006; Le Dain & Merminod, 2014; Lifshitz-Assaf, 2018; Lindberg et al., 2017; Smith, 2016). These studies found that knowledge boundaries are more dynamic and fluid than originally conceptualised, exhibiting blurred lines between them, and often co-occurring. This raises the need to understand how and why knowledge boundaries may change and whether they may be experienced and managed differently by diverse actors, suggesting the need to adopt a multi-actor perspective in the study of boundaries.

In this context, this paper explores how knowledge boundaries occur and may change in the context of an interdisciplinary research project. It aims to understand the contextual aspects that give rise to and inform the evolution of boundaries in dynamic situations, how this is experienced differently by multiple actors and what strategies they develop as a response.

2 | KNOWLEDGE BOUNDARIES AND CROSS-BOUNDARY COLLABORATION

There is no universally accepted definition of a knowledge boundary. Boundaries, in the context of this study, are understood as social intersections and sociocultural differences between different actors leading to a discontinuity in the interaction between them (Akkerman & Bakker, 2011). Boundaries are conceptualised as arising between individuals or groups (Wenger, 2000). Boundaries are fluid, changeable, and invisible (Paraponaris & Sigal, 2015; Wenger, 2000). Different disciplines exhibit differences in traditions and cultures of thought, assumptions, values, interests, interpretations, conceptual and methodological standards, and use of language (Akkerman & Bakker, 2011; Becher, 1994; Cummings & Kiesler, 2005; Siedlok & Hibbert, 2014; Wenger, 2000). Such differences create knowledge boundaries (Bozeman et al., 2016; Carlile, 2002, 2004; Siedlok & Hibbert, 2014).

Boundary spanning is the establishment of continuity and interaction across different contexts and practices. Interdisciplinary boundary spanning can be understood as the establishment of continuity and interactions as well as combining and, in some cases, integrating concepts, methods, and theories drawn from different disciplines (Akkerman & Bakker, 2011; Bechky, 2003; Wenger, 2000).

In theorising knowledge boundaries and boundary spanning, Carlile's (2002, 2004) work has been seminal. It integrates three primary perspectives in the organisational literature on knowledge management and cross-boundary collaboration: information processing perspectives, cultural perspectives, and political perspectives (Kellogg et al., 2006). It identifies three properties of knowledge at a boundary: difference (in the type and amount of knowledge accumulated), dependency (between two entities that must take each other into account for meeting their common goals), and novelty (inability to draw upon existing knowledge in assimilating or developing new knowledge). Different levels of these knowledge properties create three progressively more complex knowledge boundaries: namely syntactic, semantic, and pragmatic boundaries, each requiring different processes to overcome them: knowledge transfer, knowledge translation, and knowledge transformation.

At a syntactic boundary, knowledge is low in difference, dependency, and novelty between members from different backgrounds. Knowledge is perceived as an entity; it is explicit and capable of being codified, captured, stored, retrieved, and transferred across different contexts. The development of a common language or lexicon is sufficient to transfer knowledge at a boundary. Thus, this boundary is primarily concerned with knowledge transfer processes through information processing capacity, taxonomies, and storage and retrieval technologies. A semantic boundary occurs when members of different communities interpret the same situations differently. Thus, a semantic boundary is mainly concerned with knowledge translation processes. It requires knowledge translation capability, cross-functional interactions, co-location of working, boundary brokers, translators, and boundary objects (Star & Griesemer, 1989; Wenger, 2000) to reconcile discrepancies in interpretation and to develop shared understandings between different communities. A pragmatic boundary occurs when the interests of different communities are different and in conflict. To overcome a pragmatic boundary, individuals in one or more communities must transform and adapt knowledge used by a different community, and generate new knowledge to resolve the friction that arises at the boundary in order to work together. To do this, negotiation and political drivers for knowledge transformation processes are required.

Carlile's work was developed in the context of new product development in private sector organisations. A number of scholars have adopted Carlile's three-tier model to study knowledge management across boundaries in particular contexts such as new product development in research collaborations between academia, industry, and government in the areas of environmental science and technology (Rosenlund et al., 2017), energy and domestic appliance companies (Le Dain & Merminod, 2014), the development of dynamic virtual spaces or online communities (Farag et al., 2011), an emergency response organisation (Yates & Paquette, 2011), a technology company (Maaninen-Olsson et al., 2008), healthcare research institutes and healthcare services (Edenius et al., 2010; Kotlarsky et al., 2015; Maaninen-Olsson et al., 2008), a multinational bank (Feng et al., 2010), and engineering construction projects (Fellows & Liu, 2012). The major findings of these studies were in line with Carlile in identifying three types of knowledge boundaries that can arise in interactions between members from different knowledge communities. Other authors have labelled knowledge boundaries differently, albeit referring to similar concepts to Carlile's boundary types (2002, 2004). The three types of boundary have been labelled display, representation, and assembly practices by Kellogg et al. (2006); and information process-oriented, cultural, and political boundaries by Rosenlund et al. (2017). In this paper, Carlile's labels are replaced by the more immediately understandable terms of information-processing, interpretative, and political boundaries.

Some scholars have proposed extensions and changes to Carlile's model. Kellogg et al. (2006), for instance, argued that cross-boundary collaboration is a temporary, ongoing, and dynamic phenomenon. Attempts to develop common terminology, meanings, and understandings, as well as boundary-spanning mechanisms, are often too difficult in fluid and rapidly changing contexts. Further, Le Dain and Merminod (2014) studied knowledge sharing in product development involving different client and supplier collaboration configurations. They argued that the model needs to consider the relative intensity of each boundary and related knowledge processes within these different configurations. Similarly, Smith (2016) and Lindberg et al. (2017) argued that the processes of boundary work are dynamic, whereby different types of knowledge boundaries co-exist at the same time, and within the same context. Smith (2016) suggested that Carlile's model implies a hierarchy among knowledge boundaries moving from a low level of complexity to high levels of novelty, in a linear fashion and that only one type of knowledge boundary is experienced at one time. She offers a more granular and detailed typology of boundaries and proposes that multiple knowledge boundaries may co-exist in a project, either continually or simultaneously, and that boundaries are relational.

