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How does learning drive sustainability transitions?

Perspectives, problems and prospects from a systematic literature review

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How does learning drive sustainability transitions? Perspectives, problems and prospects from a systematic literature review

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ABSTRACT

Learning has been put forward as a critical aspect to achieve sustainable transformation of societal systems. However, there is a lack of a systematic review of empirical evidence on how learning is related to sustainability transitions. To bridge this gap, we systematically reviewed 113 empirical papers that addressed the role of learning in transitions. Our results show that the complexity of the relationship between learning and transitions is not deeply analysed and that there is a need to distinguish more precisely between learning processes and learning outcomes. Further, there is a need to shift the focus towards analysing regime-level learning to increase our understanding of how learning contributes to system transformation. Finally, networks, trust, disagreement, and power are key aspects related to learning that will require further examination, especially in terms of how they play out dynamically in learning for sustainability transitions.

1. Introduction

Our planet and the global community are confronted with multiple persistent sustainability problems, such as climate change, loss of biodiversity, and growing socio-economic inequality. Therefore, there is an urgent need to transform societal systems towards more sustainable alternatives, both environmentally and socio-economically (Köhler et al., 2019; Loorbach et al., 2017; Markard et al., 2012). Learning has been put forward as a critical aspect to achieve sustainable transformation of societal systems. Learning has been deemed necessary to make actors question and challenge dominant and taken-for-granted practices, structures, and cultures and to transform them creatively (Loeber et al., 2007; Loorbach et al., 2017; Van Mierlo and Beers, 2020; Van Poeck et al., 2020). Learning has also been associated with better governance of transitions as learning between actors with different perspectives and goals can enhance decision-making and promote the legitimacy of governance solutions (Loeber et al., 2007; Van Poeck et al., 2020).

Previous reviews of transitions research have addressed the origins and scientific approaches of the field (Loorbach et al., 2017; Markard et al., 2012), the geography of transitions (Hansen and Coenen, 2015), the role of actors and agency (Fischer and Newig, 2016; Kivimaa et al., 2019), and the types and genealogy of experimentation for transitions (Sengers et al., 2019). These previous reviews have underscored the importance of learning for transitions. Growing interest in learning has led to the publication of a special issue in this journal with the objective of increasing our understanding of the role of learning in transitions. This special issue included three review and conceptual papers (Goyal and Howlett, 2020; Van Mierlo and Beers, 2020; Van Poeck et al., 2020) and two empirical papers (Scholz and Methner, 2020; Vinke-de Kruijf et al., 2020). Based on these five papers, learning has been defined by the editors as

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"a process of acquiring and generating new knowledge and insights, and of meaning-making of experiences in communicative interaction […]. Moreover, it is a non-linear, iterative process in which ideas and possibilities for collaborative action are being developed, experimented with and pursued in a diversity of networks" (Van Mierlo et al., 2020, p. 253).

More specifically, Van Mierlo and Beers (2020) argued that two main modes of learning for transitions exist: learning as 'discursive interaction' and learning as 'reflexive action'. Learning as discursive interaction takes place when actors exchange knowledge and meanings, which can lead to a shared understanding of a sustainability problem and possible solutions. Learning as reflexive action occurs through a process of action and reflection, which can lead to changing practices. Transforming dominant and taken-for-granted practices, structures, and cultures has been described earlier as a matter of learning-by-doing and doing-by-learning, which often takes place in an experimental setting (Geels and Deuten, 2006; Loorbach et al., 2017; Van Mierlo and Beers, 2020; Van Poeck et al., 2020). Based on a systematic review of transitions research, Sengers et al. (2019) defined an experiment as "an inclusive, practice-based and challenge-led initiative designed to promote system innovation through social learning under conditions of uncertainty and ambiguity" (p. 162).

Concerning the outcomes of learning, changes in thoughts and changes in actions have been reported as important learning outcomes (Loorbach et al., 2017; Van Poeck et al., 2020). Based on an exploratory review of transitions research, Van Poeck et al. (2020) viewed learning outcomes in practical, relational and conceptual terms. Practical learning outcomes refer to all forms of novelty that contribute to achieve transitions, with an emphasis on novel action (e.g., behaviour, habits, routines, technologies). Relational learning outcomes refer to new relationships and network development, social arrangements, and building trust to address sustainability problems. Finally, conceptual learning outcomes refer to broadening the scope of how problems are framed and defined and to 'skills' that may contribute to achieve transitions, such as creativity, critical thinking, reflection, and reframing. In addition, Goyal and Howlett (2020) found that technology constituencies engage in technological learning and that policy communities engage in learning about problem definitions, policies and politics.

While previous reviews have shined the spotlight on learning, they have also concluded that a gap remains between learning research and transitions research (Van Mierlo and Beers, 2020; Van Poeck et al., 2020). The complexity of transitions and the fact that learning is one of many factors in a transition, make that transitions researchers often struggle to analyse learning and to explain the suggested positive relationship between learning and transitions. It has been argued that this is the result of a lack of conceptual clarity: transitions researchers are not always clear about the theories they use to analyse learning, or they are only loosely applied (Van Mierlo and Beers, 2020; Van Poeck et al., 2020). Moreover, it has been argued that the empirical evidence-base is still weak, and that strong claims on how learning leads to transitions are made without substantive and convincing empirical evidence (Brown et al., 2003; Van Poeck et al., 2020).

