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Harvesting living labs outcomes through learning pathways

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ABSTRACT

Living labs have emerged as a long-term, collaborative approach to addressing complex societal challenges, such as sustainable land and water management and climate change adaption. While these transdisciplinary environments foster continuous knowledge exchange and interactions among actors from diverse disciplines and sectors, the role of learning in realizing the impacts of living labs on participating actors and broader society is often underexplored. This paper aims to identify and analyze learning that occurs within a sequence of co-creative activities and their resulting outcomes, using the concept of '*learning pathways*'. The '*living lab learning framework*' provides a systematic approach to organizing and categorizing living lab activities, enabling to infer learning pathways. An ex-post analysis of an empirical case study on a climate adaptation project, KLIMAP, resulted in seven distinct *learning pathways*: 1) harnessing collective integrated knowledge, 2) building collaborative networks, 3) enhancing stakeholder capacity, 4) adapting and contextualizing knowledge, 5) diffusing knowledge, 6) facilitating co-creation, and 7) reflecting on learning. These pathways were developed by examining the types of learning activities, their processes, and the entities involved, linking them to the outcomes achieved. The findings highlight that learning pathways contribute to identifying outcomes and broader impacts of living labs.

1. Introduction

Our water and land systems lie at the heart of some of the most pressing sustainability challenges, such as climate change, water scarcity, intensive agricultural practices, nature conservation, and resource conflicts (Ingrao et al., 2023; Meyfroidt et al., 2022; Rodell et al., 2018). These systems represent complex societal challenges, and managing them requires long-term, strategic, and collaborative planning (Haddeland et al., 2014; Karimi et al., 2018). In response, many water and land management practices are increasingly adopting sustainable development principles and fostering collaboration across diverse sectors, disciplines, and stakeholder groups, aiming to integrate innovations into society, policy, and governance (Bhatta et al., 2023a; Larsson and Holmberg, 2018). In recent years, living labs have emerged as a transdisciplinary approach to tackling environmental challenges through innovative solutions (Peña-Torres and Reina-Rozo, 2022; Unger et al., 2022). Conceptualized as "a milieu (ecosystem, arena), a methodology, or an approach" (Bergvall-Kåreborn et al., 2009)or an "innovation network" (Leminen et al., 2012), living labs may take the form of physical spaces, platforms, or interaction spaces (Zingraff-Hamed et al., 2020). They have proliferated across geographical domains—such as campuses, rural and urban areas, and across application domains—such as energy, healthcare, and land and water management (Bhatta et al., 2023b, p. fig. 2). Tailored to specific applications, living labs drive innovation through co-creative activities within a network of public organizations, private organizations, academia, and civil society (Bhatta et al., 2023b; Hermans et al., 2013). The exchange of knowledge and experiences among these diverse actors establishes a strong foundation for cross-sectoral and interdisciplinary understanding of the challenges, leading to effective and innovative solutions (Castán Broto et al., 2022; Roux et al., 2017). Indeed, continuous mutual learning and interactions among stakeholders are vital in shaping innovative solutions (Boaz et al., 2018; Metz et al., 2019).

Although widely used as an approach to innovation, living labs rarely highlight the role of learning in co-creation (Bhatta et al., 2024). Often, co-creation is seen as a 'virtue in itself' with little to no attention to how it drives innovation (Dekker et al., 2021; Voorberg et al., 2015). Further, living lab impacts are usually assessed by their direct and

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tangible results, overlooking the significant outcomes emerging from learning activities and interactions (Bhatta et al., 2024; Lux et al., 2019). Yet, learning within living labs contributes to a broader understanding of the subject area, increases cross-sectoral engagement, and supports network-formation, value-creation, and scaling-up of innovations (Pärli et al., 2022). Thus, recognizing and mapping learning in living labs can significantly enhance their innovation capacity by capturing valuable outcomes, fostering continuous improvement, and providing recommendations for future initiatives (Andrade et al., 2022).

Learning is not merely a single activity or a moment of action in the context of living lab projects. Instead, it is a continuous and iterative process that includes multiple activities that lead to specific outcomes (Viera Trevisan et al., 2024). This learning journey can be effectively captured through *learning pathways* (Harris et al., 2006). *Learning pathways* provide a structured approach to navigating and sequencing learning experiences and guide individuals and organizations through acquiring and refining their knowledge and competencies, leading to specific outcomes (Harris et al., 2006; Mphinyane, 2013; Ramsarup, 2017). In a living lab co-creative environment, these pathways include diverse activities, such as training sessions, co-creation workshops, user meetings, self-directed learning, and hands-on experiences (Huang and Thomas, 2021). Designing or mapping learning within living labs to distill such pathways can deepen understanding of the project's broader impacts, ensuring recognition of the full spectrum of learning activities leading to the outcomes. Indeed, a *learning pathway* is a pluralistic approach that attends to multiple levels intrinsic to learning across time (de Royston et al., 2020).

While a *learning pathway* can serve as a pragmatic way for a co-creative project to either design or map project outcomes, empirical research on learning pathways remains limited (De Smet et al., 2016). This gap is partly due to the lack of a consistent and relevant way of describing pathways in relation to the resulting outcomes (Janssen et al., 2008). A framework that aligns learning activities and experiences in a co-creative environment with their resulting outcomes can aid in developing *learning pathways* (Bhatta et al., 2024; Travers et al., 2019). In this paper, the *living lab learning framework* grounded in learning theories developed by Bhatta et al. (2024) is applied to distinguish *learning pathways* in an empirical case of climate adaptation in the Netherlands.

The selected case study is intriguing in that diverse stakeholders were involved in developing climate-adaptive solutions at the landscape scale in a multi-layered approach extending from local-level field experiments to regional transformative agendas. This living lab provided the empirical context in which learning pathways are explored. The paper is organized as follows: after this introduction, a theoretical section on the extension of the *living lab learning framework* by Bhatta et al. (2024) to address learning pathways is presented, followed by an introduction to the case study and the methods section. Then, learning in the empirical case study is categorized according to the framework, and *learning pathways* are drawn. Lastly, the concluding section summarizes the findings, identifies research limitations, and provides recommendations for future research.

2. Theoretical background on the living lab learning framework

Participants in a living lab co-creative environment contribute a diversity of knowledge and expertise, making their interactions reciprocal and the benefits mutual (Napan, 2015). Thus, the roles of "novice" and "expert" are fluid and interchangeable, unlike in traditional learning environments. Although living labs may include expert-led workshops or capacity-building training, they do not maintain fixed learner-educator roles throughout the project (Bhatta et al., 2024; McCormick and Kiss, 2015). This creates a dynamic learning environment that prioritizes continuous co-learning and development in physical, virtual, or blended settings. A learning environment is understood as the physical and virtual interaction space between the learning participants (stakeholders), learning content, and learning tools (McCormick and Kiss, 2015). Within a learning environment such as a living lab, a learning framework can serve as a guide to identify and structurally categorize learning activities and experiences (Bhatta et al., 2024; Travers et al., 2019). It is applicable at different phases of the living lab, as,

- During the initiation phase (ex-ante), it facilitates designing and aligning learning activities to the project outcomes,
- During implementation (ongoing), it can aid in monitoring learning progress and identifying knowledge gaps,
- During post-project evaluation phase (ex-post), it can be applied to map learning to recognize and enhance the outcomes systematically.

In this light, Bhatta et al. (2024) developed a *living lab learning framework* rooted in learning theories. They identify ten relevant learning theories—behaviorism, cognitivism, constructivism, experimental, situated, social, organizational, transformative, and connectivism—based on the characteristics of living labs. These theories are explored through three key questions; "What type of knowledge is produced?", "Who is learning?" and "How does learning occur?". The insights are synthesized into an analytical *Living Lab Learning Framework* with three interacting components: 'Learning Type' (what), 'Learning Process' (how), and 'Learning Level' (who), which are connected to learning outcomes, as shown in Fig. 1.

In the framework, *'Learning Type'* refers to the nature of the knowledge shared and created; *'Learning Process'* is understood as the method of acquiring learning; and *'Learning Level'* relates to the entities involved in learning. The *'Learning Type'* is categorized as content, capacity, and network, where *content* involves acquiring substantive knowledge on a specific concept or subject area; *capacity* involves applying content knowledge and acquiring skills in real-life, and *network* involves understanding the behavior, priorities, and values of relevant actors to engage meaningfully with them. The *'Learning Process'* incorporates various ways of engagement, such as cognitive activities (cognitivism and constructivism learning theory), learning-by-experiencing (experiential and situated learning theory), learning-by-interacting (situated and social learning theory), and learning-by-reflecting (transformative learning theory). The learning process is classified as intentional and incidental, where *intentional* is understood as deliberate learning facilitated by implementing diverse tools, methods, and activities to achieve planned outcomes, and *incidental* involves unplanned learning that occurs as a byproduct of other activities/experiences. While *incidental learning* can't be pre-designed in a project, it can be monitored through ongoing reflection and can be mapped after the project's completion. Likewise, *'Learning Level'* is classified as individual, team, organizational, and systemic level learning.