Previous studies in knowledge boundaries and in knowledge transfer across boundaries have often focused on particular contexts, especially new product development in private sector contexts (e.g., Bechky, 2003; Carlile, 2004; Edenius et al., 2010; Le Dain & Merminod, 2014; Zhang & Pastel, 2015). There is a comparative lack of studies on the nature of knowledge boundaries and of the challenges of boundary in public sector interdisciplinary research. Concepts and models that have been developed in private sector contexts may require adaptation to understand the specific challenges of public sector interdisciplinary research. The focus of this paper is a public sector R&D organisation. Public sector R&D organisations have some unique characteristics leading to specific challenges relating to boundary spanning as they face tensions arising from the different environments they bridge. Firstly, they have a commitment towards public the good and the advancement of society (Bark et al., 2016; Hall et al., 2006; Rosenlund et al., 2017). Public- and policy-driven research is a typical focus for the organisations (Bark et al., 2016). Secondly, a major source of funding for the organisations is government (Jin & Sun, 2010). Therefore, the goals of such organisations must respond to government and public policy requirements. However, more recently public R&D organisations have been increasingly forced to respond to external market forces to cope with decreased public funds and to collaborate with the private sector. Consequently, they have a quasi-market-oriented organisation (Coccia & Rolfo, 2009).

The above points mean that public sector R&D organisations often exhibit a hybrid nature. That is, they operate at the intersection between science and society, and between private agencies and government bureaucracies. In the science and society dimension, they reflect tensions between academic and civil service cultures. In the private and public dimensions, they need to have a close relationship to their users in the private sector as well as having a need to retain characteristics of public service organisations to maintain access to public funds and tax regimes. They must balance norms and values arising from the different cultures of the hybrid dimensions: the academic, industrial, bureaucratic, and civil cultures (Coccia & Rolfo, 2009). Furthermore, such organisations must operate with openness, transparency, and accountability in all research activities (Coccia & Rolfo, 2009; Hall et al., 2006; Rosenlund et al., 2017). These tensions, arising from the hybrid nature of these organisations, create specific challenges that inform the development of interdisciplinary research projects, the nature and dynamics of knowledge boundaries that arise as projects evolve, and the boundary spanning processes that are deployed to bridge them.

The above studies suggest that there is a need to further understand the dynamics of knowledge boundaries and of cross-boundary collaboration in interdisciplinary research. If boundaries are fluid and dynamic, it is important to understand how and why they evolve as projects develop. The proposition that different types of configurations in collaboration lead to differences in boundary intensity suggests this could also manifest itself in different project stages. If multiple boundaries co-exist and are at play simultaneously, they may be experienced diversely by different actors, and therefore we need to understand their different perspectives, as well as the different strategies they deploy to resolve boundary issues. The added layer of complexity involving the tensions arising from the hybrid nature of public sector interdisciplinary research is a further area that lacks exploration. This paper aims to offer a conceptualisation of these complexities and processes taking into account the multiple perspectives that different organisational actors hold over them.

3 | A CASE STUDY OF COMPLEX KNOWLEDGE BOUNDARIES IN INTERDISCIPLINARY RESEARCH

3.1 | Methodology

This study adopted a case study strategy and an interpretive qualitative research approach. The case was an interdisciplinary research project: the development of computerised tomography (CT) and digital X-ray scanners (DR) in a governmental research organisation, the National Science and Technology Development Agency (NSTDA), under the Ministry of Science and Technology in Thailand. It was an ongoing joint project between two groups from different disciplines, with different functions, and from different organisations under

NSTDA: the software group from the National Electronics and Computer Technology Center (NECTEC) and the hardware group from the National Metal and Materials Technology Center (MTEC).

Data were generated through a combination of semi-structured face-to-face interviews and participant observation, as well as the collection and analysis of documentation and other artefacts. Data collection occurred in two phases, the first lasting 3 months, and the second 4 months. This phasing of data collection periods provided different opportunities for the exploration of emergent constructs, as the second phase of data collection and analysis aimed to explore grey areas and new avenues of inquiry suggested by the first stage of data collection and analysis.

Twenty-one interviews were conducted with fourteen participants over approximately 17 h. The participants were selected through purposive sampling. The selection criteria were: that participants belonged to different disciplinary backgrounds, had to have been involved in the project for three or more years and to be well acquainted with the project's evolution and with the organisational background, activities, and communication and decision-making flow. Thus, they could provide rich and in-depth data about interdisciplinary collaboration in the project to the researcher. In the interviews, participants were encouraged to talk about: the differences and similarities of project members; interactions with the other project members; communication and decision-making flows in the project; types of knowledge, which were shared among project members; knowledge sharing and communication channels; and difficulties in undertaking activities in cross-community working and how these were managed. These themes helped to explore the interviewees' experiences and perspectives about the nature of cross-community collaboration, the construction of boundaries, the types of knowledge boundaries, and processes and mechanisms to manage knowledge across them.

To complement interviews, participant observation was used as another main data collection method. This offered opportunities for immersion in the project to observe and capture actions, interactions, activities, perspectives, feelings, and meanings that project members attach to phenomena in cross-community collaboration within their natural context. It helped to explore and explain what happened, who or what was involved, when and where things happened, how they occurred, and why things happened in collaboration with the research project (Saunders et al., 2015; Thomas, 2011). Observations occurred in three contexts: the laboratory; the project monthly meetings; and the meetings relating to the implementation of ISO 13485 and risk management. These contexts were selected because social interactions of project members mainly occurred in these places. Thirty-one hours of observations were recorded, complemented by field notes and photographs. Photographs helped to capture the places and environments of collaboration, actors involved, activities, and objects of cross-community collaboration in order to provide an extension of observation.