Another deficiency in our current understanding of learning for transitions is that previous reviews on learning were exploratory, and therefore there is still a lack of an integrative review of empirical evidence on how learning is related to sustainability transitions. To bridge these gaps, this paper presents a systematic review of empirical papers that have addressed the role of learning in transitions. The central research question that guides this review is: ***how is learning defined and studied in transitions research, and how is learning related to sustainability transitions?*** The objective of this paper is to analyse the empirical evidence-based on the role of learning in transitions to explain common perspectives, to address major problems, and to identify prospects for future research.

The remainder of this paper is structured as follows. In Section 2, we explain how we identified relevant empirical papers and how we analysed them. In Section 3, we present the results of our analysis, based on our research question and the analytical themes we describe in Section 2. In Section 4, we discuss our results and in Section 5, we present our main conclusions.

Table 1
Inclusion and exclusion criteria.

Criteria	For inclusion	For exclusion
Population	Papers addressing sustainability transitions in various sectors, policy fields and geographical regions.	Papers focusing on changes or interventions that are not clear transitions.
	Papers addressing sustainability transitions in a real-world context.	Papers focusing on transitions without a link to sustainability. Papers focusing on sustainability in an educational context.
Intervention	Papers addressing individual learning, organizational learning, mutual learning, etc.	Papers not discussing learning clearly (e.g., papers focusing on drawing lessons on transitions without analysing learning).
	Papers discussing learning as input, process, or outcome.	
	Papers discussing learning but use other terms like knowledge exchange, etc.	
	Papers discussing learning as 'discursive interaction' and/or learning as 'reflexive action' (van Mierlo and Beers, 2020).	
Comparator	Comparison of learning processes for transitions between papers.	N/A
Outcome	Papers describing sustainability transitions.	N/A
	Other results including practical, relational, and conceptual learning outcomes as defined by van Poeck et al. (2020) related to sustainability transitions.	
Additional criteria	Papers published between 2015 and 2020.	N/A
	Papers written in English.	
	Papers based on original empirical work.	

2. Materials and methods

A systematic literature review provides a comprehensive and reproducible method to identify and evaluate relevant literature in a research field (Booth et al., 2016; Tranfield et al., 2003). Systematic reviews are not new to transitions research. Others have, for example, systematically reviewed the literature to propose a typology of intermediary actors (Kivimaa et al., 2019) and to identify distinct types of experiments (Sengers et al., 2019). We focus our review on learning for transitions, a topic that has not yet been reviewed systematically. In this section, we define the scope of our review and explain the search strategy, the screening process, and the thematic analysis.

2.1. Research scope and search strategy

The scope of our review was on learning and sustainability transitions, irrespective of specific sectors, policy fields, or geographical regions. To further refine the scope, we developed inclusion and exclusion criteria using PICO (population-intervention-comparator-outcome) as a guiding framework (Petticrew and Roberts, 2008). The two most important inclusion criteria were that papers addressed sustainability transitions in a real-world context (and not in an educational context), and that those papers addressed learning in a real-world sustainability transition (see Table 1).

The keywords we used in our search strategy were based on the central research question of our review, previous experience with undertaking systematic literature reviews aimed at evidence-mapping and gap-spotting (e.g., Nakamba et al., 2017; Van Ewijk and Ros-Tonen, 2021), and exploratory searches in Google Scholar and Elsevier's Scopus database. We included several keywords closely related to learning and sustainability transitions in our search strategy to be as inclusive as possible while maintaining a clear scope to avoid too many irrelevant papers (see Table 2). The search strategy, as well as the screening process and the thematic analysis were developed and discussed multiple times with the wider research consortium including other researchers and practitioners dealing with sustainability transitions in urban development.

To identify relevant papers, we used Scopus as our main source. Scopus is the largest abstract and citation database of peer-reviewed literature and has been considered the most complete database in our field (e.g., Markard et al., 2012). We included only peer-reviewed papers written in English in our search strategy. This is common practice in systematic literature reviews because this type of literature is considered as certified knowledge (Saggese et al., 2016). We did our search in November 2020 whereby we combined the search strings on 'learning' and 'sustainability transitions'. We restricted our search to papers published between 2015 and 2020, which we considered most relevant to present a contemporary and comprehensive overview of a highly dynamic field like transitions research. In addition, a brief exploration in Scopus showed that the number of papers published increased significantly from 2015. With this limitation, 1620 papers were identified for the next phase.

2.2. Screening process

The 1620 papers were transferred to the free web-based software Rayyan to screen the title, abstract, and keywords of each paper. In Rayyan, we used the double-blind assessment option and the option to include reasons for inclusion or exclusion of papers. The first 20 papers (sorted by publication data) were jointly screened by the research team of four researchers to discuss and calibrate our interpretations, as well as to refine the inclusion and exclusion criteria. Thereafter, 400 papers were screened in pairs (2×200) and the remaining 1200 papers were divided amongst the members of the research team (4×300). Papers that were marked as 'maybe' were screened by at least one other researcher. A final assessment of 'maybes' was done by the most experienced researcher of the team. Based on our inclusion and exclusion criteria, 1353 papers were excluded after screening the title, abstract, and keywords of each paper.