The three learning components and their composite elements (subcomponents) can be building blocks in designing, mapping, and monitoring *learning pathways* toward outcomes within empirical living lab projects. Indeed, living lab projects may be viewed as comprising a series of project activities with specific outcomes. Such activities are designed to enable and promote collaboration. They are often described using a variety of terms, including participation, co-creation, stakeholder engagement, joint knowledge sharing and creation, and more (d'Hont, 2020). In this approach, each pathway connects elements from the learning process, learning type, and learning levels to outcomes to distinguish the learning occurring within a particular living lab co-creative activity.

While many learning pathways are possible (Supplementary Material), they do not necessarily unfold within a single co-creative project. Thus, it is both impractical and unlikely for a qualitative study to capture the vast variety of possible learning routes. Instead, a pragmatic approach to mapping learning pathways is to start with a focal component of the framework. For example, if the outcomes of unintentional learning are of interest, then the analysis could focus on activities in which unintentional learning occurred and identify their

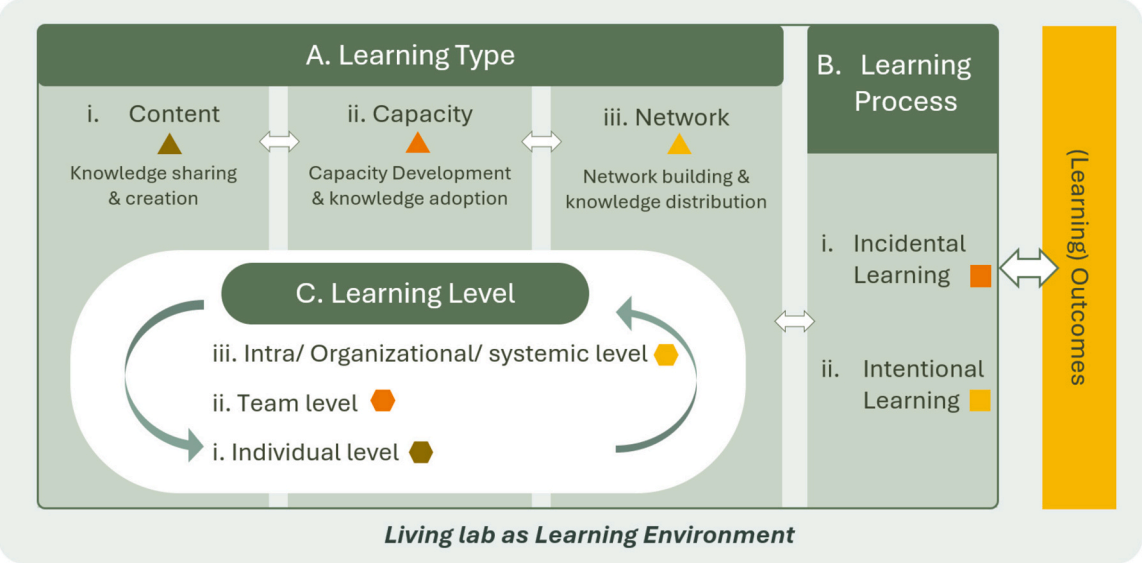

Fig. 1. Analytical learning framework for living labs as a learning environment; adapted from (Bhatta et al., 2024).

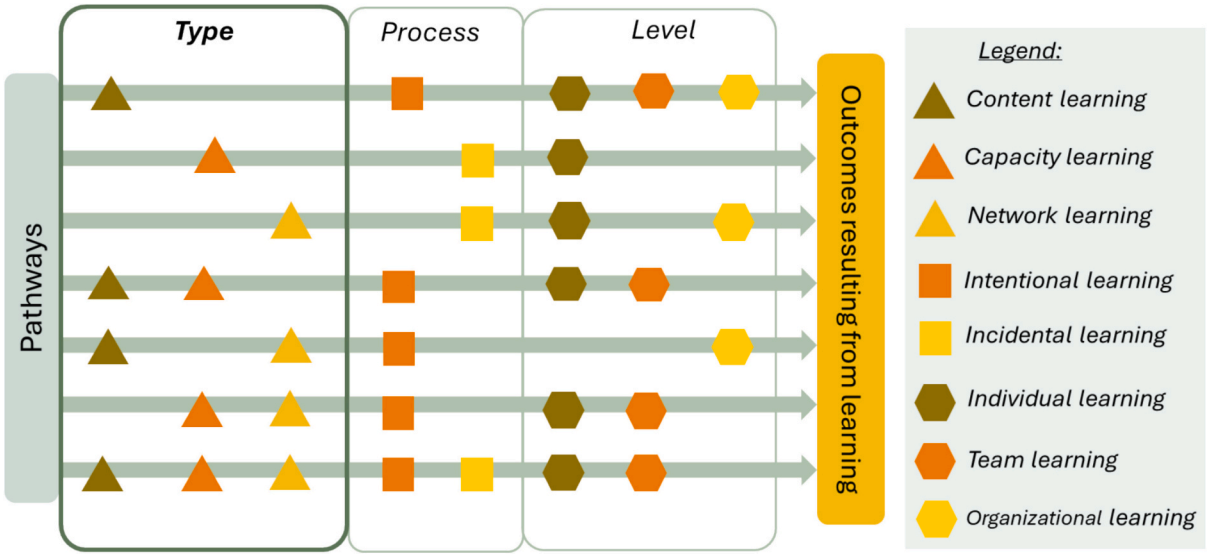

Fig. 2. A complete set of activity-specific learning pathways, built by focusing on learning types.

associated learning types and learning levels. Similarly, if the sphere of influence of learning or scaling-up of outcomes is of interest, then the analysis could focus on activities with distinct learning levels and identify their associated learning process and learning types. Likewise, if the outcomes from different learning types are of interest, then the analysis could focus on activities with different learning types and identify their associated learning process and learning levels. In this way, activity-specific learning pathways, comprising combinations of learning type, learning process, and learning level, may be mapped. When activity-specific learning pathway is mapped for unique learning type (Fig. 2), the associated learning process can be either intentional, incidental, or both, and learning level can be either individual, team, organization, any two of them, or all of them. is unique for each pathway. These distinct combinations form unique learning pathways. In this case, the pathways are unique to the learning types yet may vary in the learning process and level. No two activity-specific pathways mapped in this manner can exhibit the same learning type category, but they may exhibit similar learning processes or learning levels.

3. Case and methods

Addressing complex societal challenges requires more than just academic insights; it necessitates the practical application of knowledge in real-world contexts. This calls for transdisciplinary research in a socially relevant problem field, where the collaboration between researchers and practitioners can lead to innovative solutions (Pohl and Hadorn, 2008). Thus, this paper adopts a case study as the method of gathering evidence in a real-life context (Flyvbjerg, 2006; Yin, 2003), where key findings on learning within the case study are explored by applying the *Living Lab Learning Framework* and presented via *learning pathways*. The following sections provide an overview of the selected case study and details of the methods employed in this research.

3.1. KLIMAP case study

KLIMAP (KLIMaat Adaptatie in de Praktijk/ Climate Adaptation in Practice) is a collaborative network researching how the water and soil systems in the high sandy soil landscape of the Netherlands can be

designed for climate adaption. Due to their permeability, sandy soils are increasingly vulnerable to climate change effects, such as droughts and floods (Ladányi et al., 2021). The eastern and southern regions of the Netherlands, characterized by sandy soils, experienced severe droughts in the years 2018–2020 and 2022 (Bartholomeus et al., 2023; Rakovec et al., 2022). In the summer of 2021, extremely heavy precipitation affected many parts of the southern Netherlands (Lehmkuhl et al., 2022). In response to such extreme events, many projects are actively addressing these challenges at different scales in these areas, KLIMAP being one of them. From 2020 to 2024, KLIMAP collaborated with stakeholders from the regional authorities (provinces and water-authorities), private companies (farmer business owners, farmer organizations), and research institutes to generate insights on climate adaptation at the landscape level (KLIMAP, 2020-2024). KLIMAP focused on designing climate-adaptive sandy soil landscapes in six larger regions, termed 'case studies' through 'development pathways'. 'Development pathways' is a flexible planning tool for an uncertain future where multiple paths are designed toward a desired future, and steps are taken to identify a necessary set of different climate-adaptive measures for the short-term, mid-term, and long-term. These actions include technical measures, changes in spatial function, policy, and regulations. Experiments with some of these measures were conducted in more than 25 sites (Fig. 3). The experiments broadly focus on diversifying crop types, improving water retention, or enhancing soil structure. The experiments developed relevant technical knowledge concerning the effects of interventions such as wet-crop cultivation, a mix of different herb types, and innovative drainage systems. Additionally, national and regional hydrological models and analyses were used to explore possible future trends. In sum, KLIMAP sought to develop innovative approaches for creating climate-resilient sandy landscapes and to support various organizations, particularly public organizations, in implementing these approaches.