The collection and analysis of documentation and other artefacts were chosen as a further source of data. Documents included project proposals, project plans and schedules, project reports, documentation of scanner development procedures, and scanner prototypes. The documentation and artefacts provided data to explain differences and dependencies in knowledge and tasks as well as to explain communication, discussion, negotiation, and agreement between different knowledge communities in the project. This data helped to explain the construction of boundaries and the mechanisms to manage knowledge across them.

Data collected through these complementary methods generated an extensive and multifaceted corpus which allowed for the triangulation of perspectives held by participants.

Data were analysed using thematic analysis (Clarke & Braun, 2017). Thematic analysis was selected because it can be applied across different theoretical frameworks (although might not suit all). It can be used to examine experiences, meanings, and the reality of actors. Also, it can be used to examine the ways in which events, realities, meanings, and experiences are the effects of a range of discourses operating within society. In this study, the data analysis procedure consisted of six stages: (1) becoming familiar with the collected data; (2) generating initial codes; (3) identifying themes; (4) reviewing themes; (5) defining and naming themes; and (6) reporting (Clarke & Braun, 2017). The data analysis was an iterative process and involved a constant moving back and forth as needed, throughout the stages. This helped to shape the direction of data collection as well as to improve the themes and the relationships between them.

3.2 | Background to the case study

NSTDA consists of four different national research centres in different branches of science: (1) genetic engineering and biotechnology; (2) electronics and computer technology; (3) metal and materials; and (4) nanotechnology. NSTDA has adopted a concept of interdisciplinary and inter-organisational collaboration since 2006 to integrate its resources and capabilities among its national research centres to meet challenges in the knowledge-based economy and globalisation (National Science and Technology Development Agency, 2012).

An interdisciplinary research project of NSTDA involving the development of CT and DR scanners was selected as a case study for this paper through purposive sampling. It was an ongoing joint project between two groups from different disciplines, with different functions, and from different organisations under NSTDA: the software group from the National Electronics and Computer Technology Center (NECTEC) and the hardware group from the National Metal and Materials Technology Center (MTEC). Collaboration had been evolving since 2007 to develop CT and DR scanners for medical diagnosis and operations. It aimed to reduce the costs of scanner imports which are very considerable, to improve scanner development knowledge, and to increase the country's competency in medical industries and services. This project was considered as a successful interdisciplinary research project because it proposed the first development of the cone-beam CT scanner in Thailand, called DentiiScan. The dental CT scanners of this project have been used in hospitals in Thailand and have generated social impact on Thai health, well-being, and social care.

This project consisted of four sub-projects which were conducted in parallel: the development of a dental CT scanner, a mobile CT scanner, a mini CT scanner, and a DR scanner. The project team consisted of: the project director, the project managers of the software and the hardware groups, and the other members of the two groups. Most project members had knowledge backgrounds in engineering. However, there were differences in their academic disciplines and in expertise between the software and the hardware group members, as well as among members of the same group. Most software group members graduated in electrical engineering and computer science. They had knowledge in fields such as signal processing, image processing, electronics, and computer systems, computer graphics, and visualisation, including computer programs and databases. By contrast, most hardware group members graduated in electrical engineering, chemical engineering, mechanical engineering, biomedical engineering, and mechatronics. This suggested that there was a range of academic disciplinary boundaries involved in this case study.

This was a governmental research institute marked by a hierarchical structure and project members were grouped into different levels. While previous research has proposed that bureaucratic organisations are less able to respond to fluid boundaries (Kellogg et al., 2006), the results from this study shed a different light on this. Some of the participants welcomed forms of control to manage responsibilities, and resources among them, associated with hierarchy:

> "Doing a big project like this requires actors with a higher level in a position of a deputy director because they have authority to order project members to do this or to do that as well as to manage human resources."

Hierarchical organisational structures, as perceived by some participants, in this case, were presented as helping to allocate and manage authority and responsibilities among project members and to clarify differences and dependencies in knowledge, authority, and responsibilities among project members. The hierarchical organisational structures were perceived to create clearer lines of communication and to give project members spokes person participants knew who to report to and where to get knowledge and directives from, based on their authority and responsibilities.

> "For the software group, if there are problems about plans, the project manager will make decisions. If there are problems about programming, the front-line members will make decisions. However, we [the project manager and members of the software group] will talk to each other again to discuss solutions."

The organisational context of the research project, particularly its hierarchical organisational structure, influenced significantly the knowledge-sharing practices exhibited by its participants and how boundaries were bridged throughout the project.

3.3 | Complexity and evolution of knowledge boundaries throughout the project life-cycle

The development of the scanners in this case could be categorised into three major stages: (1) the planning and design stage covering project concept design, hardware and software design, and hardware procurement; (2) the development and manufacturing stage covering hardware and software development; and (3) the testing and implementation stage covering quality and safety testing, hardware and software improvement, scanner installation in customers' sites, user training, scanner implementation with patients, scanner improvement and maintenance. Although three types of knowledge boundaries manifested themselves throughout the project, they did so in different ways at the three stages project and with different intensities, as will be discussed in the following sections.

3.3.1 | Planning and design

At the initial planning and design stage, political boundaries played a stronger influence, as the project was driven by a political decision to develop scanners in-house, in order to save national hospitals and medical centres import costs, and to expand opportunities for patients for diagnosis and treatment. The output and outcome of the project were therefore seen of potentially high social and economic impacts on NSTDA and Thailand. The project was initiated by the project director, a very influential actor in the organisation, who invited the hardware and software project managers to conduct the project. Each of these project managers pooled members of their research teams to join in the project. This required a shift of effort and of research focus which affected the interests of different participants.