To assess the eligibility and relevance of the remaining 267 papers, the full text of each paper was screened by at least one researcher. Based on this full text screening (and discussions afterwards), we excluded 115 papers that did not meet our initial inclusion criteria (learning in a real-world sustainability transition). We captured the 152 papers that remained in an MS Excel file and first assessed the methodological approach of each paper. In this phase, 39 review and/or conceptual papers were excluded. The final selection of papers to review thus included 113 papers based on original empirical work (see Appendix A). Based on a simple review of methodological approaches we assessed the quality of the evidence presented in each paper. We did not exclude papers based on this critical assessment. Fig. 1 presents a flow chart that summarises the screening process.

Table 2
Key concepts and related keywords.

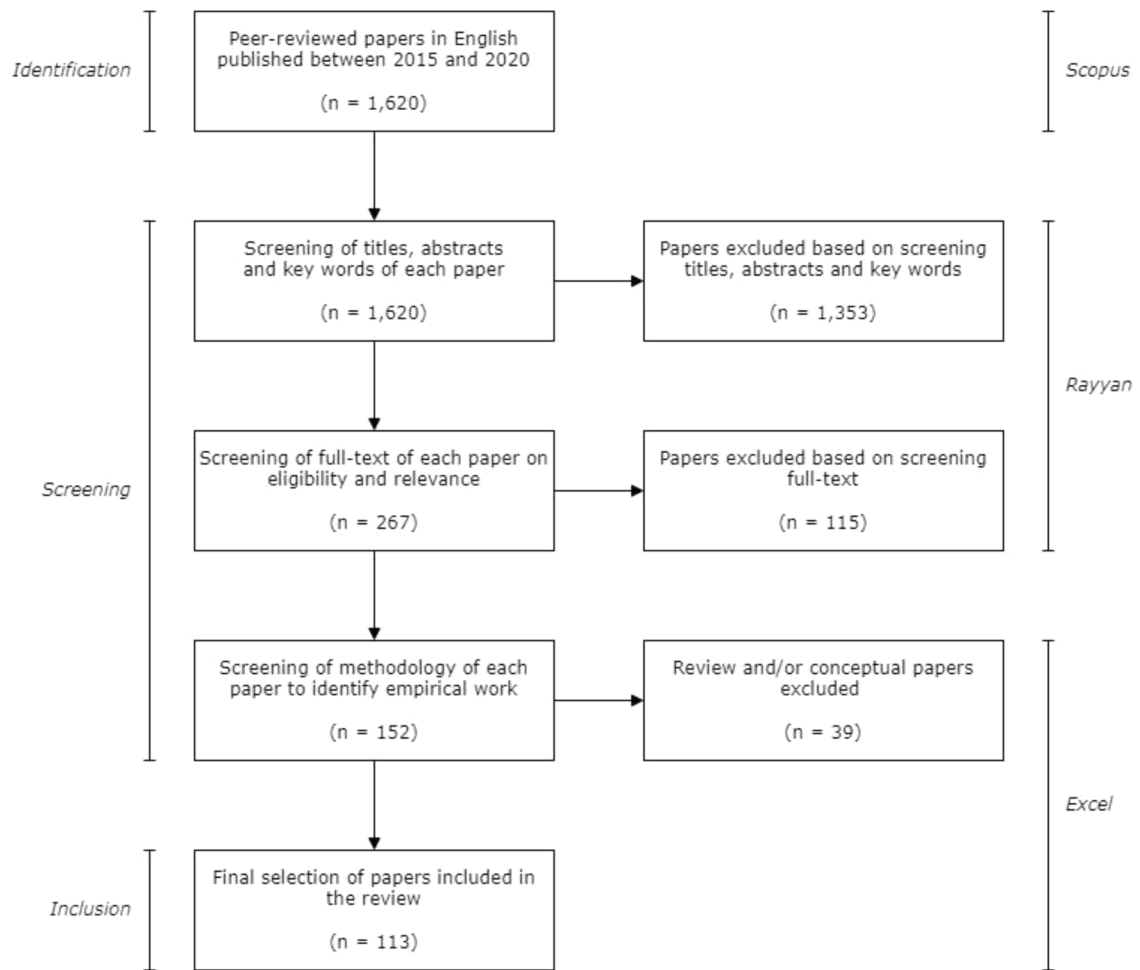| Key concept	Related keywords
Learning	Learning, co-learning, co-creation, co-production, knowledge-transfer, -acquisition, -acquiring, -exchange, -sharing, -use, -uptake, -broker.
Sustainability transitions	Sustainable, sustainability, resilient, resilience, transition, transformation.

Fig. 1. Flow chart summary of the screening process.

2.3. Thematic analysis

To analyse the 113 papers, we used a 'thematic analysis' which seeks to identify the range of factors that is significant for understanding a particular phenomenon (in our case learning for sustainability transitions) and to organise these factors into the main themes for further analysis (Booth et al., 2016). We created a 'data extraction form' in MS Excel to capture general information like author(s), title, year of publication, and journal. We also captured more substantive information like the research question, the geographical region, the empirical setting and methodology, and the key finding(s) of each paper (Denyer and Tranfield, 2009).