Geographically embedded in the east and south of the Netherlands, as shown in Fig. 3, KLIMAP embodies the core characteristics of a living lab (Bhatta et al., 2023b; Hossain et al., 2019; Steen and Van Bueren, 2017). It explored, experimented, and evaluated climate adaptation measures and pathways in a real-world context through a 'multi-stakeholder' approach within the Dutch governance system (KLIMAP, 2020-2024). The multi-stakeholder approach followed the quadruple helix model of collaboration, involving the public and private sectors, academia, and farmers; although individual farmers were not directly involved in co-creation, their interests were represented by farming groups. The innovative solutions developed within KLIMAP were co-designed in a flexible and iterative environment from diverse perspectives of stakeholders, where stakeholders and users played a central role.

The KLIMAP project contained multiple experiment sites and study regions that connected the field-level experiments to landscape-level development pathways. Thus, the single case study of KLIMAP was sufficiently broad to enable the mapping of learning pathways - the focus of this research (Yin, 2003). The research team followed the KLIMAP project for over two years. At the time of writing, KLIMAP had completed its research phase and was primarily focused on documenting and reporting its final findings.

3.2. Methods

The research adopts a mixed method approach, including (i) Desk-based document analysis, (ii) Participation in workshops and meetings, (iii) Survey, and (iv) Interviews. The document analysis was conducted to understand KLIMAP's aim, design, inputs, activities, lessons learned, expected output, and outcomes. The analyzed documents comprised KLIMAP progress reports, documents on KLIMAP case

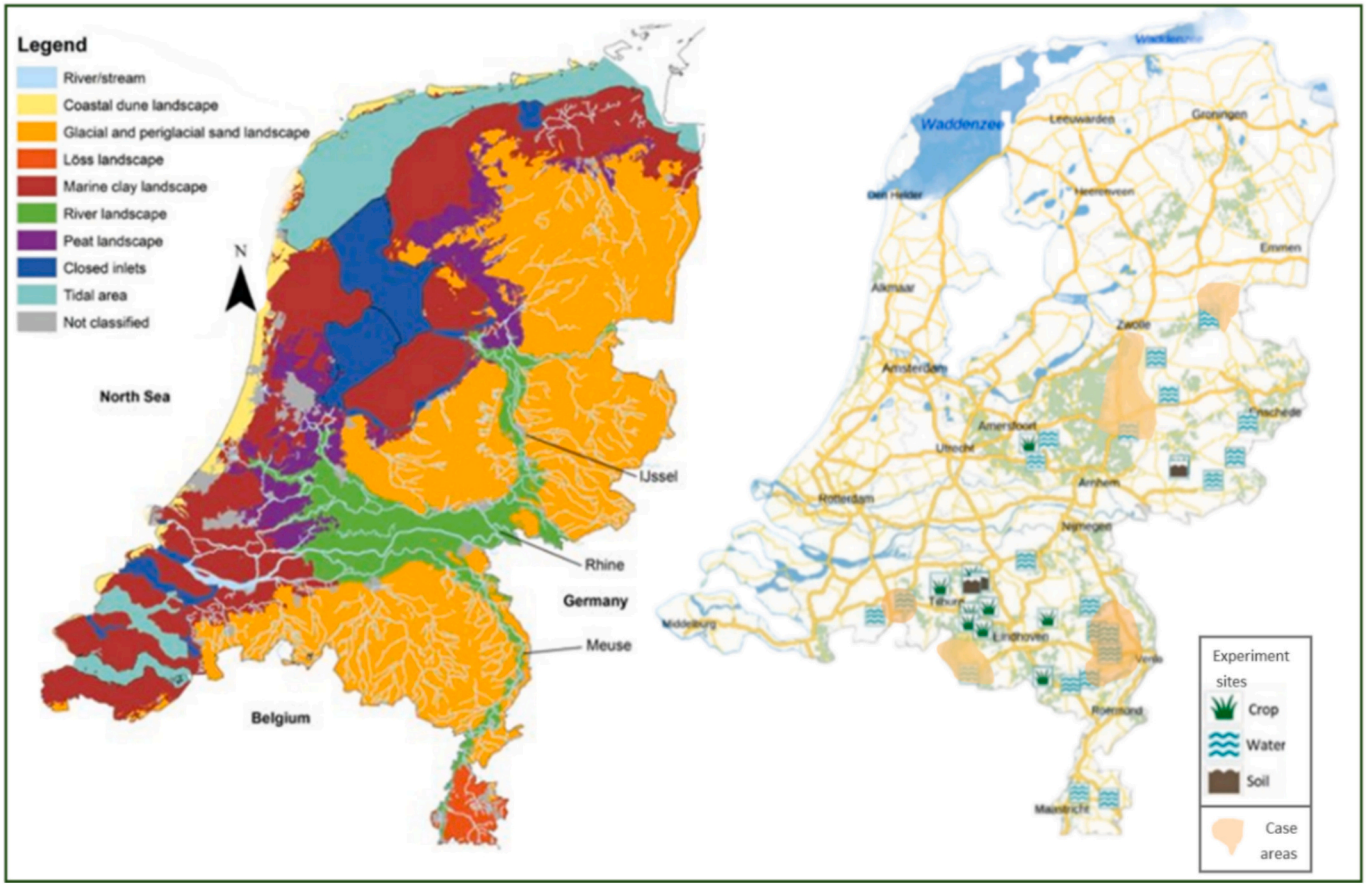

Fig. 3. Dutch landscape highlighting sandy landscape in the east and south of the Netherlands (left), KLIMAP experimentation sites, and case study areas (right).

studies, factsheets on the experiments, minutes of living lab meetings, and knowledge sessions from 2021 to 2024. No final living lab project reporting was analyzed, as this was not yet available. The document analysis facilitated capturing the project's progress timeline, experimental and case study locations, involved actors, co-creative activities, and the associated outcomes and learning. Additionally, the author(s) actively participated in several co-creative and brainstorming sessions on-site ($N = 3$), community of practice (COP) meetings ($N = 2$), and the final project symposium ($N = 1$). The authors' involvement in these sessions can best be described as participatory and non-interventionist, as they neither acted as the designers nor the facilitators of the workshops and meetings.

A survey was conducted at the final KLIMAP symposium on 21st March 2024 with a relevant pool of stakeholders ($N = 26$), where almost half ($N = 12$) were external actors present only at the symposium, and the rest ($N = 14$) were directly involved in KLIMAP (Supplementary Material). The surveys were conducted to gather the stakeholders' insights and reflections on the co-creation activities and outcomes of the KLIMAP living lab project. Survey respondents were asked to assess how various project activities contributed to the learning and outcomes of the project (only for KLIMAP respondents) and potentially to future projects (all respondents). The survey was conducted and analyzed using Qualtrics software, which complies with EU regulations by meeting the requirements of GDPR Article 28, which governs acquisition, processing, and storage of personal data.

Semi-structured interviews (N = 12) were conducted with a selection of KLIMAP coordinators, work package leaders, field-experiment experts, and knowledge session facilitators, all of whom were actively involved in designing and conducting activities within the project (Supplementary Material). A widely applied method in qualitative research, the snowball sampling procedure (Goodman, 1961), was adopted in selecting the interviewees. The interview started with a small pool of known informants; they were asked to recommend further potential interviewees, leading to the full selection of interviewees. In the final selection, attention was paid to ensuring a good mix between sectors (e.g., agriculture, water management, knowledge management). In the semi-structured interviews, the discussion focused on what went well, what didn't, and why, aiming to capture strengths, limitations, and reflective learning on project activities. The interviews were coded using Atlas.ti data analysis software.

In analyzing the data, 32 key activities in the KLIMAP project were coded. The *project activities* were taken as the unit of analysis (d'Hont and Slinger, 2022; McEvoy, 2019). An activity is a combination of subject or material being addressed and the way in which it is organized or executed (McEvoy et al., 2018; Thissen and Twaalfhoven, 2001). The organizational aspects, such as the interactions and communication between participants, relate to the structure and flow of the activity. Meanwhile, the substance of the activity, like the knowledge or information shared and utilized, focuses on the material being addressed. Thus, an activity is a singular event, such as a workshop, that involves stakeholders in carrying out various actions aimed at jointly supporting problem-structuring, finding solutions, making decisions, or implementing (McEvoy et al., 2018). The project's activities were identified primarily from the interview data, document analysis and participatory observation.

