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Project-based learning principles

Insights from the development of large infrastructure

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DOI
10.1007/s42524-024-3113-z

Publication date
2024

Document Version
Final published version

Published in
Frontiers of Engineering Management

Citation (APA)
Liu, Y., Houwing, E. J., Hertogh, M., & Bakker, H. (2024). Project-based learning principles: Insights from the development of large infrastructure. *Frontiers of Engineering Management*, *11*(3), 501-515. https://doi.org/10.1007/s42524-024-3113-z

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Front. Eng. Manag.
https://doi.org/10.1007/s42524-024-3113-z

RESEARCH ARTICLE

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Project-based learning principles: Insights from the development of large infrastructure

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Abstract In recent decades, interest in project-based learning within organizational learning has grown significantly. This study synthesizes principles that facilitate learning at the project level. Through a cross-case analysis of the Gaasperdammer Tunnel project in the Netherlands and the Hong Kong-Zhuhai-Macao Bridge in China, and validation via focus group discussions, we have identified five key principles: Owner Commitment, Social Environment Approach, Collaboration Vision, Value Orientation, and Open Mindset. These principles highlight the mindsets that guide the behavior and thinking of project practitioners beyond prescriptive processes and routines. Our research enhances the understanding of how project participants can learn from their involvement in unique, complex projects and improve their capabilities for future endeavors. We emphasize the critical role of learning in the development of project capabilities and suggest it be a focal point in future research on infrastructure development projects.

Keywords organizational learning, project-based learning, principles, project capabilities, infrastructure development

1 Introduction

Learning is a broad term with varying definitions, and it has been extensively studied by psychologists, linguists, and educators across different disciplines. The research on learning has undergone significant developments, with a substantial amount of literature focusing on the expansion of knowledge in organizational learning (Alerasoul et al., 2022). In recent years, there has been a notable increase in research on organizational learning in project management, extending beyond traditional organizations to include projects and temporary organizations (Iftikhar et al., 2022; Wiewiora et al., 2020). Learning from both successful and unsuccessful projects within and between projects is considered a crucial factor in enhancing project performance (Keegan and Turner, 2001; Prencipe and Tell, 2001; Schindler and Eppler, 2003). Best practices and lessons learned bring fresh ideas and approaches, empowering project participants to make more effective and efficient decisions. This enables them to tackle new and complex challenges, ultimately ensuring profitability and competitiveness.

However, despite the importance of learning and knowledge reuse, it remains challenging (Wasko and Faraj, 2005), often due to professional or organizational constraints and contractual concerns. Project knowledge heavily relies on the situational context and project processes employed (Hartmann and Dorée, 2015). The ultimate objective for the client is to achieve strategic expectations and profits. Therefore, project participants often overlook the accumulation and transfer of knowledge, leading to "project forgetting" where valuable knowledge and experience generated throughout the project life cycle are lost at the project's conclusion (Bronte-Stewart, 2015). Applying organizational learning theory directly to project studies encounters obstacles due to the ongoing debate surrounding project uniqueness and temporality, limiting its applicability (Koskinen, 2012). Consequently, the opportunity to learn from experience and avoid reinventing the wheel in subsequent projects is missed.

The construction industry operates primarily on a project-based approach. With the increasing need for infrastructure development and maintenance, effective

Received Oct. 24, 2023; revised Jun. 7, 2024; accepted Jul. 5, 2024

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This work was supported by the National Natural Science Foundation of China (Grant No. 72201125), China Postdoctoral Science Foundation (Grant No. 2022M721549), Jiangsu Funding Program for Excellent Postdoctoral Talent (Grant No. 2022ZB19) and the Yuxiu Young Scholars Program of Nanjing University.

project management and the ability to capitalize on new opportunities require participants to learn from both internal and external experiences. This includes drawing upon lessons learned to avoid repeating mistakes and achieving more efficient and sustainable project delivery. However, a conservative culture within the industry often leads to the belief that each construction project is entirely unique, disregarding certain repetitive elements that exist across all projects. Currently, there are two main challenges: (1) project managers recognize the importance of learning from projects but tend to overlook lessons learned and execute projects according to their own discretion and goals; (2) there is a lack of organizational controls and routines that support and facilitate a project-based learning environment (Love et al., 2019).

Furthermore, there is a notable dearth in the development of theories related to project-level learning and gaining a comprehensive understanding of this type of learning (AlSaied and Alkhoraif, 2024). Our research aims to address this gap by exploring the question: "How can we establish principles to promote learning in large infrastructure development projects"? Through case studies conducted on the Gaasperdammer tunnel project in the Netherlands and the Hong Kong-Zhuhai-Macao Bridge in China, we empirically investigate this question using a cross-case analysis. By presenting our reflections, we strive to foster learning within and across projects in the context of infrastructure development. The validation process, involving focus group discussions, helps us reach a mutually agreed understanding of project-based learning that can be repeated and applied. We elucidate the unfolding nature of learning and synthesize our findings into five key principles. Furthermore, we demonstrate how identifying these principles can enhance learning practices within project settings. Lastly, we emphasize the importance of developing learning capabilities to facilitate improvement in infrastructure development projects.

2 Literature review

Projects involve multiple participants collaborating in teams and inter-organizational structures to produce new knowledge (Klessova et al., 2020). Project-based learning practices can be defined as a series of actions that project participants employ to share knowledge within the project itself (intra-project), transfer knowledge across projects (inter-project), and ultimately reuse that knowledge (Eltigani et al., 2020).

2.1 Distinguishing project-based learning in organizational contexts

The organization is perceived as a means of storing and leveraging knowledge from the perspective of organizational learning. Extensive research has been conducted on learning within organizations, primarily at the firm level. Numerous theories address the types of knowledge present within organizations, how organizational knowledge can develop, be recorded and shared, as well as how traditional organizations learn from unique experiences and adapt accordingly (Garud et al., 2011; Weick, 1991).

The project, on the other hand, is conceptualized as a temporary organization (Sydow and Braun, 2018). The progression of project-based learning theories is considered an evolution from the broader organizational learning theory to more focused theories within the field of project studies. Project-based learning can be regarded as a subset of the organizational learning theory (Keegan and Turner, 2001). While some research distinctively differentiates organizational learning from project-based learning (Chan et al., 2005; Koskinen, 2012), there is often confusion surrounding the interchangeability of project-based learning, knowledge management, and organizational learning (King and Ko, 2001).