The thematic analysis consisted of a combination of deductively derived themes from previous work on learning for transitions and from reading the abstracts of the 113 papers, and inductively derived themes from an in-depth analysis of the 113 papers. Themes were identified by and discussed within the research team of four researchers and were organised based on the three main topics of our central research question: how learning is defined, how learning is studied, and how learning is related to sustainability transitions. Once the team agreed on the most important themes related to the three main topics of our research question, we synthesised how these themes were discussed in the 113 papers and we analysed general patterns, communalities, differences, interesting exceptions, etc. (Booth et al., 2016).

First, to analyse how learning is defined, we focused on the learning theories that were used in the papers and how these theories were applied. Our interest in learning theories was mainly inspired by earlier claims that transitions researchers are not always clear about the learning theories they use, or that they are only loosely applied (Van Mierlo and Beers, 2020; Van Poeck et al., 2020).

Second, to analyse how learning is studied, we were interested in empirical settings where learning was analysed and in methodological approaches, including methods of data collection and analysis. We also identified papers that focused on specific tools designed to facilitate and foster learning. Reading the papers' abstracts in the screening phase already sparked our interest in the role of the researcher, since many papers were based on action research, engaged scholarship, or transdisciplinary approaches. Moreover, we realised that many papers had a relatively short-term perspective on learning, while transition usually cover a long period of time. Therefore, we paid specific attention to the time horizon in the papers. We also included an analysis whether papers focused on

discussing and questioning a sustainability problem or mainly emphasised possible solutions to the problem.

Third, we were interested in the relationship between learning and transitions since it has been argued that transitions researchers have made strong claims on how learning leads to change without convincing empirical evidence (Brown et al., 2003; Van Poeck et al., 2020). Previous exploratory reviews on learning for transitions focused on specific aspects of this relationship. For example, Van Poeck et al. (2020) addressed the question how learning takes shape in transitions but answered this question by elaborating on "learning settings" and "enabling conditions and impediments" (p. 302). We also realised that many papers analysed learning in an experimental setting. Therefore, we made a connection to the multi-level perspective of niches, regimes, and landscape, a central conceptual framework in transitions research (Markard et al., 2012). Finally, trust, disagreement, and power emerged as important themes when we analysed the papers, which resonates with previous research on partnership conditions in learning processes (e.g., Robinson et al., 2000; Vangen and Huxham, 2003).

Table 3 provides a summary of the topics and themes we included in our analysis and shows the structure of our 'Results' section.

3. Results

In this section, we present the results of our analysis, following the structure we presented in Table 1 (see Section 2.3). We must note that, although all 113 papers underscored the importance of learning for transitions, not all 113 deeply analysed learning processes and learning outcomes. Therefore, we draw on a selection of the included papers to discuss theoretical perspectives (Section 3.2), methodological approaches (Section 3.3), and the relationship between learning and transitions (Section 3.4).

3.1. Academic fields, empirical settings, and geographical regions

In total, 51 journals published papers on learning for sustainability transitions between 2015 and 2020 (see Table 4). Five journals (Sustainability, Sustainability Science, Journal of Cleaner Production, Ecology and Society, and Environmental Science and Policy) published more than three papers on the topic. The journal Sustainability was the number one publisher with 18 papers (16%) followed by Sustainability Science with 11 papers (10%). Together these five core journals published 49 out of 113 papers (43%). Four other journals (Environmental Education Research, Environmental Innovation and Societal Transitions, International Review of Education and Local Environment) published three papers each and have together published 12 out of 113 papers (11%).

Learning for transitions was analysed in a variety of empirical settings (see Table 5): 28 papers focused on governance and planning (25%), followed by 18 papers on agriculture and food (16%) and 17 papers on the energy sector (15%). Moreover, 14 papers analysed multiple empirical settings or made a comparison between different settings (12%). Although we deliberately excluded papers that focused on education for sustainability and wanted to analysed learning in real-world transitions (see Section 2.1), the selection of papers still included 10 papers that addressed the changing role of academia in sustainability transitions (9%) and were still relevant for our review. For example, Fazey et al. (2020) focused on discussions between academics on the future of knowledge systems during a sustainability conference, and Eriksson et al. (2019) reported on learning between academics in a workshop to better understand the concept of social values for sustainability.

Learning for transitions was studied in all of the world's geographical regions, though with a dominant focus in Europe (see Table 6). In total, 58 papers were based on transitions in Europe (51%), and another 18 papers analysed multiple cases from different regions, often including at least one case in Europe (16%). Within Europe, the Netherlands was a frontrunner on the topic: 14 papers addressed transitions in the Netherlands (24% of papers in Europe, and 12% of 113 included papers).

3.2. How is learning defined in transitions research?

3.2.1. Social learning

Our analysis showed that usually a variety of actors participate in learning for transitions, basically representing the quadruple-helix of government, industry, academia, and civil society (see Carayannis and Campbell, 2009). Many papers focused on multi-actor settings where learning occurred when actors with different perspectives and goals discussed a certain sustainability problem and possible solutions. At this basic level, learning can be defined as a process of acquiring new information (e.g., Domènech et al., 2015), through interaction in social networks.