These key activities were grouped with a primary focus on the "Learning Types" component of the *living lab learning framework* by Bhatta et al. (2024) to determine the learning pathways. This means that each activity was first categorized into one of seven unique learning types (Fig. 2), namely: (i) content learning only, (ii) capacity learning only, (iii) network learning only, (iv) content and capacity learning, (v) content and network learning, (vi) capacity and network learning, or (vii) content, capacity and network learning.

Next, the learning process and learning levels associated with each of the seven activity-specific learning types were identified and coded. These distinct combinations form unique learning pathways. In this case, the pathways are unique to the learning types but may exhibit similar learning processes or levels. Some activities were coded in multiple pathways as they exhibited more than one learning type depending on their design and context. For instance, "workshop" is a common co-creation activity conducted numerous times with different goals within KLIMAP. When subjects dealt in a workshop led to substantive content knowledge, it was coded as content learning type, whereas when ways in which the workshop are organized within a COP helped refine one's understanding, enhanced their skills, and led to new connections, it was coded as content, capacity, and network learning.

As this study involved human subjects, the authors developed a data management and human ethics review plan in accordance with the requirements of the Delft University of Technology, as approved by the Human Research Ethics Committee under application number 106178, where all personally identifiable information (PII) was anonymized and processed confidentially (Supplementary Material).

4. Results

The following section identifies key activities undertaken in the KLIMAP living lab project. Each activity was categorized into one of seven unique learning types, described in section 2. Activities with the same learning types were grouped and linked to their corresponding outcomes. Table 1 highlights key activities, categorizes them into their respective learning types, and links them to their resulting outcomes and impact.

The respective learning process and levels for activities within all seven unique learning types are categorized as conceptualized in Fig. 4. Based on the connection between these activities and their outcomes, seven distinct learning pathways were distinguished as described in Sections 4.1 to 4.7 and summarized in Fig. 7.

4.1. Pathway 1: Integrated substantive knowledge creation pathway

This learning pathway emphasizes intentional co-development of content-specific knowledge on climate-resilient measures across all learning levels. A range of activities (Table 1)—such as expert-led lectures, field trials, and joint knowledge development—contributed to creating integrated substantive knowledge. Stakeholders were updated and connected through regular in-person, online meetings, and seasonal field experiment sessions with minutes recorded for each meeting. These activities were intentionally planned to facilitate the knowledge exchange and are formative in acquiring content-related insights on climate adaptive concepts and measures.

Early in the process, the KLIMAP actors recognized the need to clarify, contrast, and connect new measures with existing practices in the region. Consequently, knowledge from national and institutional sources, literature, and policy documents were integrated with local insights, novel measures arising from field experimentations, and introduction of the 'development pathways' concept in the area. These measures consisted not only of physical interventions but also of policy and social interventions. A few field experiments included,

- introducing different species of earthworms in the soil,
- combating silting and compaction in the soil,
- determining crop evaporation by mixing diverse crop types,
- deep soil mixing, and wet agriculture (paludiculture) among others.

These measures were collectively developed and evaluated for their resilience to climate change, soil and water quality improvement, and ecosystem restoration. The concept of development pathways was theoretically explored in the case study areas. This concept was investigated to highlight possible strategic choices toward climate adaptation in sandy soil landscapes and identify the signals as to when to adjust the course of an existing strategy. KLIMAP theoretically investigated the concept of development paths to support decision-making and learn

about the changing living environment and social needs (KLIMAP, 2020-2024).

The multi-perspective collaboration between the actors from diverse sectors and areas of expertise led to a unified knowledge management resource, namely the 'KLIMAP Menu'. This is a catalog of climate adaptive measures for sandy soils that detail each measure's favorable conditions, degree of climate robustness, risks and opportunities, economic aspects, hydrological effects, and more.

Different combinations of these measures need to be applied coherently to address the effects of climate change. As the type of measures and their effectiveness depend on the water-soil interaction (groundwater table level), sets of measures were grouped into sub-areas, namely high grounds, flanks, and stream valleys. These sets of measures provide an overview of the effectiveness and applicability of adaptation measures in a specific (sub)area. The students, interns, and graduates who participated in the project produced numerous theses, papers, and policy briefs on climate adaptation. In the survey, 93 % of participants from KLIMAP reported a better understanding of climate adaptation measures.

While many minor setbacks were gradually overcome with the lessons learned, the experiment on drip irrigation was considered a significant failure in KLIMAP. Intended to conserve water in sandy soil during dry summers, the experiment failed owing to an unexpectedly wet year and the reliance on single-use materials, preventing continuation in a subsequent hot and dry year. Some participants described this series of unfortunate events and decisions as 'a very bitter pill to shallow'. Still, whether successful or not, the measures experimented and researched served to establish new insights across all learning levels.

4.2. *Pathway 2: Collaborative network formation pathway*

The process of collaboratively identifying stakeholders begins in several ways, depending on the context, project, and existing relationships among initial participants. The main activities in network formation as initiated by the KLIMAP's core group (Table 1) include framing the challenge, identifying key stakeholders, inviting these relevant stakeholders, establishing agreements on contributions, and assigning

Table 1
KLIMAP activities, their respective learning types, and resulting outcomes.

Activities	'Learning types'		Outcomes
1)	Expert-led lectures and presentations, utilization of existing knowledge sources and platforms, operationalization of diverse field trials, sensor logs reports from the field trials, documentation of meeting-minutes, meetings reporting, co-creative workshops, and joint knowledge sharing and creation	*Content learning*: These activities allowed stakeholders to share and acquire substantiative knowledge on a specific concept or subject, e.g., climate adaptive measures and co-create new insights to further the knowledge	*New integrated knowledge, insights and lessons learnt:* Formation of joint-knowledge base, a catalog of climate adaptive measures for sandy soils divided into sub-regions (high grounds, flanks and stream valleys); production of numerous theses, papers, and policy briefs in relation to climate adaptation
2)	Identifying key stakeholders with stakes in the issue (snowball approach), reaching out and communicating to invite the relevant stakeholders, opening dialogues and exploration, establishing agreements on stakeholder organization's contribution, holding strategic planning sessions, mutually assigning roles within the living lab project, workshops to open dialogue around framing the challenge	*Network learning:* These activities enabled stakeholders to understand the importance of each other's perspectives, behavior, priorities, and thus, engage meaningfully with each other	*Formation of a collaborative network:* Improved trust and better understanding of sectoral interests and resources, leading to various new relations and projects, such as smaller internal collaborations, new projects such as CASTOR, NAT, Waterscapes, and Reshape (Fig. 4).
3)	Co-creative workshop/sessions to design or apply diverse methods & tools to support working with development pathways across various case study regions: (i) Co-development and use of a "framework" to guide the exploration of development paths, (ii) Development & application of an "evaluation tool" to assess pathways and a "serious game" to an accessible experience to engage with the development path concepts	*Content and capacity learning:* These activities allowed stakeholders to acquire knowledge on diverse co-creative methods and tools and apply them in various real-life context within KLIMAP	*Capacity to use right tools in right way:* Improved readiness level in relation to application of development paths; Enhanced capacity to design & use diverse methods, frameworks and tools to guide practical exploration of climate-adaptive development pathways, evaluate them against selected criteria; Understanding on 'know-how'/ procedural knowledge
4)	Community of practice (COPs), co-creative workshops, and learning sessions that utilize techniques such as round table & table-swap discussion, virtual engagement, different co-creation techniques, learning and engagement activities, joint analysis, discussion on concepts, and feedback on methods and tools, to evaluate constraints and opportunities in different contexts and modify methods and tools accordingly	*Content, capacity, and network learning:* These activities allowed stakeholders to refine their understanding on diverse concepts, tools, co-creative methods; contextualize them in different situations; make new connections with other actors; and learn from peers	*Resituating knowledge in diverse contexts:* Refined framework and tools resulting from practical implementation in multiple contexts, new insights formation through participatory frameworks such as COPs, enhanced capacity to adapt knowledge and tools in diverse contexts, understanding on new perspectives and formation of new connections
5)	Activities to disseminate and upscale knowledge, via storytelling and blog writing in social media platforms, interviews in mainstream media channels such as newspapers and radio, podcasts, sharing preliminary and intermediate results in impactful magazines and project website, presenting results to wider network and advocacy to public bodies	*Content and network learning:* These activities enabled stakeholders to share the acquired substantive knowledge beyond the boundary of the living lab and engage meaningfully with other interest groups by leveraging both depth of content as well as the strength of the networks.	*Knowledge & innovation dissemination:* Wider application of the knowledge created, and tools developed beyond the project's immediate boundaries nationally and internationally; increased collaboration and networking; improved awareness of climate-adaptive measures, potential impact on institutional and policy change
6)	Designing effective communication strategies and operational guidelines, multiple methods to promote open dialogues and active listening, facilitating group discussions, creating inclusive environments, and providing additional support training	*Capacity and network learning:* These activities allow stakeholders to improve their own competencies but also leverage shared experiences and insights from a broader network	*Increased engagement leading to better decision making:* Improved trust and understanding, Informed decision making, better engagement, reduced miscommunication, improved inclusivity, deepened understanding of each other's values
7)	Goal setting and collective reflection on the process, self-reflection, continuous feedback and discussions, reporting and meeting minutes, recording experiences, using methods that have reflective elements to them, and (informal) participatory monitoring	*Capacity learning:* These activities enabled assessing and adapting the project process and interventions, with a focus on learning & reflection based on feedback and discussion	*Capacity to reflect, rectify and recommend:* Better understanding of project process, improved adaptability, insights for future projects, understanding on how actions interact with the broader system & how usual practices are embedded in the institutions