> "At the beginning, I was actually uninterested in and I seldom agreed with this project because I thought that computerised tomography would be too far for Thailand [...]. However, when the research unit decided to do it, I had to help the unit to make it successful."

Different actors experienced the situation differently depending on the type of knowledge and on the level of expertise that they had about the phenomenon, how they were affected by it, and how much change they felt it involved for them. This was manifested by experiencing the situation through different knowledge boundaries. For instance, a participant from the hardware group, who had a background in chemical and material engineering, engineering design, material selection, and design methodology, perceived that he had to change his research interests and agenda to participate in this project because his research unit decided to commit to it. This implied the development of new knowledge bases and competencies. For him, project participation involved overcoming both interpretative and political boundaries. Conversely, another participant from the same group, who had knowledge in mechatronics and electricity, perceived that participation in this research involved just an extension of his existing knowledge base.

> "I did not change anything. The development of CT and DR scanners involves electricity and I have knowledge and experience about electricity already. I just improve my knowledge and techniques about radiation […]. Doing this project makes me feel like…I gain more knowledge. I just improve my knowledge rather than change my knowledge and my way [of thinking]."

Interpretative and information-processing boundaries occurred at this stage as well. Project members codified some of their knowledge about topics such as scanner development and shared it with other project members through information technologies such as e-mail, instant messaging, Dropbox, and Google Docs. Other project members were able to retrieve and use the shared knowledge independently because differences and dependencies in the knowledge between members from different groups were known. Also, they shared sufficient common knowledge and language to be able to transfer knowledge in these areas.

"We [the hardware and software groups] have the same knowledge backgrounds in engineering, so we are likely able to talk and understand each other."

This gave rise to an initial perception that disciplinary differences were not significant. However, as the project evolved, some barriers to knowledge transfer between different groups were soon found, giving rise to information-processing boundaries.

> "At the beginning, I did not understand what a collimator was until the software group explained that it was a device to narrow a beam of waves."

To resolve this problem, two project members were asked to act as lexicon mediators. These two project members had more extensive knowledge and experience of the X-ray detector system and CT scanner, both of hardware and software aspects, than the other project members. Also, they were more widely known and more approachable to the other project members. They were often able to explain the technical terminology adopted by one group in the language of the other group to make sure that the different groups could understand each other.

Differences in interpretation over concepts, requirements, and techniques for scanner development occurred at this stage. The hardware and software groups needed to discuss unclear points about the concepts of scanner development to develop common interpretations and understandings. For instance, a participant from the hardware group commented:

> "How do the operations of a scanner work? What are the components of a scanner? We discuss about that in meetings. We bring everything about that into meetings to fine-tune with each other."

In effect, the hardware and the software group members tended to perceive the same situations differently through their own conceptual frames. Yet they seemed to lack full awareness of these differences and of dependencies. Importantly, an initial absence of awareness of these disciplinary differences of perspective over the research object and problem was itself formative of knowledge boundaries.

3.3.2 | Development and manufacturing

In the second stage, scanner development and manufacturing, information-processing, and interpretative boundaries were predominant. The two groups exhibited differences in perspective and sometimes viewed the same issues and situations with different lenses. This led to the emergence of interpretative boundaries, driven by the differing concepts, theories, and techniques adopted by the software and hardware groups.

> "The precision of the X-ray detector system setting normally was about 0.3 mm […]. However, the software group thought that it must be 0 mm. The hardware group argued with the software group that there were standard errors in hardware and the X-ray detector system. So, it was impossible and inessential to set the precision of the system at 0 mm. Sometimes we [the hardware group members] have to clarify the operation of hardware to the software group."

> "I believe that no one can develop hardware with the high level of precision at 0.1 micron […]. Machines consist of many components and each component has its standard tolerances and errors. The hardware group tries to meet the software group's requirements but it hit the hardware group's ceiling."

As the two groups had different knowledge backgrounds and specialisations, they tended to perceive the same phenomena in the development and manufacture of the scanners differently. For instance, there were differences between the two groups in ways of understanding and conceptualising the setting of an X-ray detector system and the turning of a gantry in relation to a detector.

> "The two groups have different perspectives about the setting of the X-ray detector system and the quality of X-ray photographs. The software group perceives and wants to get some things but we [the hardware group members] do not understand why these things must be like the software group's requirements. For example, we want to set a gantry of a detector away from a patient's shoulders to avoid it crashing into the patient's shoulders, while the software group wants to set the gantry close to a patient's face to take clear

> patients' oral cavity photographs as the theory of image processing requires."

Thus, in some instances, such as a difference of views over setting the parameters for the image resolution, neither side could really comprehend the other's perspective. Consequently, tension, conflicts, and difficulties in collaboration between different knowledge communities occurred. Moreover, due to the lack of a full understanding and awareness of how each group work, the two groups tended to perceive and project their tasks as more difficult than those undertaken by the other group.

To reconcile discrepancies in interpretations and understandings between the two groups at an interpretative boundary, boundary interactions were main processes involved. Boundary interactions, in this case, mainly covered face-to-face meetings, working together in the same place such as a laboratory, and training. Boundary interactions offered opportunities to the groups to share, discuss, fine tune, and learn differences and dependencies in knowledge and tasks between them through the metaphor of "let's do it together." This helped to develop common interpretations and understandings as well as to form acceptable points for coordination. A participant from the software project, for example, talked about the advantage of working together in the same place to gain a better understanding:

> "I think, it is going better because of working together in the same place, especially in the lab. Everyone has to come in and work in the lab. If we work in the same place, it works because we can talk with the other project members and understand tasks better. It does not work for working separately and integrating later because something has to talk together too much"

The other important mechanism to bridge discrepancies in interpretations and understandings between the two groups at an interpretative boundary were boundary brokers. The project director was perceived as the most influential actor in the project: a project manager said that "there are not any other strong points in this project besides the project director [smiles]". The project director pulled together human resources from different groups to conduct this project. He facilitated and coordinated collaboration between the two groups, as well as between the project members and external actors. He handled meetings to offer opportunities to project members to share knowledge and viewpoints as well as to discuss unclear points for developing common understandings in coordination. He developed and maintained the environment of collaboration and a sense of commitment between groups. He was able to enter into discussions between groups by offering ideas to promote knowledge sharing and learning, develop common understandings, encourage coordination, and facilitate problem-solving.