Papers that had this perspective on learning (e.g., Beers et al., 2016; Eriksson et al., 2019; Scholz and Methner, 2020), often used earlier work on 'social learning' in the field of natural resource management (NRM) (e.g., Cundill and Rodela, 2012; Muro and Jeffrey,

Table 3
Summary of topics and themes.

Topic	Theme(s)
How is learning defined in sustainability transitions research?	Learning theories (Section 3.2).
How is learning studied in sustainability transitions research?	Descriptive statistics: journals, empirical settings, and geographical regions (Section 3.1). Multi-actor settings (and the role of the researcher in those settings), methods of data collection and analysis, tools to facilitate and foster learning, and the time horizon to analyse learning (Section 3.3).
How is learning related to sustainability transitions?	Breakthroughs as proxies of learning (the multi-level perspective), learning for shared understanding, and partnership conditions: trust, disagreement, and power (Section 3.4).

Table 4

Distributions of papers per journal.

Type	Journal	N	%
Core journals on learning for transitions			
1	Sustainability	18	16%
2	Sustainability Science	11	10%
3	Journal of Cleaner Production	9	8%
4	Ecology and Society	6	5%
5	Environmental Science and Policy	5	4%
Total number of papers in core journals		49	43%
Other journals relating to learning for transitions			
6	Environmental Education Research	3	3%
7	Env. Innovations and Societal Transitions	3	3%
8	International Review of Education	3	3%
9	Local Environment	3	3%
Total number of papers in next related journals		12	11%
Journals without a focus on learning for transitions			
-	10 journals with 2 papers	20	18%
-	32 journals with 1 paper	32	28%
Total number of papers		113	100%

Table 5

Distribution of papers per empirical setting.

No.	Region	N	%
1	Europe	58	51%
2	World	18	16%
3	Asia	12	11%
4	Africa	9	8%
5	North America	6	5%
6	Oceania	5	4%
7	South America	5	4%
Total number of papers		113	100%

Table 6

Distribution of papers per geographical region.

No.	Region	N	%
1	Europe	58	51%
2	World	18	16%
3	Asia	12	11%
4	Africa	9	8%
5	North America	6	5%
6	Oceania	5	4%
7	South America	5	4%
Total number of papers		113	100%

2008; Reed et al., 2010). In a contribution that was cited frequently in the papers we reviewed, Reed et al. (2010) defined social learning in NRM as "a change in understanding that goes beyond the individual to become situated in wider social units or communities of practice through social interaction within social networks" ('Conclusions', paragraph 2).

Many papers used a social learning perspective to emphasise that learning for transitions takes place in the interaction between different actors and that learning can lead to (a) change at an individual level and at collective levels. Other papers (also) used similar concepts like 'co-learning' (e.g., Rossi, 2020) or 'collaborative learning' (e.g., Beers et al., 2016; Schreiber-Barsch and Mauch, 2019) to emphasise this. In any case, social learning has to take place at various levels to achieve sustainable transformation of societal systems (Halbe and Pahl-Wostl, 2019; Lotz-Sisitka et al., 2017). However, although a social learning perspective from NRM was used frequently, we found little consensus in the papers we reviewed about the boundaries of what constitutes social learning.

This lack of consensus is related to different views on what learning is and especially on what constitutes a social learning process and what is a learning outcome. For Reed et al. (2010), a 'change in understanding' is an essential ingredient of a social learning process and novel action is an outcome of a social learning process. Some papers we reviewed shared this view on social learning. For example, Eriksson et al. (2019) argued that social learning occurred in an academic workshop because they measured a "more nuanced understanding" (p. 1328) of the subject after the workshop.

Other papers however, discussed novel action as part of a social learning process and less as an outcome (e.g., Beers et al., 2016). To some extent, this broader definition of (social) learning is also reflected in the definition of learning provided by Van Mierlo et al. (2020), the editors of the special issue on learning in this journal, who defined learning as reflexive action as "a non-linear, iterative

process in which ideas and possibilities for collaborative action are being developed, experimented with and pursued in a diversity of networks" (p. 253).

In a study of an innovation initiative of Dutch greenhouse growers, Beers et al. (2016) combined social learning from NRM and collaborative learning from educational sciences. They distinguished between three dimensions that together form a social learning process: new or changed knowledge (the what), new or changed actions (the how), and new or changed relations (the who). Beers et al. (2016) clearly viewed novel action as part of a social learning process and argued that social learning resulted in a learning outcome when the three dimensions were interwoven. From this perspective, a change in understanding must lead to novel action before it can be seen as learning.

In a social learning perspective, learning takes place in interaction in social networks. The interaction itself however, received little attention in the papers we reviewed. Sometimes, authors simply assumed that learning occurred through interaction. For example, Scholz and Methner (2020), who applied a social learning perspective to a project for sustainable agriculture in South Africa, conducted interviews to analyse learning in the project, but did not focus on the natural interaction in the project. Eriksson et al. (2019) analysed the interaction in the academic workshop following the three dimensions of understanding proposed by Bentley Brymer et al. (2018), but drew their main conclusions based on surveys they conducted.