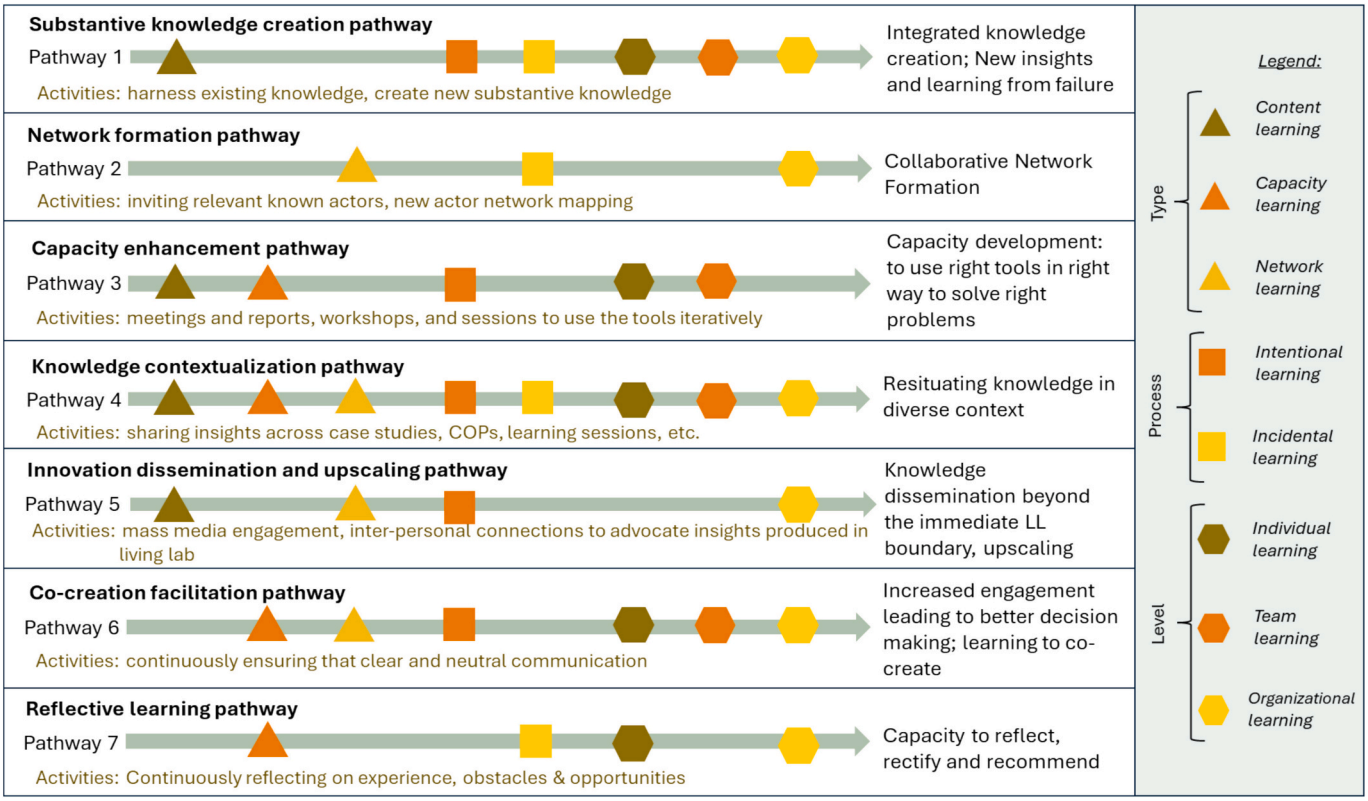

Fig. 4. Learning pathway skeleton focused on learning type component for KLIMAP.

roles within the living lab. Roles include coordinators, facilitators, team leaders, and ambassadors for the respective organizations.

KLIMAP, being a continuation of the earlier network Lumbricus, had the opportunity to leverage the existing network and expand it with new organizations. Recognizing the need to broaden and disseminate the project's knowledge, stakeholders from Lumbricus established KLIMAP with a wider scope. Consequently, various Lumbricus stakeholders joined KLIMAP and invited new organizations. The KLIMAP network numbers 24 partners and is comprised of water-authorities from the sandy soil regions, associated provinces, diverse research universities and institutes, private organizations, farmer's organizations, and individual farmers. Each stakeholder had specific roles and responsibilities: water-authorities ensured the innovation's practicality. Farming organizations aligned innovations with farmers' well-being and sustainable farming practices, while nature organizations aligned innovation with preservation of nature areas. Private organizations provided instruments

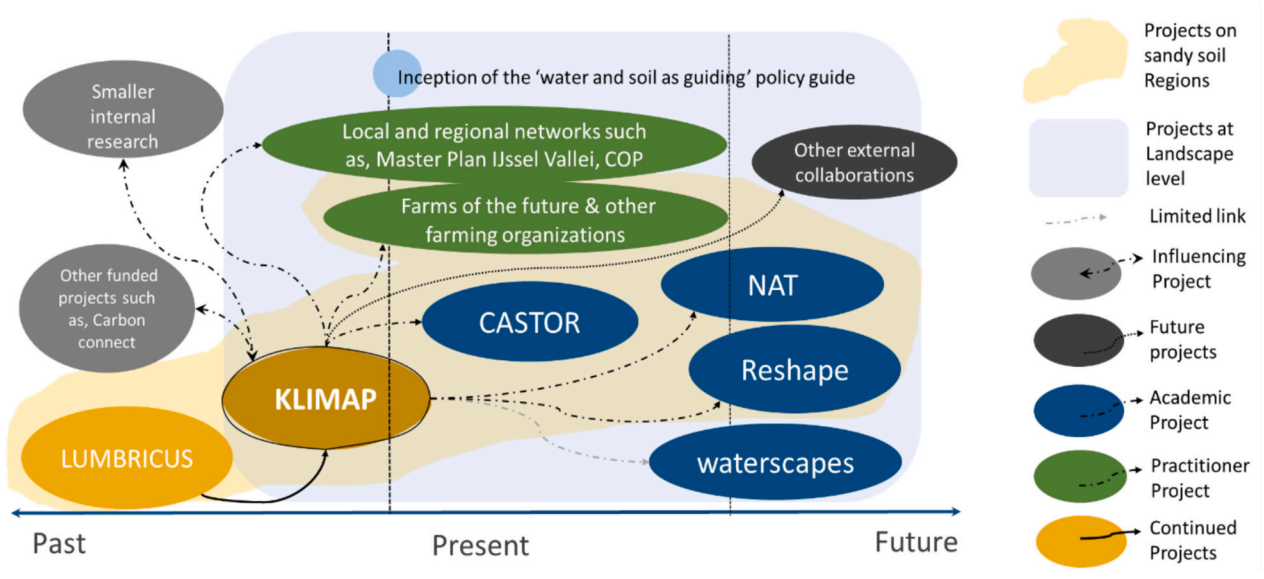

Fig. 5. A network of projects associated with KLIMAP.

and innovative business models, whereas research institutes led in knowledge contributions. However, in terms of expertise, not all were continued e.g., ecologists.