The classic literature on knowledge management primarily concentrates on techniques and methodologies for codifying knowledge and making it accessible to organizations. Organizational learning, on the other hand, strives to effectively utilize intellectual assets through the establishment of organizational rules and processes (Levitt and March, 1988; Brown and Duguid, 1991). Its focal point involves a firm's ability to adapt to evolving knowledge pressures (Irani et al., 2009). It appears that the theories of knowledge management, organizational learning, and project-based learning have been established independently, and while there are some overlaps between these concepts, their practical interactions remain unclear.

Projects are considered temporary endeavors aimed at delivering unique work. According to Ayas and Zeniuk (2001), projects offer significant opportunities for learning. It is argued that project-based organizations and their projects can enhance performance and productivity by utilizing organizational learning as a theoretical foundation. While project-based learning has gained attention in existing organizational learning theories, it has primarily emerged from routine-based organizations rather than temporary projects. This poses limitations to the applicability of organizational learning in the project setting. Temporary organizations struggle to accumulate knowledge across multidisciplinary practices, especially when knowledge is "sticky" and tacit in non-repetitive project work (Duryan and Smyth, 2018; Szulanski, 2000). Unlike automated manufacturing processes, projects involve time-bound interaction with various parties, non-repeatable activities, and one-off tasks (Wang et al., 2022). Therefore, project-based learning is influenced by temporal externalities (Eltigani et al., 2020) and requires a focus on learning at the project level rather than the team level (Senaratne and Malewana, 2011). In projects, teams are

characterized by temporary, fluid, interrupted, and distributed nature, making it challenging to establish clear role identities for project members.

When examining knowledge transferability between projects, Bakker et al. (2011a) proposed the concept of the learning paradox of projects. This paradox refers to the contradiction between the ease of creating knowledge within projects and the difficulty of disseminating that knowledge. Once the project team disbands and participants move on, the knowledge created is likely to be lost (Cacciatori, 2008; DeFillippi and Arthur, 1998). Organizational amnesia occurs when specific knowledge and experience are not effectively managed within the project (Ferres and Moehler, 2024; Schindler and Eppler, 2003). In such cases, knowledge resides with individuals and is transferred to other projects through them (Eltigani et al., 2020). Consequently, learning is often viewed as an additional aspect rather than an integral part of project work.

2.2 Previous efforts on project-based learning

Despite the wide range of perspectives, there is no significant variance in learning mechanisms between project-based organizations and other types of organizations. Zollo and Winter (2002) identified three learning mechanisms: experience accumulation (learning by doing), knowledge articulation (learning by discussing), and knowledge codification (learning by formalizing). Prencipe and Tell (2001) built upon this research and established a clear framework that distinguishes three learning processes at different levels within project-based firms. Brady and Davies (2004) integrated learning at both the project and organizational levels. The focus of the learning process differs: in the initial phase, the emphasis is on exploring new activities, whereas later on, the focus shifts to knowledge sharing and transfer between organizations. This is the approach that current design and construction firms should adopt in order to carry out project- and business-driven learning.

The project-based learning perspective promotes hybrid methodologies that integrate internal and external competencies. However, given the rapidly changing environment, establishing a specific strategic direction becomes more challenging. The challenge lies not in a lack of knowledge, but rather in structuring the learning process in a way that effectively utilizes the existing knowledge (Hartmann et al., 2023). It remains unclear how to systematically disseminate and absorb learning as we collaborate with different partners from project to project.

A significant body of research has focused on developing methodologies to capture and leverage the knowledge generated and lessons learned in projects (Kivrak et al., 2008). Numerous research projects on knowledge capture, sharing, and transfer in construction projects have emerged, indicating a growing interest in this area (Table 1). In the UK, several large-scale research projects have been conducted to address knowledge management issues in the construction industry. However, attempts in

Table 1 A quick scan of research projects on knowledge management in construction

Name	Full name	Time	Funded by	Lead
B-Hive	Building a Higher Value Construction Environment: Cross-organizational Learning Approach (COLA)	–	EPSRC and DETR	London School of Economics and Leeds Metropolitan University
KLICON	Knowledge and Learning In CONstruction (IT in knowledge management and organisational learning for construction projects)	1999–2000	EPSRC	University of Salford
CLEVER	Cross-sectoral LEarning in the Virtual entERprise	1999–2001	EPSRC	Loughborough University
KnowBiz	Knowledge Management for Improved Business Performance: Improving Management Performance through Knowledge Transformation (IMPARKT)	2000–2003	EPSRC	Loughborough University
C-SanD	Creating, Sustaining and Disseminating Knowledge for Sustainable Construction: Tools, Methods and Architecture	2001–2004	EPSRC	Loughborough University, the London School of Economics and Salford University
e-COGNOS	Methodology, tools, and architectures for electronic consistent knowledge management across projects and between enterprises in the construction domain	2001–2003	EC FP5	CSTB and University of Salford
CAPRIKON	Capture and Reuse of Project Knowledge in Construction	2003–2005	EPSRC	Loughborough University and University of Newcastle
–	A knowledge transfer approach to continuous improvement on PFI projects	2003–2004		Loughborough University
–	An Approach to Knowledge Management for SMEs	2003–2005	DTI	Glasgow Caledonian University
PROLAB-project		2003–2005		Vaasa University (Finland)
NETLIPSE	the NETwork for the dissemination of knowledge on the management and organization of Large Infrastructure ProjectS in Europe	2006–2008	EC FP6	AT OSBORNE
the Leonardo da Vinci Programme CLOEMC I	Common Learning Outcomes for European Managers in Construction	2009–2011	the European Commission, DG Education, and Culture	Warsaw University of Technology (Poland)
MEGAPROJECT	The effective design and delivery of megaprojects in the European Union	2011–2015	COST	University of Leeds

the 1990s to develop a knowledge management model, framework, or database proved largely unsuccessful.