Our analysis showed that papers rarely delved deeply into the dynamics of interactions in social learning processes. There were notable exceptions. For example, Beers et al. (2016) who explicitly focused on natural communicative interaction in meetings of the innovation initiative of Dutch greenhouse growers and distinguished between six different patterns of communicative interaction.

In similar vein, many papers we reviewed referred to learning in social networks, but only a handful of papers analysed these networks. For example, Barrie et al. (2019) used social network analysis (SNA) to evaluate the ability of an intermediary organisation to manage a niche innovation network in industrial biotechnology in Scotland and showed that the introduction of this organisation in the network contributed to network building, shared learning, and promoting shared expectations amongst the actors in the network. Imbert et al. (2019) used SNA to reveal similarities and differences of niche innovation networks in bioplastics in Italy and Germany, and Ward and Butler (2016) used SNA to assess the resilience of a niche innovation network in rainwater harvesting in the UK. Those papers focused on networks, but less on learning. So far, SNA has not contributed much to our in-depth knowledge of learning for transitions.

3.2.2. Multi-loop learning

Many papers we reviewed built on the idea of learning at different depths, often rooted in the work of Argyris and Schön on single- and double-loop learning in the field of organisational learning. Other papers used similar concepts like 'higher-order learning' to emphasise this (e.g., Cuppen et al., 2019; Schröder et al., 2019). Argyris and Schön described learning in organisations as the detection and correction of errors in organisational actions. Single-loop learning occurs when errors are corrected without questioning underlying values and assumptions that guide the actions. Double-loop learning occurs when errors are corrected by first examining and altering underlying values and assumptions and then the actions.

Later, others introduced a third learning-loop, metaphorically at a deeper level than single- and double-loop learning, with multiple variations in the definition of this triple-loop learning (Armitage et al., 2008; Tosey et al., 2011). In NRM, Pahl-Wostl (2009) defined triple-loop learning as "a transformation of the structural context and factors that determine the frame of reference [i.e., underlying values and assumptions]. This kind of societal learning refers to transitions of the whole regime" (p. 359). This definition of Pahl-Wostl (2009) is very similar to how the papers we reviewed defined triple-loop learning.

We found the most elaborate definitions of 'multi-loop (social) learning' in papers on water governance systems (Johannessen et al., 2018; Johannessen and Mostert, 2020; Medema et al., 2015). In these papers, single-loop learning was defined as reflecting on actions (are we doing the things that we do right?). Double-loop learning was defined as reflecting on underlying values and assumptions (are we doing the right things?). Triple-loop learning was defined as reflecting on the context, described as the dominant paradigm that guide action and learning (how do we decide what is right?). Johannessen and Mostert (2020) defined triple-loop learning as the institutional and governance context (the 'learning infrastructure') in which learning takes place (why do we learn the way we learn?). Put differently, by Ely et al. (2020), triple-loop learning referred to "learning about the learning process, with the hope of learning how to learn better" (p. 5).

Based on our analysis, we argue that a clear, yet often implicit, logic existed as to why multi-loop (social) learning was used frequently as a theoretical perspective on learning. If single-loop learning refers to superficial reflection on actions without questioning underlying values and assumptions, this will improve and strengthen existing systems, and if transitions are about transformation of societal systems they require deeper reflection, and thus double- and triple-loop learning. In an analysis of the water governance system in Quebec, Canada, Medema et al. (2015) argued that the key question is "what factors and conditions either support or hinder a movement beyond single-loop learning towards multi-loop learning" (p. 374). Simply put, many papers associated single-loop learning with incremental change and double- and triple-loop learning with more radical change.

3.2.3. Transformative, transgressive, and expansive learning

'Transformative learning', rooted in the work of Mezirow, was another theoretical perspective on learning that was used in the papers we reviewed (e.g., Aboytes and Barth, 2020; Phuong et al., 2019; Quang and De Wit, 2020; Schnitzler, 2020). Transformative learning focuses on critical self-reflection of people's 'frames of reference' (i.e., worldviews, values, etc.) and 'disorienting dilemma's' that challenge these frames of reference (Quang and De Wit, 2020). Critical self-reflection can be fostered by interaction with others who pursue different frames of reference (Aboytes and Barth, 2020).

Transformative learning bears some resemblance with social learning, but the relationship between individual and collective

learning and change is less clear: some authors believe that collective (societal) change precedes individual change, while others believe that individual change drives collective change (Quang and De Wit, 2020). In a transformative learning perspective, novel actions based on a change in frames of reference are essential ingredients of a transformative learning process (Aboytes and Barth, 2020).

In addition, Macintyre et al. (2020) used a 'transgressive learning' perspective, positioned as a sub-field of transformative learning. They argued that all transgressive learning is transformative, but that transgressive learning highlights the action and agency needed for the transformation of societal systems. Put simply, by Mukute et al. (2018), "transgressive learning can be viewed as transformative learning that deliberately challenges unjust and unsustainable norms and practices that have become normalised" (p. 229). Macintyre et al. (2020) illustrated transgressive learning with the metaphor of a generic plant (the 'Living Spiral' model), and defined learning as a spiralling, organic process consisting of various stages (roots, shoots, stems, leaves, blossoms, and seeds).