KLIMAP enabled stakeholders to understand each other's working methods, share diverse insights, realize the strength of collaboration, and form deeper connections. One actor shared their amusement at how neighboring water-authorities had different approaches to tackling similar problems and that KLIMAP acted as a platform to connect their knowledge. These connections allowed actors to gain insights into other similar organizations, learn from them, and share new insights with their respective organizations, leading to various new relations and projects. These included smaller collaborations between organizations, connection with similar network projects such as Farms of the Future and Masterplan IJssel Vallei, and the formulation of new projects such as CASTOR, NAT, Waterscapes, and Reshape (Fig. 5). In the survey, 93 % of KLIMAP participants reported higher understanding of other actors' and organizations' perspectives, and 100 % reported planning to apply insights to future projects or in organizations.

Involving relevant stakeholders, although crucial, can often be very challenging. One of the actors recalled network formation as a particularly time-consuming and resource-intensive process, and that "most organizations agreed to join once a few key organizations committed". Another actor noted, "working within a group of other similar organizations enhances legitimacy and reduces uncertainty in making transformative decisions that would be challenging individually".

This highlights the importance of peer influence and building relational social capital to facilitate cooperation and collaboration. In conclusion, an incidental mix between a part of the existing stakeholder network and additional new networks led to improved trust and novel perspectives in KLIMAP. Occurring primarily at the organizational levels, the network formation pathway in KLIMAP focused on building a collaborative network of relevant stakeholders.

4.3. Pathway 3: Capacity enhancement pathway

KLIMAP was designed to facilitate and support the practical application of climate-adaptive knowledge and skills development through co-creative workshops and sessions. To guide and assess exploration of development paths, a 'framework', 'evaluation tool', and 'serious game' were developed (Table 1).

Decision-makers often find themselves unprepared to implement innovative climate-resilient actions. Innovations face challenges competing with stable regimes, as existing socio-technical systems are stabilized by lock-in, path dependency, and 'entrapment' (Bulkeley et al., 2016). To address this gap, KLIMAP introduces climate-adaptive development pathways, enhancing the decision-making capacity of involved actors. It involves designing landscapes at the systems level with a long-term vision linked with current short-term actions (KLIMAP, 2020-2024). This approach ensures that decisions taken are flexible and adaptive while ensuring that decision-makers share their interests, values, and visions for the area with all relevant stakeholders early in the process.

Within KLIMAP, a 'roadmap' was developed to provide structure and facilitate the application of development paths in six case studies located at Chaamsche Beek, Vitale Peel, Reusel, Stegeren, North Limburg, and Northern IJssel Vallei. Each case was organized separately with unique goals. Some focused on developing the capacity to apply adaptive pathways in decision-making, others on testing climate adaptive measures. Various co-creation strategies were employed to achieve these goals, such as maintaining diversity within each working group, followed by moments of feedback to evaluate the usefulness of the workshops and tools such as, 'PrAAT: Practical Adaptation Assessment Tool', serious games, and future visualization were employed. PrAAT was applied to evaluate pathways. The serious game built understanding, awareness of potential unexpected situations, and capacity to make informed decisions to address such scenarios. The simulated game environment presented players with diverse scenarios and choices, highlighting the value of collaboration, forward-thinking, reflection on priorities, and building good relationships. As one actor noted, "To learn something, we need to go through the same process (practice) several times". In the survey, 100 % of the participants from KLIMAP reported that they learned from these practical experiences.

However, many actors recalled working in a large consortium as slow and almost ineffective. Nevertheless, they acknowledged that despite the substantial time it takes, co-creation is valuable in addressing climate-related issues comprehensively; as the saying goes, "Alone you go faster, but together you go further". They also remarked that KLIMAP was the first project to develop climate adaptive pathways for water and land management in Dutch sandy soil context. Developing and implementing multiple methods and tools enhances the procedural knowledge or 'know-how' involved in adaptation pathways among the stakeholders. This learning pathway combines both content and capacity learning, improving the readiness level of individuals and teams for applying climate-adaptative pathways.

4.4. Pathway 4: Knowledge and tools adaptation and contextualization pathways

A wide range of activities was organized within KLIMAP to enable actors to resituate and apply knowledge and tools in diverse contexts through cross-connecting platforms (Sole and Edmondson, 2002). These included multiple communities of practice (CoPs), co-creative workshops, learning sessions, and joint analysis (Table 1). These activities promoted refined knowledge, improved capacity for knowledge application, and fostered newer connections.

To refine the concepts and tools, insights gained through KLIMAP—such as understanding development pathways, scenario analysis, identifying area-specific climate-adaptive measures, applying various frameworks and tools, and gaining a comprehensive perspective—were adapted to different contexts both within and beyond the project. For instance, a seven-step roadmap was developed to guide the application of development pathways (Fig. 6). Initially, these steps were expected to follow a linear sequence, but as the roadmap was applied in diverse contexts, stakeholders realized that the steps need not be sequential nor start with step 1.

KLIMAP also held learning sessions open to all stakeholders, focused on unique topics that did not arise during other collaborative activities, e.g., regulating drainage systems, upscaling measures, addressing power dynamics in decision-making, and acknowledging emotions related to climate change issues. These sessions aimed to extract knowledge and make it explicit within the network, allowing it to be reintegrated into their ongoing work. Peer-to-peer interactions and feedback, collected through open participation or online tools like Mentimeter, enhanced participants' understanding and strengthened their networks. The unique nature of these topics provided new insights and experiences that participants might not have had easy access to otherwise. Notably, 100 % of survey respondents from KLIMAP found these learning sessions a valuable co-creation activity.

Regular CoP meetings created opportunities to brainstorm, co-create solutions, share results, and learn from one another. These interactions improved stakeholders' abilities to adapt their knowledge and tools to diverse contexts. The CoP invited additional external actors working on similar climate adaptation projects in the region; thus, new connections were fostered while strengthening learning and capacity-building. Ultimately, this learning pathway highlights how diverse activities within the cross-connecting platforms empower actors to aptly reapply their knowledge, skills, and network perspectives in diverse contexts. This contributed to content, capacity, and network learning at all levels.

4.5. Pathway 5: Innovation dissemination and upscaling pathway

KLIMAP organized various activities to support knowledge

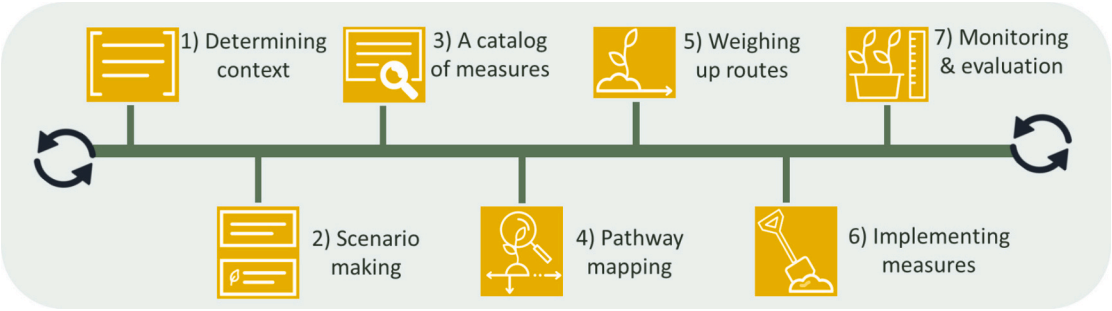

Fig. 6. KLIMAP roadmap (KLIMAP, 2020-2024).

dissemination via mass media and networks. Knowledge was scaled up through advocacy in interpersonal communication channels. Methods included storytelling and blog writing on social media platforms, interviews in mainstream media channels, sharing results in impactful magazines and the project website, and advocacy in public organizations to impact the institutional setting (Table 1).

From the outset, KLIMAP shared its vision and preliminary results on climate adaptation through its website and mass media outlets like radio, newspapers, magazines, and social media, to invite external engagement. The knowledge developed during KLIMAP was available through its website, openly or on-request. Social media platforms were used to share stories and blogs on ongoing activities that were eventually picked up by the media, gaining more attention. KLIMAP employed various communication methods to reach a diverse audience, including sharing reports, visual maps, short videos, and flyers. This multifaceted approach was designed to engage a wide range of potential collaborators and disseminate the knowledge created during the project. Consequently, many collaborations emerged from KLIMAP's communication efforts. For instance, a research team in Minnesota approached KLIMAP regarding the experiment on 'corn with permanent under-crop'. Further, KLIMAP's serious game was used in another context of Delta programs by external users and in universities for teaching purposes.

Another method of knowledge dissemination was inviting external stakeholders (Mol and Birkinshaw, 2014) to events such as CoPs and symposiums. KLIMAP consistently shared project insights across other networks, thereby influencing their decision-making. For instance, the Masterplan IJssel Vallei, which had overlapping stakeholders with KLIMAP, employed the development pathways concept in its decision-making process. A dike reinforcement plan wasn't carried out to prevent future lock-in situations. The survey of external participants showed that 50 % of participants understood more about climate adaptation, 91 % found knowledge from the symposium applicable to other projects and situations, and 100 % planned to apply the knowledge in their organization.