Efforts to create a project database have been made in the past. Table 2 outlines some characteristics of these project case bases, which primarily focus on extracting lessons from managing large infrastructure projects. On one hand, these case bases aim to collect a substantial number of cases for statistical analysis (benchmarking). They provide valuable insights for most projects and in most instances. On the other hand, they also examine specific iconic projects in great detail to unravel the complexities of megaprojects and their long-term impact. For instance, the Hertie School of Governance extensively documented the case of the Berlin Airport BER (Kostka, 2016).

Project-based case bases serve as knowledge hubs specifically created for projects. However, many of these case bases face the challenge of transitioning from active projects to inactive ones. The funding period ends, COST Action becomes inactive, and NETLIPSE adopts a new operating model. These transitions pose difficulties in sustaining and effectively utilizing the case base. Moreover, current project case bases encounter emerging issues that hinder them from achieving their full potential in the project-based sector. Merely establishing a database system will not automatically foster a learning environment or promote greater understanding (Ferres and Moehler, 2024).

While there have been advancements, challenges persist in strategically and adaptively implementing learning frameworks within rapidly changing project environments. The key challenge lies not in a lack of knowledge, but in organizing and utilizing knowledge effectively amidst continuous shifts in strategic direction and project partnerships. Hartmann and Doree argue against a simplistic sender/receiver perspective on learning (2015). Consequently, it is critical to reevaluate traditional knowledge management approaches in project settings. Rather than regarding knowledge as a static commodity to be transferred, it should be viewed as a dynamic flow enhanced through social interactions and continuous learning. Emphasizing soft skills over hard skills represents a significant shift in project learning paradigms (Lyu and Liu, 2021). This change is vital for valuing continuous learning and adaptation driven by interaction.

2.3 Toward project-based learning principles

A comprehensive examination of literature including "project" and "learning" reveals that project-based learning involves both theory and practice. It revolves around using project settings to facilitate action learning, enabling individuals to tackle real problems and achieve performance objectives (DeFillippi, 2001). Project-based learning, although "ad hoc" in nature, requires commitment and ongoing investment of time and resources, which unfortunately tends to be overlooked (Hartmann et al., 2023; Williams, 2008). Another perspective on project-based learning highlights the natural occurrence of learning through social participation within a community of practice (Brown and Duguid, 1991; Eltigani et al., 2020). However, many studies on project-based learning still adhere to organizational learning principles without considering relevant differences between subgroups and the whole.

The PMBOK 7th Edition, launched in 2021, introduced major changes, emphasizing project management principles. This shift has sparked significant interest because academic literature has not extensively covered these principles. Project management principles can be seen as a framework for good project practices for those involved (Blampied et al., 2023). However, these underlying principles are often not adequately addressed in available resources and methods. Many practitioners become so engrossed in practical details that they fail to consider these principles, leading to actions that may not align with them.

Based on the above discussions, it is evident that learning

Table 2 Characteristic of the project case base

No.	Project case base	Sponsor	Location	Leader	Existing period	Number of projects	Publicly available
1	IPA	IPA	the US	Edward Merrow	1987−now	20000 +	No
2	NETLIPSE	First EC FP6 and then client organizations mainly in North-West Europe	Europe	Marcel Hertogh, Eddy Westerveld and Pau Lian Staal-Ong	2006−now	17 (shown on its website)	Yes
3	OMEGA Centre	First the Volvo Research & Education Foundations (VREF) and then UCL	the UK	Harry Dimitrou	2006−2011	30	Yes
4	COST Action Megaproject	EU COST Action	Europe	Naomi Brookes	2011−2015	50	Yes
5	Flyvbjerg	−	The UK	Bent Flyvbjerg	−	806	No
6	Hertie School of Governance	Hertie School of Governance	Germany	Genia Kostka	2015	170	Yes
7	MPCSC	Tongji University and National Natural Science Foundation of China	China	Zhaohan Sheng	2011−now	393	Yes

within projects does not automatically translate into organizational learning, and theories on organizational learning cannot be directly applied to project settings. Therefore, it is crucial to develop project-specific principles as guidelines for good practice within the project environment.

3 Method

This study aims to describe complex phenomena within specific project-based learning contexts. It is well-suited for examining a limited number of in-depth cases (Eltigani et al., 2020). Additionally, this approach provides a more detailed and comprehensive understanding compared to a quantitative approach (Creswell and Creswell, 2017). As managing complexity and organizing multi-actor practices, like project-based learning, requires flexible heuristics or rules of thumb rather than rigid algorithms for measurement and prediction, the use of more established and accepted theories is preferable.

The study follows a constructive research approach (Oyegoke, 2011) and adopts a three-step research design: Problem Identification and Understanding, Solution Development and Justification, and Validation and Co-production. The initial step (Problem Identification and Understanding) involves reviewing essential organizational learning principles and their relevance to the project setting. These principles are gathered from authoritative publications, including academic papers and reports (AlSaied and Alkhoraif, 2024; Iftikhar et al., 2022; Iftikhar and Wiewiora, 2022). This step serves as an exploratory phase to define the research focus. It entails conducting a literature review and fieldwork in parallel, focusing on project case studies, as outlined in Section 2.

The second step, Solution Development and Justification, involves generating a tentative set of principles derived from two carefully chosen cases: the Gaasperdammer tunnel project in the Netherlands and the Hong Kong–Zhuhai–Macao Bridge in China. These projects are strategically located in significantly different regions, providing valuable insights into how geographic and cultural contexts influence project-based learning. Table 3 presents a concise summary of each case. The deliberate selection of these cases ensures that the resulting learning mechanisms are not limited to a single cultural or operational model, but rather can be applied across diverse settings. Additionally, these cases include different levels of project-oriented organizations, specifically learning within projects (intra-project) and learning between projects (inter-project) (De Groot et al., 2020) (Fig. 1). Within each project, knowledge exchange occurs among the project participants (A, B, C, D···). The smallest circle in the figure illustrates intra-project learning, representing direct interaction between the project owner and other participants. These interactions play a crucial role in accumulating valuable experiences, sharing knowledge, and adjusting practices based on immediate feedback and results within the project. The next circle represents the market or broader industry context in which these projects operate. Inter-project learning involves transferring knowledge from one project to another within the same industry, fostering improvement in practices and methodologies based on past successes and failures. Lastly, the outermost circle indicates that the benefits of learning from these projects extend beyond the projects themselves and their immediate market. The insights gained can drive innovation and continuous improvement across different fields, drawing on the unique solutions and challenges experienced in large infrastructure projects like these. Prior research indicates that these two cases have adopted different perspectives or mechanisms for project-based learning (Liu et al., 2021; Liu et al., 2022). The choice of cases supports our belief that management and organization studies should focus on outliers rather than averages (McKelvey, 2006) in order to generate valuable and insightful research results. Furthermore, a diverse sample helps explore emerging categories and ensures saturation. The unique and complex nature of these two cases provides rich and varied data, which offer insights into both specific and generalizable aspects of project-based learning across different scales and contexts.