Moreover, the hardware and software project managers acted as knowledge brokers between the two groups to facilitate knowledge sharing and learning as well as the development of mutual understandings between the two groups. They developed and maintained awareness and the environment for collaboration between the two groups. For instance, the hardware project manager reconciled the attitudes and criticisms of the hardware group about the software group to manage the relationships between the two groups.

> "Some members of my group [the hardware group] criticised the software group that the software group should do like this or that, it was very easy. But I told them that it looked easy for us because we did not do it and we were outsiders [...]. I had to explain to my members and make them understand that what the software group made may look easy in our eyes but the software group had to fix many things to reach our requirements"

Information-processing boundaries arose as well, requiring the exchange of photographs and documentation to explain issues arising during the development process. For instance, the hardware group sent photographs of machine simulation and drawings of a gantry between an X-ray source and a detector to the other project members through e-mail and instant messaging to present the progress of hardware development.

3.3.3 | Testing and implementation

At the final stage, scanner testing and implementation, political boundaries were again stronger because project members had to collaborate with external actors belonging to different knowledge communities, with diverse agendas, such as the medical staff who would be using the scanners. New requirements from physicians required changes in the project specification which led to the transformation of knowledge, skills, and practices of project members.

> "Doctors requested us to reduce image-processing time of the project DR scanner from 19 to 5 s. They also asked us to connect the scanner to the Picture Archiving and Communication System of a hospital. This system was a new thing for us [...]. We had to research and develop new algorithms and techniques to reduce image-processing time of our scanner. Also, we had to find out ways to connect the scanner to the hospital's system."

Innovations introduced by another scanner manufacturer were the major sources of novelty. This required changes in knowledge, practices, and agendas to meet customers' requirements and to compete with a commercial scanner manufacturer.

> "We were satisfied with the creation of image resolution at 0.4 mm [...]. However, in the real world many big hospitals used the [import] dental CT scanners [...] which created high-resolution images at 0.25 mm. The

> issue occurred when doctors at the [Named University Hospital] compared the performance of the project scanner with the [named Company]. Then, they complained that the project scanner generated blurred photographs, there was much noise on the photographs and the view sizes of photographs were small […]. After receiving the complaints, […] we stopped creating low-resolution images at 0.4 mm and started to create high-resolution images at 0.2 mm. We tried to answer the doctors' requirements. Those complaints were motivations."

As this research project was being conducted in a governmental research organisation, the requirements of stakeholders from various parties also affected the development and trajectory of the project. For instance, one external funding agency asked the project team for further adaptations in the scanners as part of setting subsidies for the project.

There were three main boundary objects (Star & Griesemer, 1989) facilitating knowledge transformation among project members and between the project members and external actors at boundaries during this stage: scanners; X-ray photographs; and project Gantt charts. For example, the scanners themselves and X-ray photographs were co-developed and used by the hardware and software groups in the course of their interaction and collaboration. They helped to clarify differences and dependencies in knowledge and tasks that existed between the two groups.

Common goals, teamwork, and project members' willingness to change had positive effects on knowledge transformation at a political boundary and provided a focus for action.

> "We [the hardware and software groups] are like partners, so we go towards a goal together. We are bound together. We have the same goal. That is, Hey! Brother [referring to the hardware project manager], why it is slow, something like that. When problems occur, we will help each other to solve the problems together."

This was reinforced by Thai cultural traits-"Kreng jai"-of expectations of social compromise and harmony, which helped to reduce conflicts between actors at a political boundary.

4 | DISCUSSION AND CONCLUSIONS

The findings from this study further extend understanding of the dynamic and complex character of knowledge boundaries, demonstrating that they evolve throughout project development and exhibit different intensities at different stages of the project. The multiple experiences and perspectives held by different participating actors bring a kaleidoscopic effect that expands the complexity of situations. The study depicts the complex nature and construction of knowledge boundaries as well as the diverse boundary-spanning mechanisms for bridging them at different stages of a project.

The findings suggest that knowledge boundaries tend to evolve and change throughout the project life cycle and exhibit different intensities, depending on the work that has to be undertaken, as well as on changes in the context and on the interactions between different communities. In this study, at the first stage of the project, planning and design, political boundaries were strong because novelties in the areas of the scanner development affected pre-existing knowledge of project members. This meant that to participate in the project, its members had to change their interests, practices, and related knowledge, to respond to novelties required for scanner design.

In the second stage, scanner development and manufacture, interpretative boundaries were common and these can sometimes transmute to political boundaries. This is because the ways of thinking, requirements, and practices of one group about the quality of X-ray photographs, for example, might affect research practices and agendas of the other group. Consequently, one group may need to transform its competencies, practices, and agendas to meet the requirements of the other for collaboration. Two main mechanisms to overcome interpretative boundaries were boundary interactions and boundary brokers. Boundary interactions or the co engagements of different groups in collective activities helped to overcome interpretative boundaries by offering opportunities to the groups to identify, to share, and to learn differences and dependencies in knowledge and tasks with the other group. This helped to develop common interpretations and understandings to form acceptable points for coordination. Boundary interactions, in this case, mainly covered face-to-face meetings, working together in the same place such as a laboratory, and training. Boundary brokers were the second main mechanism to overcome interpretative boundaries. Boundary brokers, in this case, were the project director and the hardware and software project managers. They facilitated collaborations between the different groups by working in different roles as coordinators, facilitators, representatives, and translators, developing common understandings in coordination.