For knowledge upscaling, KLIMAP made numerous contributions to Deltafacts— a concise and factual summary of practical knowledge in the field of water management— which is primarily consulted by policy officers, managers, and experts in the Netherlands (Deltafacts, 2023, 2024). Throughout the project, KLIMAP leveraged interpersonal connections to try and establish their innovations within diverse local settings and institutions, as one actor noted, "we are ambassadors of climate adaptation measures for our respective organizations". Another actor highlighted, "we all have a role in maintaining and continuing the project's outcomes after its completion".

KLIMAP stakeholders shared their flexible, development-focused philosophy with administrators and board members from municipalities, water-authorities, provinces, nature and agriculture organizations, and other external networks, creating possibilities for continued collaboration (KLIMAP, 2020-2024). Further, KLIMAP identified revenue models tailored to specific sub-areas (high grounds, flanks, and stream valleys) and proposed ideas for new subsidies.

KLIMAP's efforts coincided with numerous external organizational changes, e.g., many water-authorities were attempting to incorporate sustainable choices into their decision-making. At the same time, the Dutch Ministry of Water and Infrastructure introduced a "water and soil guiding" policy document. This policy document aims to restore natural water and soil systems, emphasizing the need to enhance resilience and robustness. By designing land-use functions to promote cohesion and sustainability, this approach is critical in shaping the country's resilience to climate change and biodiversity preservation (de Rooij et al., 2023). Some organizations involved with KLIMAP were involved in the phases leading up to the formulation of this policy document. Over the years, numerous living labs and co-creative projects have focused on climate-resilient water and land systems in the Netherlands. This underscores the importance of viewing water and soil management holistically. While all these forces seem to come together, a question remains regarding the extent to which the relevant bodies will use the knowledge created during KLIMAP after the project's conclusion. This pathway explains how KLIMAP took intentional actions to disseminate and upscale knowledge, reaching wider interest groups. Simultaneously, it explains the network aspect (societal engagement and policy influence) and content aspect (knowledge transfer and feedback) primarily at organizational level.

4.6. *Pathway 6: Co-creation facilitation pathway*

In a living lab approach, the mindset of collaboration and willingness to learn are prerequisites. Ensuring clear and neutral communication is continuous and requires mindful effort throughout the project. Besides having shared project goals, open communication channels are required for clear and neutral communication. The major activities to facilitate co-creation in KLIMAP included designing effective communication strategies, promoting open dialogues and active listening, facilitating group discussions, and providing additional support training (Table 1).

KLIMAP devised a communication structure resting on transparency through a web portal to share updates. KLIMAP utilized SharePoint as a platform for sharing information, making all resources, results, and reports accessible to all members. The intermediate products and links to relevant websites were placed in a central accessible location. In transdisciplinary work, where diverse disciplines and sectors interact, it's important to use plain language. Terms and concepts should be explained clearly by providing context, encouraging questions, and facilitating mutual understanding. For instance, in one of the case studies in KLIMAP, not all participants understood the hydrological concepts. Some stakeholders felt out of place and refrained from participating in discussions for fear of appearing ignorant. Consequently, additional training and supportive resources were provided, ensuring all participants were on the same page. Follow-up measures helped fill any remaining gaps. An actor reflected on the value provided by co-creative projects as, "We need to take into account the needs and wants of all stakeholders. A lot of times, we think we have an idea of what is needed, but that's a big assumption, and our idea can be very

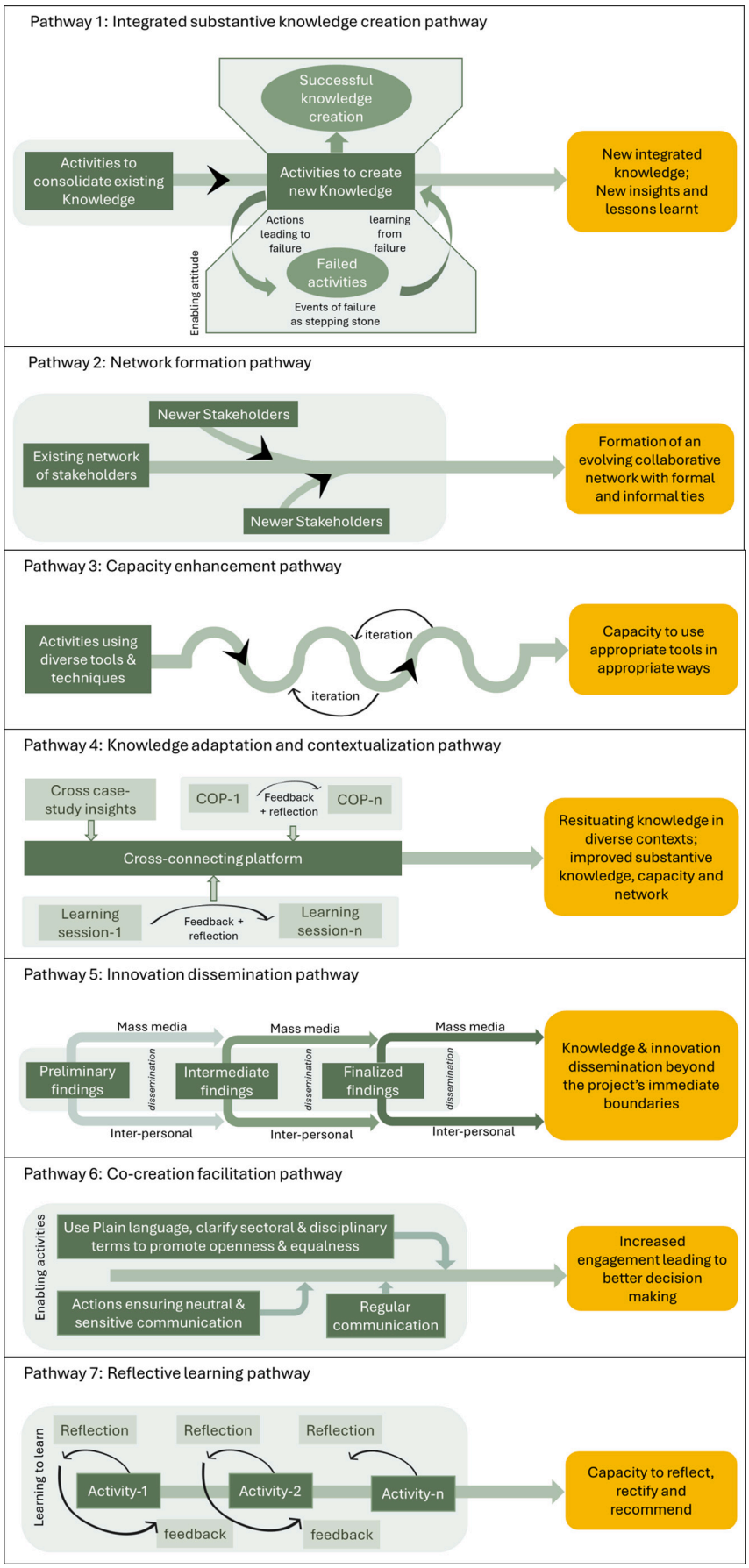

Fig. 7. Illustration of summary of the learning pathways mapped in KLIMAP.

different from reality. Co-creation will not be straightforward like other research where you'd make propositions, execute, and show results; it is a messy process. But we get to know the 'real' reality, not 'assumed' reality".

Living labs need to strike a delicate balance when addressing sensitive topics to minimize conflict and miscommunication. For example, KLIMAP aimed to develop a strategic understanding of decision-making and to foster system-level conversations about innovation measures. Since individual lands were closely tied to owners' identities, moving the discussion from a parcel-level to a regional-level was important. Thus, strategies and measures were presented based on the regional water-table, categorizing land-parcel into sub-areas: high ground, brook valley (low ground), and flank (slope area from high to low ground). Accordingly, relevant strategies and measures for each sub-area were discussed. This *learning pathway* deals with enabling factors for co-creation, requiring projects to intentionally select or develop strategies that allow all the actors to contribute equally, deepen their understanding of various topics from diverse actors' perspectives, and develop the capacity to apply these concepts in practice.