Primary data were collected directly by the researchers, while secondary data were obtained from various sources such as commercial and government agencies, marketing research firms, and digital databases. This process followed an iterative approach, with data collection, coding, and analysis occurring simultaneously. Alongside this initial step, the research focused on five key domains: leadership, environment, learning relationship, knowledge perceptions, and thought process perceptions. Within these domains, preliminary principles were formulated. To enhance external validity and develop a more robust

Table 3 Summary of two cases

Case	Description of the project	Focus on the project-based learning	Type of learning	
The Gaasperdammer tunnel (GSP)	The longest tunnel project on land in the Netherlands	To have a constant reflection going on in the project rather than just learn from the project after it has finished	Intra-project learning	Exploitative learning
Hong Kong–Zhuhai–Macao Bridge (HZMB)	The longest sea-crossing linking Mainland China, Hong Kong, and Macau all over the world, in the form of a bridge structure, an immersed tunnel, and two artificial islands	To adopt advanced technologies and management philosophies to address the project complexity and satisfy the innovation requirements	Inter-project learning	Explorative learning

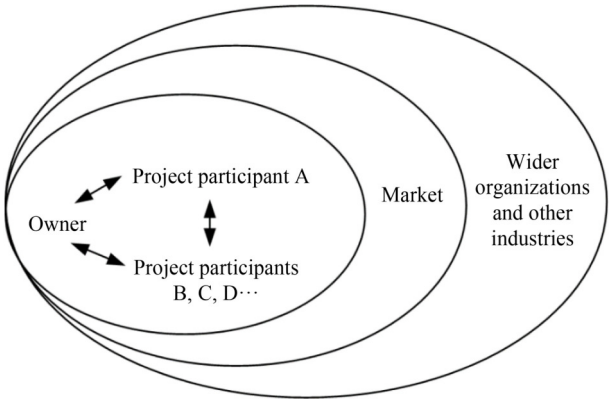

Fig. 1 Levels of project-based learning.

and testable theory, the study employed a cross-case analysis approach using multiple cases rather than relying on a single case alone (Eisenhardt and Graebner, 2007). Two cases were specifically chosen for the cross-case analysis to yield more generalizable findings and a deeper understanding of the learning principles governing large infrastructure projects.

The third step, Validation and Co-production, complements and validates the tentative principles through focus group discussions. Focus group discussions are a qualitative data collection approach wherein a group of individuals is assembled by the researcher to discuss a specific topic through moderated interaction (Morgan, 1996; Parker and Tritter, 2006). The purpose of these discussions is to substantiate and verify the feasibility of the principles. Any principles that are too vague or difficult to implement accurately and efficiently will be reorganized or re-presented. Focus group discussions were chosen as the method to validate and co-produce the tentative principles for studying megaprojects. This approach allowed informants to share their experiences and opinions on learning in megaprojects, including the two selected cases. This collective sharing facilitated the cross-fertilization of ideas and experiences, which is particularly valuable when discussing complex and multifaceted topics like learning in megaprojects. Such an environment revealed shared understandings and discrepancies that might not have emerged in individual interviews (Guest et al., 2017). Unlike surveys or individual interviews, focus group discussions involve real-time interaction among participants (Nyumba et al., 2018). This immediate feedback was used to verify the feasibility and clarity of the principles. Vague or impractical principles could be quickly identified and refined based on group consensus or contention. Three focus group discussions were conducted separately at TU Delft in the Netherlands with participants from the 9th IPMA Research Conference and the British Academy of Management 2021 Conference, which acted as member checking, peer debriefing, and an external check on the research process (Birt et al., 2016; Spall, 1998). Theoretical saturation was reached in this step as no new themes, insights, or concepts emerged from the discussions.

The researchers used various data sources, including literature, archives, interviews, participant observations, and focus group discussions (Yin, 1984), to explore the learning principles in large-scale infrastructure projects and programs. This integration allowed for an examination of popular concepts in the literature and their relevance to the project management discourse (the "outside-in" approach). Additionally, the researcher considered how knowledge within the field of project management could enhance the findings from the discipline (the "inside-out" approach). This approach ensured the validity and reliability of the data.

4 Findings

Best practices may not always be easily replicable, but more general principles for project-based learning can be derived (Bhattacherjee, 2012). While different cultural environments and development processes distinguish cases, there are commonalities. Through an inductive cross-case analysis, common conditions were identified from the data. Numerous conditions must be in place to facilitate learning within and between projects. Ultimately, principles can be categorized into five domains that emerged across both cases: Leadership, Environment, Learning relationship, Knowledge perceptions, and Thought process perceptions. The following subsections provide an explanation of how cases can create and manage these conditions.

4.1 Leadership

In both cases, it was found that each participant has a partial and limited vision of the project and its learning objectives. It is not possible for a particular group of experts or stakeholders to learn on behalf of all stakeholders (Pahl-Wostl et al., 2007). Leadership is necessary to ensure that knowledge is widely distributed. The responsibility for valuing and utilizing knowledge lies with the project parent organization, not the project manager (Winch and Leiringer, 2016). Both project owners set the tone, broke barriers, and played a crucial role in driving learning. In Case GSP, an alliance named RIXWAS was formed to show the relationship between the owner and contractor, intertwining RWS (the government representative) and IXAS (the contractor consortium). In the case of HZMB, the partnership philosophy is pursued by the HZMB Authority. The owner requires the cooperation of all parties to address project-related challenges.