In the final stage, scanner testing and implementation, political boundaries manifested themselves more strongly because project members needed to interact with external actors with additional requirements. For example, in this case, new requirements by medical practitioners about the scanners properties and the innovations introduced by another scanner manufacturer required the re-negotiation and adaptation of work practices and of related knowledge to improve the scanners to meet the end users requirements Boundary objects facilitated communication, interaction, and knowledge transformation among the project members and between the project members and external actors at a political boundary. In this study, there were three main boundary objects: CT and DR scanners; X-ray photographs; and project Gantt charts. These boundary objects were co-developed and used by members of the groups in the course of their interaction and collaboration. They were shared and shareable across different groups and contexts. Furthermore, common goals, teamwork, and willingness to change by project members had positive effects on knowledge transformation at a political boundary. Having a common goal facilitated cross-community collaboration and helped to overcome political boundaries. This was because a common goal was regarded as a focus

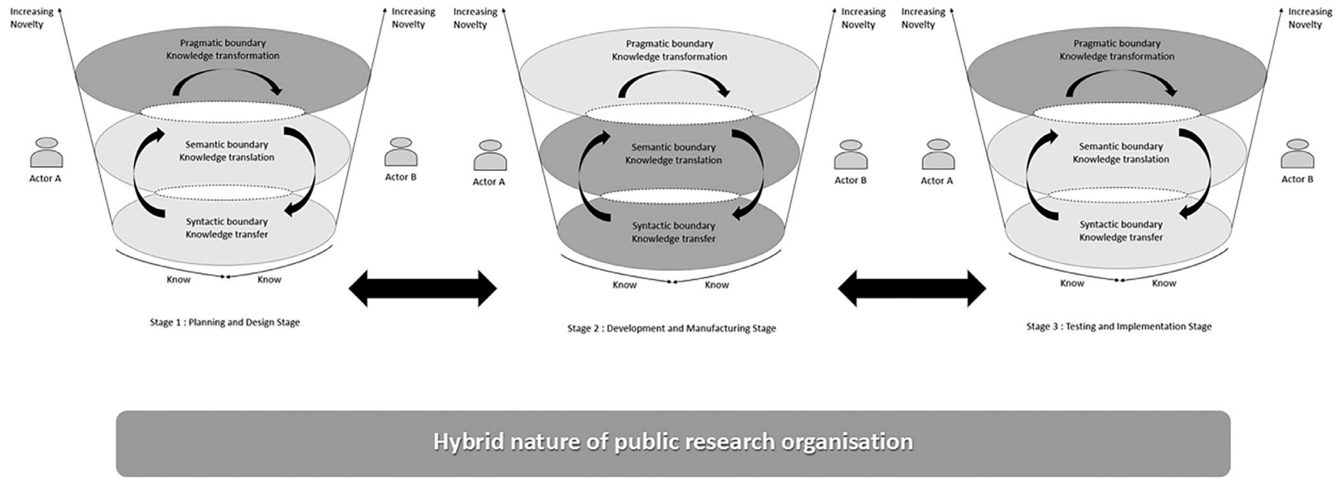

FIGURE 1 Complexity and evolution of knowledge boundaries

and a direction for the different groups in the project. Although the two groups took on different responsibilities and had different goals in their groups, they had dependencies on knowledge and tasks to reach a common goal of the project together.

The framework below presents the complexities and dynamics of knowledge boundaries and processes that emerged from the study and highlights the evolution of the relative intensity of knowledge boundaries across the different project stages (Figure 1).

The other findings from the study reinforce the sense that cross-community collaboration and knowledge management are more complex than often thought, in three ways. Firstly, the same context can be experienced as a different type of boundary by different actors. This depends on the knowledge that individuals have about a phenomenon, how they are affected by it, and the extent of changes that they feel the phenomenon requires. For instance, participants who had differences in type and level of knowledge relating to the project experienced joining as involving different types of knowledge boundaries. This required different investment and agency in spanning boundaries. Similar cases were observed by Lifshitz-Assaf (2018) at NASA.

Secondly, knowledge boundaries not only occur because of differences in knowledge between members from different communities, as other studies suggest (Carlile, 2002, 2004; Edenius et al., 2010; Kotlarsky et al., 2015; Maaninen-Olsson et al., 2008), but as importantly, because of the lack of awareness of these differences and of the knowledge dependencies associated with them. In this study, it was seen that often friction at boundaries was exacerbated by the two groups failing to recognise how each other's perspectives were so different. As noted by Edmondson and Harvey (2018), members of different disciplinary and professional communities often take their frames of understanding, norms, and values for granted and bring implicit assumptions to collaboration based on them. This study demonstrates that the lack of awareness of these assumptions gives rise to knowledge boundaries. Working across boundaries implies the re-examination of these perceptions and assumptions.

Thirdly, the findings point to the role of context in shaping cross-community collaboration, in the formation of different boundaries, as well as in the choice of boundary spanning mechanisms used to bridge them. In this study, the hybrid nature of a public research organisation was seen to introduce particular tensions and challenges in the operation of the organisation. This meant that it had to be prepared to change research practices, agendas, and related knowledge. Furthermore, the study suggests that fundamental forms of organisational structure and culture shape how boundaries are perceived and handled. Previous research suggests that hierarchical organisational structures have negative impacts on knowledge management and sharing practices (Seba & Rowley, 2010), dealing therefore less effectively with fluid boundaries (Kellogg et al., 2006). However, in this case, bureaucratic cultures in hierarchical organisational structures were perceived to have a positive impact on cross-community collaboration and knowledge management. In a hierarchy, the authority, responsibilities, and job functions of each member are clearly specified and allocated (Heathfield, 2016). Consequently, in this study, no one seemed to be confused about differences and dependencies among project members. Communication paths were generally clear. The expert and managerial power of the project director, who was at the top of the pyramid of the project, was used to bridge gaps between different knowledge communities in different types of knowledge boundaries. This could, nevertheless, be interpreted as a shortcut to a deeper engagement and interaction across the research teams which, as noted by Edmondson and Harvey (2018), are required to resolve differences in perspective and in agenda. Moreover, wider contextual factors such as cultural traits seemed to have an impact on how knowledge boundaries are handled. In this case, Thai expectations of social compromise and harmony- "Kreng jai" -helped to reduce conflicts between actors at a political boundary. Such findings suggest strongly that context plays a crucial role in managing knowledge and collaboration across boundaries.