4.7. Pathway 7: Reflective learning pathway

KLIMAP encouraged reflexivity among the stakeholders and the project itself. The activities included continuous feedback and discussions, recording experiences, and (informal) participatory monitoring (Table 1). KLIMAP engaged in several reflective moments, which eventually led to development of diverse interventions. One notable instance involved the use of causal loop diagrams. To let actors realize the difference between decision-making in "isolated sectoral silos" versus "interdisciplinary groups", sector-specific groups were formed and tasked with creating causal loop diagrams of water flow in the area. The diagrams produced by each group were strikingly different, highlighting the diversity of perspectives and sparking meaningful conversations on how and why the flows were perceived differently. These interventions deepened actors' understanding of each other's priorities and perceptions from the standpoint of their organizational roles. One participant noted that this exchange among diverse stakeholders made the KLIMAP experience uniquely valuable.

Another example of reflective intervention occurred when KLIMAP actors reflected on the need for better communication across different working groups. Many actors chose to focus primarily on their individual responsibilities and thematic working groups, only cross-connecting with the rest at a later stage. Reflecting on the lack of strategies to connect working groups, coordinators made additional efforts to improve connections midway through the project. This strategic facilitation to cross-connect different thematic work led to some successful collaborations, even though some actors still felt these efforts should have started earlier for better integration. The core concept applied in KLIMAP, i.e., development pathways, has a reflective element to it as well. Designing these pathways requires actors to think forward to a future situation and then reflect on the appropriate short-term interventions. Thus, self-reflection, collective reflection, and feedback and discussions were central to KLIMAP.

KLIMAP started with the goal of developing system-wide measures for sustainable water and landscapes. However, it was soon realized that a complete set of measures at the landscape level requires much greater political and social support. While this was initially frustrating to the stakeholders, they realized their role was to initiate change by disseminating their knowledge and engaging with relevant organizations so that ideas could take root. Thus, KLIMAP did not follow the familiar forms of monitoring and evaluation. An actor noted that recording learning and reflecting collectively during the project would have been valuable, as people tend to forget what they learned over time.

However, informal and participatory monitoring and evaluation were selected so that actors learned together to tackle challenges and jointly develop solutions. Reflecting on their experience allowed actors to reflect on their activities and recognize the resulting incidental learning (van Mierlo et al., 2020). The capacity to (collectively) reflect, rectify, and make recommendations can greatly benefit individuals and organizations, enhancing their current and future learning (Fig. 7).

5. Discussion

This research developed learning pathways based on the KLIMAP project by applying the learning framework of Bhatta et al. (2024). The ex-post analysis of KLIMAP has affirmed the existence of 7 learning pathways, primarily determined by the learning type (Fig. 7). These pathways highlight how KILMAP's co-creation activities influenced knowledge acquisition, capacity building, and perspective understanding, among other factors, leading to diverse outcomes. Often, strategies change when an innovative project is underway, and the results also only become visible after some time has elapsed (Van Mierlo et al., 2010). However, the learning pathways support capturing values that extend beyond immediate results, contributing to a broader understanding of the topic, increasing collaborative efforts, and scaling up innovations.

The first pathway, which deals with leveraging existing knowledge and integrating it with new knowledge developed during the project, also accepts that moments of failures are likely in innovative projects owing to their uncertain and experimental nature (D'Este et al., 2016; Jenson et al., 2016). Although failure is never intentional, it is intertwined with the innovation process to the extent that its probability increases with the intensity of innovation (Kamoto, 2017; Rhaiem and Amara, 2021). Counterintuitively, failure provides valuable lessons. Research shows that knowledge gained from failure depreciates more slowly than from success (D'Este et al., 2016; Madsen and Desai, 2010). Factors like a shared vision, a sense of belonging, and high-quality relationships can positively influence learning from failure, generating new insights, and enhancing reflection on past decisions.

Similarly, the second pathway identifies the stakeholders' role in bringing legitimacy and resources to address the issues (Chen and Musango, 2022). When establishing a living lab, integrating an existing network, or a part thereof, can be advantageous if it aligns well with the lab's goals (Willem and Lucidarme, 2014). Existing networks leverage pre-established trust and accelerate the collaboration process, while new networks bring new resources, perspectives, and heterogeneity (Soda et al., 2021). Thus, it is beneficial to adopt ongoing collaborations as *social capital* while enriching them with perspectives from new stakeholder networks. However, which part of an existing network is continued can depend on the availability of existing partners and the interests of personnel driving the project.

More generally, to enable transdisciplinarity, living labs can choose to maintain a unified knowledge base, common vocabulary, and consistent interpretations to ensure effective communication regardless of participants' background or expertise, as terms and concepts common in one field might be new to another (Hunter, 2016; Smol, 2018). Likewise, the pathway on knowledge diffusion and upscaling that aims for institutional and policy changes for system-wide sustainability (Moore et al., 2015; Scholl et al., 2022; Sengers et al., 2019) determines the fit (or misfit) between diffusing practices and adopters regarding technical, cultural, and political elements (Ansari et al., 2010). While KLIMAP carried out several activities to disseminate and scale up the knowledge produced, its long-term impact and potential to drive institutional and policy changes remain unclear. The proposed revenue models are still in the early exploratory stages, meaning that start-ups rely on external funding or subsidies to compete in an established market. This highlights the need for top-down intervention to create viable business opportunities. However, it is unclear whether relevant organizations will adopt these policy recommendations. Such impacts can only come to light over time and cannot be addressed in the short-term (Watermeyer, 2014). Nevertheless, CoPs are still planned even after the project's completion by other partners in the network (Fig. 5).

These learning pathways align closely with the core principles of living labs. Pathway 1 advances learning through *real-life exploration and experimentation.* Pathway 2 augments *early and continuous engagement* with all relevant stakeholders within the *quadruple helix framework*. Pathways 3 and 4 focus on *iterative learning processes,* emphasizing *inclusivity, openness, and transparency*. Pathway 5 stresses the need for *value co-creation* to enable *upscaling*. Finally, pathways 6 and 7 adopt a *reflective* approach, centering on understanding *stakeholders' needs, motivations, expectations, and mindsets*.

6. Concluding remarks

This paper examines how living labs can serve as effective strategies for sustainable land and water management. It offers insights into how learning in co-creation activities can contribute to a project's overall success by enabling the identification of outcomes and broader impacts of living labs. A sequence of learning activities leading to their respective outcomes was systematically documented through '*learning pathways*', in alignment with the '*living lab learning framework'*.

The paper demonstrates how learning pathways can be used to reflect on and leverage the knowledge gained from a project, enabling actors to better understand the outcomes of their collaborative efforts, identify valuable lessons, and apply these insights to future initiatives. It retrospectively collects learning evidence in the KLIMAP case study to demonstrate how structured learning pathways can reveal the deeper, often overlooked effects of co-creation processes. Seven distinct pathways were identified, focusing on: 1) harnessing collective, integrated knowledge, 2) building collaborative networks, 3) enhancing stakeholder capacity, 4) adapting and contextualizing knowledge, 5) innovation diffusion, 6) facilitating co-creation, and 7) reflecting and learning. Each pathway highlights learning activities—categorizing learning type, process, and involved entities—and their resulting outcomes. These pathways document the evolution of knowledge and skills, demonstrate the effectiveness of activities and interventions, offer enhanced accountability, and provide valuable insights for improving future project design and implementation.

A limitation of our study lies in the generalizability of our case study results. While the learning framework is grounded in a systematized theoretical system, making it applicable to various empirical studies, the learning pathways were developed within a single case study in the context of Dutch governance, where sustainable land and water are a priority (Pot, 2024). Thus, it is unclear how reflective KLIMAP is of other complex, real-world challenges in different regions and governance systems worldwide. Pathways for other living labs can be different based on their design, socio-political position, and operationalization. More case studies on living labs in other regions are, therefore, recommended by developing pathways to identify their outcomes and impacts. Since the learning pathways in this study were developed retrospectively based on the stakeholder's recollections, certain components of the *living lab learning framework*—such as the diverse levels of learning—weren't fully captured. Accordingly, future research should focus on refining and expanding these pathways, not only in ex-post project evaluations but also during the design phase of projects and incorporating multiple case studies. Further, the paper approaches learning pathways from the primary perspective of learning type; the implication of adopting learning process or level as the primary perspective is unknown and could offer a fruitful starting point for future research. While this paper highlights the significance of learning in amplifying the broader impact of living labs, further research is also needed to deepen the understanding of living labs within policy contexts. Living labs and its learning outcomes can offer valuable evidence for policymaking, not only through the co-design and co-creation of innovative solutions and substantive knowledge but also through knowledge dissemination, inclusive network building, adaptability, transparency, and increased credibility. Therefore, additional research is necessary to determine how living labs can best support the inception, implementation, execution, and monitoring of policies, particularly those focused on sustainable land and water management.

Declaration of competing interest

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Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.crsust.2024.100277.

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