Unlike the manufacturing setting, clients in infrastructure development projects are generally highly motivated to engage with professionals because professional services are primarily aimed at addressing their needs. The owner,

who aims to implement knowledge governance and act as the integrator of the learning organization, should recognize their central and influential role in prioritizing effective learning and sustaining it throughout the project. As stated by the assistant director of the HZMB Authority, the owner expects the project's learning impact to extend from early planning to later operational stages. However, the learning of project-based organizations is mainly used to achieve economies of scale. The cycle of accumulating experience, articulating knowledge, and codifying knowledge (Prencipe and Tell, 2001) necessitates the intervention of senior leadership in mediating policies and cultures.

In both cases, the owner bears the primary responsibility for establishing the culture, and it is crucial for all parties involved to maintain this culture. The GSP case contract includes a provision for regular alignment sessions in which the client and contractor can exchange views on specific topics. This arrangement creates a clear incentive to improve knowledge sharing among the different parties.

To summarize, the behavior of knowledge sharing depends on the active, committed, and engaged role of the owner. This aligns with Winch and Leiringer's argument that a strong owner is discussed in the context where the owner is more than just a contract giver but a client (2016). The attitudes and actions of the owner shape the knowledge sharing behaviors of project participants and influence how they learn and adapt.

4.2 Environment

Quantifying the type of knowledge shared in the learning process is challenging. Tacit knowledge, such as know-how and know-who, is more difficult to codify and measure (Lundvall and Johnson, 1994). In our cases, "soft" knowledge is more relevant. In the GSP case, an exploitative learning trajectory program has been established through collaboration between the owner and the contractor. This program provides a platform for open dialog and has generally been viewed positively. One of the main objectives of co-located work in this case is to reduce social distance between stakeholders. Profound learning occurs when individuals share their experiences, ask open questions, and share honest stories. The learning trajectory introduces a mindset shift that encourages thinking and discussing new things. Learning is facilitated by establishing a cultural and social environment that emphasizes reflection on experiences, trust among partners, and open communication to ensure effective decision-making and problem-solving processes (McClory et al., 2017). Learning is regarded as a people-oriented strategy, with project knowledge playing a crucial role in conveying narrative characteristics. In practical terms, project managers focus on the project's context and complexity, providing detailed narratives and case analyses. Due to the diverse backgrounds of individuals involved, various interpretations of objects within different contexts can arise. Throughout this process, project participants and their interactions are influenced by social conditions, leading to situational interpretations. The HZMB authority recognizes that projects primarily have short-term goals, while knowledge management is geared toward long-term objectives. Projects, being temporary organizational structures, possess unique characteristics that pose challenges for knowledge management (Lindner and Wald, 2011). The focus of concern lies in capturing and sustaining attention for learning. The social environment plays a crucial role in creating conditions for effective communication and knowledge sharing, allowing project participants to overcome the limitations of traditional hierarchical structures. For the HZMB project, the ambition is not to establish a formal knowledge system or record knowledge within systems for the broader organization. Instead, the emphasis is on active knowledge transfer to and within the target project team. This approach ensures that knowledge remains with the individuals involved, and only a limited number of documents are generated when the project concludes.

4.3 Learning relationship

Each individual has a "learning horizon," representing the extent of their effective learning in terms of time and space. When our actions have repercussions beyond our learning horizon, direct experiential learning becomes impossible (Senge, 2006). It is evident that project participants should learn from various stakeholders, and knowledge should be shared and transferred between organizations and projects.

The construction industry is inherently inclined toward collaboration. However, it faces challenges in identifying suitable partners for collaboration and extracting value from such collaborations. Previously, the scope of a project was determined by the owner, and the market was responsible for its delivery. In the case of the GSP project, both the owner and the market find themselves in unfamiliar territory, grappling with the uncertainty of how to proceed correctly. Strengthening the bond between public and private entities becomes crucial, thereby placing "collaborate to learn" and "learn to collaborate" on the agenda (Liu et al., 2021). Collaboration is a valuable learning strategy in project-based organizations as it offers access to new human and intellectual resources, facilitates knowledge exchange, and enhances performance. Project managers from both cases emphasized the importance of collaboration, particularly within the supply chain, over the practice of hiding information. As evidenced by the interviews, "who cannot share, cannot multiply" (GSP) and "differences in perspectives can be helpful, once recognized!" (HZMB), project participants can leverage their capabilities over time

through successive projects. This learning effect translates experience into adaptability and allows for more efficient and effective operations in new environments.

In both cases, collaboration was identified as the most significant factor in the learning process. The owner and contractor actively sought to promote a shift from a traditional, adversarial mindset to a more collaborative culture, as clearly reflected in their charters. Collaboration is centered around learning and creating value through cooperation. The resulting partnership embodies this project culture, as the collaboration was experienced as open and friendly. The owner's culture in both Case GSP and Case HZMB is described as an alliance culture, where working together is the norm. Lessons were learned from each other during this collaboration, aligning with the objectives of the learning process. Coincidentally, both projects initiated the creation of books to share their lessons learned, foster a collaborative learning culture, and disseminate knowledge among all participants. The GSP contract specifically highlights the need to enhance knowledge sharing among the parties involved.

4.4 Knowledge perceptions

Learning is a value-enhancing practice acknowledged by the Construction Industry Institute (CII) and Independent Project Analysis (IPA). Project-based learning goes beyond the mere achievement of transferring knowledge as a product and instead focuses on continuous performance, where learning is ingrained in daily processes. Traditional knowledge management revolves around managing projects within critical parameters like schedule and cost. However, we have observed that our cases place greater importance on the service logic of solving specific client problems rather than adhering strictly to project management logic.

The HZMB case study has discovered the benefits of extensive communication and value proposition discussions before the formal contract stage. Communication, particularly knowledge exchange and discussions surrounding previous experiences with similar projects, plays a central role in identifying adaptive solutions and strengthening the value propositions addressed in the megaproject as a program of projects. Emphasizing value-oriented learning is crucial as it fosters a sense of ownership among individuals. This can be further substantiated and expanded by incorporating new information from the GSP and HZMB cases.

In the conventional sense, knowledge was perceived as an object. However, in our two cases, the knowledge gained by the interviewees was not just practical but also tied to "soft" knowledge. The temporary nature of expertise generated in projects does not significantly impact its assimilation possibilities. Instead of solely focusing on cost reduction and project schedule compression, it may be more important to consider the value that learning brings to overall performance and organizational capabilities. Project participants are motivated by creating value and prioritize broader interests over short-term business gains. They gain a new understanding of the challenges they face and value diverse perspectives, leading to the emergence of a new consensus.