Finally, rooted in the work of Engeström, a few papers had an 'expansive learning' perspective on learning based on cultural-historical activity theory (CHAT) (e.g., Jalasi, 2020; Lotz-Sisitka et al., 2017; Mukute et al., 2018). In CHAT, Engeström and Sannino (2021) defined expansive learning as "a collective process of creating and acquiring something that is not yet there. An expansive learning process proceeds from questioning the existing practice to analysing it, then to modelling, examining, and implementing a new solution" [i.e., the 'expansive learning cycle'] (p. 10). This perspective on learning includes novel action (the implementation of a new solution that is first modelled and examined). The 'Change Lab' method from CHAT was used to support expansive learning processes (Jalasi, 2020; Lotz-Sisitka et al., 2017), but also transgressive learning processes (Mukute et al., 2018).

Remarkably, we observed in the papers we reviewed that the perspectives of transformative, transgressive, and expansive learning were often used in non-European settings, like cases in Africa (Jalasi, 2020; Lotz-Sisitka et al., 2017), Asia (Quang and De Wit, 2020; Phuong et al., 2015), and Latin-America (Aboytes and Barth, 2020). The multi-loop social learning perspective was used, with some exceptions (Johannessen et al., 2018; Scholz and Methner, 2020), more often in European cases.

3.3. How is learning studied in transitions research?

3.3.1. Learning in multi-actor settings

The question how learning is defined is closely related to the question how learning is studied. Our analysis showed that most papers analysed learning in multi-actor settings, ranging from formal settings (meetings or workshops) to informal settings (learning-on-the-job) and ranging from spaces created to facilitate and foster learning to spaces without specific learning objectives. We also found a distinction between papers in which researchers had an outsider's perspective (observing and analysing learning from a distance) versus papers in which researchers were actively engaged with the actors in practice.

When researchers were part of a multi-actor setting, the setting or methodological approach was described frequently as 'transdisciplinary'. Maye (2018) defined a transdisciplinary approach as: "a co-produced epistemology and data collection process, which involved stakeholders and research participants from the start, actively informing and co-constructing research design as well as outputs/findings" (p. 337). Approximately one-third of the papers referred to action research, engaged scholarship, or transdisciplinary approaches.

In those papers, researchers were actively engaged with an objective to not only analyse learning but also to facilitate and foster learning (e.g., Beers et al., 2019; Fazey et al., 2020; Macintyre et al., 2020; Sharp and Salter, 2017). From the perspective of the researcher, being engaged was perceived as highly relevant to understand learning in the interaction between actors. For example, Souza et al. (2020) did participant observations in a neighbourhood initiative to improve the socio-ecological conditions of a watershed, including residents, teachers, students, and public sector technicians, in Porto Alegre, Brazil, whereby the presence of the researcher was crucial to understand learning processes through direct experience.

3.3.2. Methods of data collection and data analysis

Most papers described the quantitative and qualitative methods they used without explaining why they used these methods as part of their methodological approach (e.g., Johannessen and Mostert, 2020; Scholz and Methner, 2020; Puerari et al., 2018). A few papers made a clear distinction between phases where they used quantitative and qualitative methods. Surveys were often used to capture change (like new relations or network development) while qualitative methods like interviews were often used to analyse learning. For example, the methodological approach of Domènech et al. (2015) in a study of innovative greywater reuse technologies in Catalonia, Spain, consisted of two phases. First, a survey was used to analyse users' perceptions and acceptance of the new technologies. Second,

Table 7
Methods of data collection.

Methods of data collection	N	%
Interviews	74	66%
Document analysis	40	35%
Organizing or analysing workshop(s)	34	30%
Surveys	22	19%
Focus group discussions	19	17%
Participant observation (e.g., during workshops)	16	14%
Other methods	28	25%
Not clear	3	3%

interviews were held with environmental and urban planning managers of municipalities. Conducting interviews (66%), document analysis (35%), and organising and/or participant observation in workshops (30%) were the most common research methods, while researchers also used surveys (19%), focus group discussions (17%), and participant observations (14%) (see Table 7). Researchers often combined quantitative and qualitative methods in mixed methods approaches or used a combination of qualitative methods.

Half of the papers were based on geographical case studies (48%). These case studies covered a range of different scales, from specific meetings or workshops to a project, a neighbourhood, or a city. In 24 out of 54 papers based on case study research, one case was central in which learning processes were analysed in a specific context. In total, 41 out of 54 papers based on case study research included a maximum of three case studies.

As discussed earlier, 58 papers addressed sustainability problems in Europe, while 18 papers analysed multiple cases in different geographical regions, often including one or more cases in Europe (see Section 3.1). References were also made to the use of 'living labs' (e.g., Puerari et al., 2018), 'transformation labs' (e.g., Macintyre et al., 2020) or 'change labs' (e.g., Lotz-Sisitka et al., 2017). Such labs were the (experimental) settings where research was conducted and were usually aimed at creating a space for transdisciplinary research, co-creation, and experimentation (Scholl et al., 2018). Therefore, in several studies these labs were part of the methodological approach.