The dynamic nature of boundaries and the change of emphasis in different boundaries throughout the project life cycle lead to an element of circularity, rather than linearity, in how project members experience and navigate them. The framework proposed here takes into account the critical features of blurring, simultaneity, and overlapping of boundaries. It recognises that sometimes the categorisation of knowledge boundaries is not easily made because different actors face the same phenomenon but perceive them as different types of knowledge boundaries. Further, the nature, dynamics, and complexities of knowledge boundaries and of boundary spanning processes that bridge them are informed and shaped by tensions and challenges arising from the hybrid nature of these organisations.

This study emphasises the importance of context to the development and management of boundaries. It suggests that the hybrid nature of public research organisations introduces challenges in relation to the occurrence of knowledge boundaries, especially political boundaries, for such organisations have to maintain a balance in the relationship between different stakeholders and be accountable to public policy requirements, while also operating in a market. They need to respond to the various requirements of government and external agencies both in the private and public sectors to obtain funding and resources for their work. New requirements of stakeholders require that project members revise and re-think their knowledge and practices. It has also been seen that the characteristics of the organisation influence boundary management. Bureaucratic cultures within the hierarchical structures of a public-sector organisation, the power of individual boundary brokers in hierarchical organisational structures, and cultural traits favouring social harmony in organisational culture, all emerge as significant aspects of how boundaries occur and are managed. Thus, the theorisation of boundaries and the three-tier model needs to be considered in a much wider context.

The findings have practical implications for organisational actors who are involved in interdisciplinary work. They need to be aware of the complex nature of boundaries, the different types of knowledge boundaries and knowledge processes, and how they are experienced differently by other co-workers, to manage knowledge across them. This will enable them to create more effective mechanisms to encourage sharing and learning about diversity among staff to increase recognition of the differences in knowledge and perspectives among them. As an aspect of this, managers should examine their own agency and authority for managing and organising cross-community collaboration. They should look at organisational processes to support and encourage cross-community collaboration and knowledge management. Finally, they should foster conditions for collaborators to recognise the complexities and challenges of cross-community work.

DATA AVAILABILITY STATEMENT

Data available on request from the authors

ORCID

Ana Vasconcelos https://orcid.org/0000-0002-8921-5256

REFERENCES

Akkerman, S., & Bakker, A. (2011). Boundary crossing and boundary objects. *Review of Educational Research*, *81*(2), 132–169. https://doi.org/10.3102/0034654311404435

Bark, R. H., Kragt, M. E., & Robson, B. J. (2016). Evaluating an interdisciplinary research project: Lessons learned for organisations, researchers and funders. *International Journal of Project Management*, *34*(8), 1449–1459. https://doi.org/10.1016/j.ijproman.2016.08.004

Becher, T. (1994). The significance of disciplinary differences. *Studies in Higher Education*, *19*(2), 151–161. https://doi.org/10.1080/03075079412331382007

Bechky, B. A. (2003). Sharing meaning across occupational communities: The transformation of understanding on a production floor. *Organization Science*, *14*(3), 312–330. https://doi.org/10.1287/orsc.14.3.312.15162

Bozeman, B., Gaughan, M., Youtie, J., Slade, C. P., & Rimes, H. (2016). Research collaboration experiences, good and bad: Dispatches from the front lines. *Science and Public Policy*, *43*(2), 226–244. https://doi.org/10.1093/scipol/scv035

Bronstein, L. R. (2003). A model for interdisciplinary collaboration. *Social Work*, *48*(3), 297–306. https://doi.org/10.1093/sw/48.3.297

Carlile, P. R. (2002). A pragmatic view of knowledge and boundaries: Boundary objects in new product development. *Organization Science*, *13*(4), 442–455. https://doi.org/10.1287/orsc.13.4.442.2953

Carlile, P. R. (2004). Transferring, translating, and transforming: An integrative framework for managing knowledge across boundaries. *Organization Science*, *15*(5), 555–568. https://doi.org/10.1287/orsc.1040.0094

Clarke, V., & Braun, V. (2017). Thematic analysis. *Journal of Positive Psychology*, *12*(3), 297–298. https://doi.org/10.1080/17439760.2016.1262613

Coccia, M., & Rolfo, S. (2009). Project management in public research organisations: Strategic change in complex scenarios. *International Journal of Project Organisation and Management*, *1*(3), 235–252. https://doi.org/10.1504/IJPOM.2009.027537

Cummings, J., & Kiesler, S. (2005). Collaborative research across disciplinary and organizational boundaries. *Social Studies of Science*, *35*(5), 703–722. https://doi.org/10.1177/0306312705055535

Edenius, M., Keller, C., & Lindblad, S. (2010). Managing knowledge across boundaries in healthcare when innovation is desired. *Knowledge Management & E-Learning: An International Journal*, *2*(2), 134–153. https://doi.org/10.34105/j.kmel.2010.02.011

Edmondson, A., & Harvey, J.-F. (2018). Cross-boundary teaming for innovation: Integrating research on teams and knowledge organisation. *Human Resource Management Review*, *28*(4), 347–360.