Learning assigns meaning to project happenings and serves as a carrier of organizational culture. All project participants take into account the situational considerations and sub-cultural context in the project environment. In Case GSP, the owner and contractor share a closer relationship with each other than with their parent organizations. Collaboration in this case was predominantly positive and personal, exemplifying the shared project culture and the mindset that should be carried forward to future projects. This project culture was experienced more strongly than individual organizational cultures. In conclusion, it is important to establish a relationship between organizational culture and the learning environment, encouraging participants to communicate and share knowledge and expertise not only with their colleagues but also across the supply chain, breaking down silos.

4.5 Thought process perceptions

Undertaking projects with temporary inter-organizational teams can pose challenges to knowledge sharing and transfer (Bakker, Knoben, et al., 2011b; Papadonikolaki et al., 2019). Therefore, it is necessary to look beyond present requirements and consider the future context of usage, properly plan for execution, and remain vigilant to external factors. The role of knowledge management and learning goes beyond a mere best practice toolkit for immediate use. The HZMB case provides alternative procurement and delivery models that can be emulated, but it is crucial to understand that there is no one-size-fits-all approach. As a groundbreaking megaproject, HZMB has also demonstrated that incorporating best practices from other industries and implementing innovations such as large precast and prefabricated elements, remote control, and information technology can significantly enhance project performance and productivity (Davies and Mackenzie, 2014). Each project presents unique challenges and structures, and ideas, practices, knowledge, and tools flow between projects. It is not necessary to have all capabilities in-house; rather, it is important to understand the specific type or scope of capabilities required for each project and how to develop and nurture the corresponding skill set.

Learning within projects is a cognitive and experiential process. Edmondson (2018) observed that high-performing teams are willing to acknowledge and discuss errors, fostering an environment of openness. In the case of HZMB, despite the installation of the first few tunnel elements in 2015, the E15 tunnel element faced a

significant challenge due to intense siltation. The contractor pooled their technical resources to tackle the problem. After two unsuccessful attempts at towing and immersion, the E15 tunnel element finally achieved a precise connection through trial-and-error learning on March 26, 2015. This experience served as an exemplary lesson for subsequent tunnel immersion projects. To foster productivity, individuals must focus on finding solutions for the project rather than placing blame for mistakes or complaining about processes. Open communication is essential, but it should aim to facilitate improvement rather than assigning blame or venting dissatisfaction.

5 Encapsulating project-based learning principles

Existing literature has demonstrated that different learning approaches are complementary instead of mutually exclusive, leading to an integrative socio-technical perspective (Cao et al., 2021). Theoretical and empirical evidence provides valuable insights for the future implementation of project-based learning principles in infrastructure development projects. By examining the fundamental conditions that enable project-based learning, we can establish principles for effective implementation. These principles act as astute guidelines for recurring situations. Both case studies provided informative narrative data and confirmed the significance of five principles for project-based learning. As a concise and accessible guide, we present the following five principles for project-based learning:

1) Owner commitment: This principle emphasizes the importance of the owner's motivation, engagement, and active participation in project-based learning. It recognizes the critical role of a committed owner as a project champion.

2) Social environment approach: This principle focuses on motivating and engaging teams, as well as facilitating meaningful dialogs and interactions within the social environment.

3) Collaboration vision: This principle emphasizes the coordination, quality, and ability of team members to work together effectively toward achieving the learning objectives.

4) Value orientation: This principle calls for assigning a more strategic role to learning within the project setting.

5) Open mindset: This principle highlights the ability of project participants to think outside the box during both the project design and implementation phases.

These principles define the necessary conditions for effective learning by project participants. They are dynamic and closely interconnected, working together to enhance each other's effects. Therefore, they should be implemented collectively rather than in isolation. The outputs of one principle provide critical input for another, creating a synergistic and systemic learning process. The arrows between the principles in Fig. 2 highlight the essential interconnections that exist between them. By reinforcing each other, the principles emphasize that the whole can be greater than the sum of its parts.

Theoretical and empirical research within the AEC industry reveals two structures for learning: the top-down approach and the bottom-up approach. The top-down approach, which is formal and institutional, relies on organizational procedures and is primarily used for business-led learning. This approach allows top management to have a strategic overview of market dynamics and the need to develop specific capabilities to maintain a competitive edge. New knowledge that is not directly related to the core business can still bring strategic advantages to the project. This approach encourages the creation of knowledge communities and supports knowledge exchange between "knowledge providers" and "knowledge seekers." This fosters the convergence of different perspectives and enhances the meaningfulness of learning as a value-enhancing practice.

On the other hand, the bottom-up approach to learning, which is informal and behavioral, occurs mainly within the social environment. It is characterized by day-to-day management practices that contribute to collaboration among project participants. This approach allows for different access to knowledge sources and encourages experimentation with sound practices and best practices when incorporating new technologies or developing new capabilities. Our case studies highlight numerous bottom-up learning initiatives and underscore the importance of learning from and with one another in various project situations.

The owner plays a crucial role in project management, possessing a strategic overview of project needs and the ability to motivate the team to stay ahead (Winch and Leiringer, 2016). To distribute necessary knowledge throughout the project, the owner can establish a specific learning program and database. Respondents and interviewees overwhelmingly believe that direct interactions with colleagues and project team members, both within

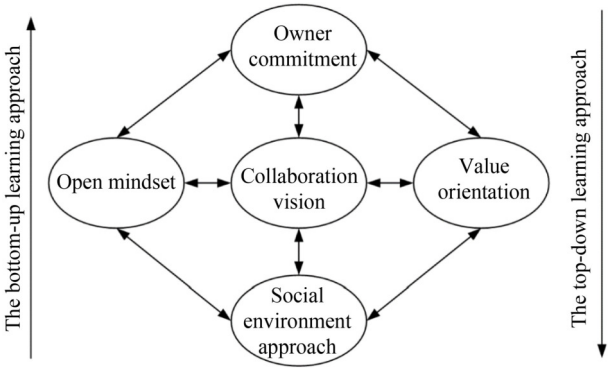

Fig. 2 Five project-based learning principles.

and outside the organization, are the most effective means of learning. The bottom-up learning approach in a social environment allows participants to construct a meaningful narrative about their experiences. Therefore, project-based learning should be fostered through social learning processes (Eltigani et al., 2020).

The principles of owner commitment and social environment can facilitate the other three principles. By building trust and providing access to information, individuals, and networks, a strong collaborative spirit is established and maintained (Ika and Donnelly, 2017). The value orientation principle reminds project participants of the importance of learning rather than solely focusing on short-term problem-solving and performance improvements. The final principle emphasizes embracing new ideas from outside the industry, encouraging the acceptance of mistakes, and fostering a culture of experimentation and trial and error (Liu et al., 2022). Unlike the value orientation principle, which centers on strategic positioning, this principle emphasizes the flexibility of learning, allowing it to evolve and expand its scope. The principles are summarized in Table 4.

We acknowledge that project-based reflection and analysis can also be initiated from the top down when deemed necessary by the owner and concerned project participants. However, the collection of lessons learned from each other and aligning thinking with the learning process is better suited to a social environment and a bottom-up approach. Collaboration provides a project-based organization with access to new human and intellectual resources. It is encouraged to adopt a service logic, prioritizing the resolution of the client's business problems rather than solely focusing on project management (Grabher, 2004). These principles advocate for a shift toward a principle-based approach that governs behavior and thinking, and includes a meta-capability rather than just a process (Eltigani et al., 2020). A process-based approach, in contrast, tends to focus too heavily on predictive work, providing specific actions and relying on external motivation. We contend that this type of approach is better suited to a hierarchical management structure. In the context of projects, a principle-based approach is more appropriate, particularly in a flat organizational structure with semi-autonomous operating units. Our principles provide a framework within which to operate, recognizing that there are various ways to adhere to their underlying intent. This is in line with the recently published Seventh Edition of the PMBOK Guide, which transitions from a process-oriented to a principles-oriented approach.

The concept of learning principles did not emerge out of thin air. Senge (2006) proposed the notion of a learning organization through five key disciplines, which offer a comprehensive framework for understanding how organizations can foster learning and adaptability. These principles of project-based learning can be viewed as a tailored and practical application of organizational learning principles within a project context. Effective learning should maximize value creation throughout the project lifecycle. The Value Delivery System, as introduced in the PMBOK Guide 7th edition, adopts a Systems Thinking approach, examining patterns and events as interconnected components. The discipline of Personal Mastery is specifically relevant to projects, emphasizing the owner's commitment. The owner acts as an orchestrator, establishing a network where project participants interact and share knowledge. Project participants are encouraged to actively engage in learning activities and adopt a continuous learning mindset alongside the project owner. An open and adaptable atmosphere is essential for innovation and problem-solving within project-based learning. An open mindset serves as a mental framework, while Shared Vision and Collaboration Vision complement each other. Genuine commitment and active participation are crucial for all forms of organizational learning. In project-based learning, the focus is on fostering collaboration, as project participants may have differing goals. Together, they form a team. Existing literature and practices highlight the limited effectiveness of codification and emphasize the need for social learning. Team learning and a social learning environment encourage collective and genuine thinking. Overall, Senge's principles not only endorse but also significantly enhance these principles of project-based learning.

6 Link project-based learning with project capabilities

The knowledge accumulated in projects may be lost when

Table 4 Use of five project-based learning principles

Principles	How principles can be achieved	Relation to other principles	Application
Owner commitment	Demonstrating learning value; Helping mediate tensions	strengthen	Creating a particular learning program and database; Reward instead of punishment; Proactive engagement
Social environment approach	Creating safe spaces for feedback	enable	Knowledge sharing workshops; An external knowledge party
Collaboration vision	Generating feelings of partnership	contribute to	Partnership; supply chain management
Value orientation	Attaining consensus and sustainability	set goals to	Management tool; Shaping the project culture
Open mindset	Thinking out of the box; Allowing mistakes	influence	Innovations from other industries; Experiment

the project team(s) is disbanded (Bakker et al., 2011a). Project-based organizations lack natural mechanisms for transferring and reusing knowledge captured in one project to subsequent phases and other projects. There is no efficient way to transfer knowledge learned in one project to the next. Both cases agree that the most important lessons learned are primarily tied to the experiences of the individuals involved in the project (Liu et al., 2021). Brady and Davies (2004) offer an interesting perspective on project-based learning. They argue that project-based learning can be analyzed and understood to build project capability over time. In this context, project capability refers to the knowledge and experience required to engage with customers and manage projects.

Learning enables project teams to develop a set of capabilities that can be applied in a dynamic environment. This construct refers to the specific skills and experience needed by project-based organizations to plan, design, and execute projects (Eriksson et al., 2017). It also includes high-level management skills and experiences that enable organizations to strategically design and implement projects.

Construction is innovative in many ways, but much of this innovation remains hidden as it happens in practice when problems arise, are solved, and then forgotten. Introducing ideas from outside the project team and learning through practical experience not only expands the potential sources of innovation but also emphasizes a new range of capabilities required to establish and develop collaborations with weak ties (Chesbrough, 2004). These capabilities involve managing external stakeholders, allowing the free flow of intellectual property and ideas, strengthening problem-solving abilities, and maintaining an agile and proactive organization. Project-based organizations implementing large-scale infrastructure development projects must build capability by understanding their cultural environment and employees' perspectives on the factors that enable or hinder knowledge transfer (Davies and Brady, 2000). Project capabilities involve acquiring the unique knowledge necessary to execute projects tailored to individual customer requirements (Davies and Brady, 2016). These capabilities are developed through the integration and transfer of knowledge (Grant, 1996). The firm's ability to adapt is dependent on and influenced by previously acquired managerial expertise and experience, as well as its ability to absorb new learning and build new capabilities.

To acquire project capabilities, project participants must cultivate and uphold in-house skills, competencies, and abilities that enable them to effectively engage with the supply chain. Certain capabilities can be viewed as learning outcomes through repeated interactions and follow different learning paths, such as the learning program observed in Case GSP and the partnership strategy promoted among international participants in Case HZMB.