Farag, S., Jarvenpaa, S. L., & Majchrzak, A. (2011). Knowledge collaboration in online communities. *Organization Science*, *22*(5), 1224–1239. https://doi.org/10.1287/orsc.1100.0614

Feng, Y., Ye, H., & Pan, S. L. (2010). Delivering knowledge across boundaries: a process model of knowledge delivery in offshoring projects. *Pacific Asia Journal of the Association for Information Systems*, *3*(3), 1504–1515.

Fellows, R., & Liu, A. (2012). Managing organizational interfaces in engineering construction projects: Addressing fragmentation and boundary issues across multiple interfaces. *Construction Management and Economics*, *30*(8), 653–671. https://doi.org/10.1080/01446193.2012.668199

Hall, J. G., Bainbridge, L., Buchan, A., Cribb, A., Drummond, J., Gyles, C., Hicks, T. P., McWilliam, C., Paterson, B., Ratner, P. A., Skarakis-Doyle, E., & Solomon, P. (2006). A meeting of minds: Interdisciplinary research in the health sciences in Canada. *Canadian Medical Association Journal*, *175*(7), 763–771. https://doi.org/10.1503/cmaj.060783

Heathfield, S. M. (2016). Understanding the chain of command: Position power resides in the chain of command at work. Retrived from http://www.thebalance.com/chain-of-command-1918082

Hislop, D. (2013). *Knowledge management in organizations: A critical introduction* (3rd ed.). Oxford University Press.

Jin, L., & Sun, H. (2010). The effect of researchers' interdisciplinary characteristics on team innovation performance: Evidence from university R&D teams in China. *International Journal of Human Resource Management*, *21*(13), 2488–2502. https://doi.org/10.1080/09585192.2010.516599

Kellogg, K., Orlikowski, W., & Yates, J. (2006). Life in the trading zone: Structuring coordination across boundaries in post-bureaucratic

organizations. *Organization Science*, *17*(1), 22–44. https://doi.org/10.1287/orsc.1050.0157
Kotlarsky, J., Hooff, B., & Houtman, L. (2015). Are we on the same page? Knowledge boundaries and transactive memory system development in cross-functional teams. *Communication Research*, *42*(3), 319–344. https://doi.org/10.1177/0093650212469402
Le Dain, M. A., & Merminod, V. (2014). A knowledge sharing framework for black, grey and white box supplier configurations in new product development. *Technovation*, *34*(11), 688–701. https://doi.org/10.1016/j.technovation.2014.09.005
Lifshitz-Assaf, H. (2018). Dismantling knowledge boundaries at NASA: The critical role of professional identity in open innovation. *Administrative Science Quarterly*, *63*(4), 746–782. https://doi.org/10.1177/0001839217747876
Lindberg, K., Walter, L., & Raviola, E. (2017). Performing boundary work: The emergence of a new practice in a hybrid operating room. *Social Science & Medicine*, *182*, 81–88. https://doi.org/10.1016/j.socscimed.2017.04.021
Maaninen-Olsson, E., Wismen, M., & Carlsson, S. (2008). Permanent and temporary work practices: Knowledge integration and the meaning of boundary activities. *Knowledge Management Research & Practice*, *6*, 260–273. https://doi.org/10.1057/kmrp.2008.27
National Science and Technology Development Agency. (2012). *NSTDA at a glance*. National Science and Technology Development Agency.
Noorden, R. (2015). Interdisciplinary research is on the rise. *Nature*, *525*(7569), 326–327.
Paraponaris, C., & Sigal, M. (2015). From knowledge to knowing, from boundaries to boundary construction. *Journal of Knowledge Management*, *19*(5), 881–899. https://doi.org/10.1108/JKM-01-2015-0034
Rosenlund, J., Rosell, E., & Hogland, W. (2017). Overcoming the triple helix boundaries in an environmental research collaboration. *Science and Public Policy*, *44*(2), 153–162. https://doi.org/10.1093/scipol/scw045
Saunders, M., Lewis, P., & Thornhill, A. (2015). *Research methods for business students* (7th ed.). Prentice Hall.
Seba, I., & Rowley, J. (2010). Knowledge management in UKpolice forces. *Journal of Knowledge Management*, *14*(4), 611–626. https://doi.org/10.1108/13673271011059554
Siedlok, F., & Hibbert, P. (2014). The organization of interdisciplinary research: Modes, drivers and barriers. *International Journal of Management Reviews*, *16*(2), 194–210. https://doi.org/10.1111/ijmr.12016
Smith, P. (2016). Boundary emergence in inter-organizational innovation: The influence of strategizing, identification and sensemaking. *European Journal of Innovation Management*, *19*(1), 47–71. https://doi.org/10.1108/EJIM-04-2015-0024
Star, S. L., & Griesemer, J. R. (1989). Translations and boundary objects: Amateurs and professionals in Berkeley's museum of vertebrate zoology. *Social Studies of Science*, *19*(3), 387–420.
Thomas, G. (2011). *How to do your case study: A guide for students and researchers*. SAGE.
Wenger, E. (2000). Communities of practice and social learning systems. *Organization*, *7*(2), 225–246. https://doi.org/10.1177/135050840072002
Yates, D., & Paquette, S. (2011). Emergency knowledge management and social media technologies: A case study of the 2010 Haitian earthquake. *International Journal of Information Management*, *31*(1), 6–13. https://doi.org/10.1016/j.ijinfomgt.2010.10.001
Zhang, W., & Pastel, R. (2015). Interdisciplinary team collaboration between software engineers and technical communicators. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *59*(1), 1137–1141. https://doi.org/10.1177/1541931215591166

How to cite this article: Thumbumrung, T., Vasconcelos, A., & Cox, A. (2022). Complexity and evolution of knowledge boundaries in an interdisciplinary research project. *Knowledge and Process Management*, 1–11. https://doi.org/10.1002/kpm.1727