Scholars argue that dynamic capabilities can be developed through deliberate learning activities (Winter, 2003; Zollo and Winter, 2002). Eisenhardt and Martin similarly identified experiential learning mechanisms involving repeated practice, learning from mistakes, and gaining experience over time (2000). In a similar vein, Dodgson defined learning as a dynamic capability, highlighting the continuously evolving nature of organizations (1993). Newell and Edelman also shared this perspective on project-based learning as a dynamic capability, as it involves adjusting routines and practices (2008). Easterby-Smith and Prieto independently supported a comparable stance and expanded their theory by incorporating the mediating effect of learning capabilities (2008). In the context of the project, we further developed the model originally proposed by Easterby-Smith and Prieto (2008). This model aligns with insights derived from prevailing trends and key studies on project-based learning found in the literature (represented in Fig. 3).

Critical project-based learning processes utilize both existing knowledge (exploitative learning) (Liu et al., 2021) and the creation of new knowledge (explorative learning) (Liu et al., 2022). Although exploitation and exploration are treated as separate entities, both exhibit ambidexterity. It is recommended to integrate exploitation and exploration to facilitate project-based learning (Turner et al., 2015). Within the integrative framework, exploitative and explorative learning contribute to the enhancement of project capabilities. Effective knowledge management involves both codification (technical process) (Ferres and Moehler, 2024) and personalization (social process) (Haesli and Boxall, 2005). Knowledge management can be strengthened by incorporating lessons from both exploitation and exploration (Zhou et al., 2022), while technical and social components offer complementary resources for the learning processes. Project-based learning serves as a crucial link between knowledge management and project capabilities. Following the original integral framework developed by Easterby-Smith and Prieto, the bidirectional arrows connecting learning processes, project capabilities, and knowledge management signify mutual interaction among them. Through its learning capabilities, a project-based organization can establish new project capabilities by implementing enhanced learning practices within and across projects (Ahern et al., 2015), thereby transforming itself to influence various projects throughout the organization.

The learning aspect undergoes dynamic changes in a complex environment with ambiguous challenges (Dowson et al., 2024). Innovation processes are stimulated by collaboration in megaprojects (He et al., 2021). It revolves around optimizing learning capabilities, recognizing and evaluating assumptions and patterns of action. This necessitates reflection on one's thoughts, actions, and learning, as well as the underlying assumptions that

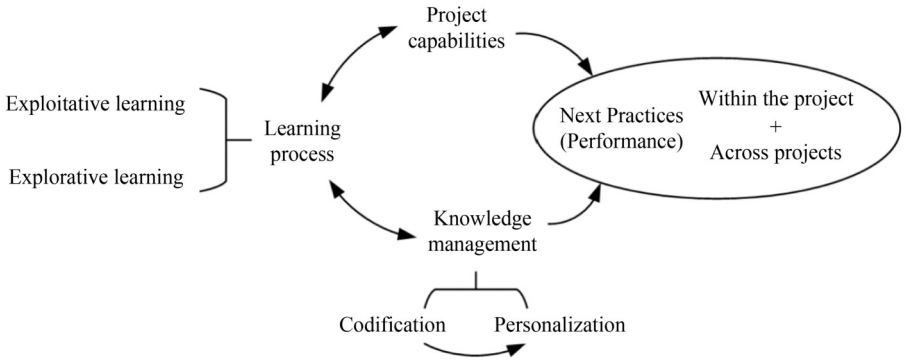

Fig. 3 An integrative framework linking learning, capabilities, and performance (Easterby-Smith and Prieto, 2008).

shape how project managers observe, interpret, define problems, analyze, conceptualize, act, and interact, as we have discussed in the five principles of project-based learning. This form of learning occurs through communication and exchange with others, seeking feedback, or, more simply, learning from the act of learning itself (McClory et al., 2017).

Considering the strong connection between learning and capabilities, we contend that research on project capabilities must also focus on learning capabilities. In project-based learning involving multiple parties, existing capabilities can be leveraged to generate new knowledge (Edmondson, 2012).

7 Conclusions

Project-based learning presents unique challenges due to the temporary and specialized nature of projects. It is not feasible to simply apply organizational learning theories developed for routine-based industries to the project context. To address this issue, a cross-case analysis of the Gaasperdammer tunnel project in the Netherlands and the Hong Kong–Zhuhai–Macao Bridge in China was conducted. The analysis yielded five project-based learning principles: 1) Owner commitment, 2) Social environment approach, 3) Collaboration vision, 4) Value orientation, and 5) Open mindset. It should be noted that reflecting on and analyzing project-based learning remains a priority only when deemed necessary by the owner and concerned project participants. Collaboration allows project-based organizations to access new human and intellectual resources, while learning from each other and aligning thoughts with the learning process is best achieved in a social environment.

This research sheds light on the dynamics of learning in the context of large infrastructure projects, which often occur within long-standing, stable business relationships among partners despite their temporary nature. It contributes to the advancement of project-based learning theories, moving beyond general organizational learning theories to focus on project-specific studies. This progression deepens our understanding of how project participants learn and develop through their involvement in unique and complex (especially large infrastructure) projects, enhancing their ability to manage and deliver such projects effectively. Central to our argument is the connection between learning and project capabilities, a link that is supported by empirical evidence from various case studies. This viewpoint aligns with the model proposed by Easterby-Smith and Prieto, which recognizes learning as the crucial mechanism bridging dynamic capabilities and knowledge management. This perspective challenges the traditional notion of project management as a mere set of best practices, emphasizing instead the identification and deployment of specific capabilities that are most valuable in a given project context. The research also underlines the significance of cultivating learning capabilities within project-based organizations as a fundamental competency for successful project management. It advocates for the establishment of continuous learning and development programs, the creation of a learning-oriented culture, and the allocation of dedicated resources to these endeavors. Such a strategic focus not only improves current project execution but also equips organizations to better handle future infrastructure projects, ensuring their long-term viability and adaptability.

In conclusion, through the deep integration of project-based learning into the operational framework of organizations engaged in large-scale infrastructure, project-based organizations can enhance their preparedness and empower themselves in order to effectively tackle the complex project demands of the future. This approach not only optimizes project delivery mechanisms, but also reinforces the overall strategic capabilities of these organizations, thereby ensuring their long-term sustainability and adaptability in an ever more uncertain global landscape.

Competing Interests The authors declare that they have no competing interests.

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