In sum, papers often used a combination of qualitative and quantitative methods in mixed method approaches or a combination of qualitative methods. A common methodological approach consisted of designing workshops (as action researcher or engaged scholar) or participating in workshops organised by others, wherein researchers used participant observation and field notes to collect data, often followed by a limited number of interviews or a survey with workshop participants (e.g., Beers et al., 2019; Eriksson et al., 2019).

The methods of data analysis used in the papers we reviewed ranged from deductive to inductive approaches or a combination of both. In a number of papers, the methodological approach consisted of analysing data along predefined themes (e.g., Puerari et al., 2018; Beers et al., 2016; Scholz and Methner, 2020). A few papers made a clear link to the theoretical framework, such as Johannessen et al. (2018) who stated that their analytical framework combined the learning-loops from Argyris and Schön with the learning cycle from Kolb (see also Section 3.2.1). Vangansbeke et al. (2015) used 'transition lenses' to analyse the 'learning history' of forest management in Flanders, Belgium. In data analysis with a dominant open coding approach, the coding was usually done in a number of rounds (e.g., Beers et al., 2016; Castán Broto and Dewberry, 2016), while codes were also discussed within a team of researchers (e.g., Anderson et al., 2018). A combination of deductive and inductive coding was used in several papers (e.g., Aboytes and Barth, 2020; Johannessen and Mostert, 2020) as well as qualitative content analysis to identify the main themes and types of learning related to actors and transition phases (e.g., Domènech et al., 2015).

3.3.3. Tools to facilitate and foster learning

Several papers focused on specific tools or principles designed or used by researchers to facilitate knowledge exchange and learning between different actors to foster the integration of different perspectives. For example, 'World Café principles' were used in workshops to create a more informal setting conducive to learning (Preller et al., 2017) and 'scenario planning' was used to develop shared understanding and foster learning about future planning (Butler et al., 2016; Oteros-Rozas et al., 2015). Other papers used serious games to facilitate and foster learning (e.g., Bekebrede et al., 2018; Gugerell and Zuidema, 2017). For example, Morris et al. (2020) used a computer simulation game and transformation board game to co-design sustainable pathways for livestock production in Burkina Faso, Ethiopia, and Tanzania.

3.3.4. The time horizon to analyse learning

Because many papers analysed learning processes in and around one or several meeting(s) or workshop(s), learning was often captured as a 'snapshot' in a longer transition period. A distinction can be made between papers with a time horizon of a research project (usually a few years with a maximum of four years) and papers which trace learning processes over a longer period of time. An example of the latter is the paper by Vangansbeke et al. (2015) who reconstructed the change trajectory of forest management in Flanders between 2003 and 2012, based on document analysis and interviews. An example of a study with a perspective of a few years is a paper by Sol et al. (2018) who monitored social learning in the Dutch policy program 'Duurzaam Door' (Moving Forward Sustainable) between 2014 and 2016. They used a combination of methods, including workshops, surveys, and 'learning histories' (in the form of interviews with actors) to gain deeper understanding of interventions done in the past. In the Resilience Lab in Rotterdam, the Netherlands, Frantzeskaki et al. (2018) covered four years (2011–2015) and distinguished between a scoping phase, a mobilisation and place-making phase, a deepening, broadening, and upscaling phase, and an evaluation and transferability phase, each marked with a specific research approach. In sum, only a few papers had a time horizon that exceeded a typical research project horizon.

3.4. How is learning related to sustainability transitions?

3.4.1. Breakthroughs as proxies of learning in the multi-level perspective

Our analysis showed that many papers analysed learning in an experimental setting, such as a pilot project, living lab, or innovation initiative (e.g., Beers et al., 2016; Scholz and Methner, 2020). In transitions research, such experimental settings have been defined as niches: protected spaces where novel ideas and radical innovations can develop and mature (e.g., Kemp et al., 1998). Niches are embedded in the multi-level perspective (MLP), a central conceptual framework in transitions research (Markard et al., 2012), to explain transitions by the interplay of dynamics at three different levels: niches, regimes, and landscape (Geels, 2002, 2011; Geels and Schot, 2007). Although learning is not central in the MLP, it has been suggested that learning (and knowledge development) for transitions mainly takes place in niches (Geels and Deuten, 2006; Van Mierlo and Beers, 2020). This does not mean that learning

cannot take place at the regime-level, or that incumbents do not learn (e.g., Hoes et al., 2016). However, our analysis showed that learning in regimes and by incumbents has received little attention.

Some papers we reviewed presented a rather direct relationship between learning and transitions through interactions between niches and regimes. For example, Ingram (2015) and Ingram et al. (2015) analysed how niche innovation networks for sustainable agriculture in Europe were linked to mainstream agriculture and defined niche-regime interactions as adaptive (learning) processes wherein incumbents need to adapt to implement niche innovations. Van Doren et al. (2020) analysed what the City of Copenhagen, Denmark, learned from multiple low-carbon initiatives. Domènech et al. (2015) focused on the 'policy learning' between municipalities in Catalonia, Spain, and between municipalities and higher (regional and national) authorities. They described how in 2002 a first municipality in Catalonia (defined as a niche) experimented with innovative greywater reuse technologies in new buildings and associated policies instead of the traditional 'flush and forget' model. In 10 years, more than 50 municipalities in Catalonia used these technologies and implemented similar policies. This is viewed as a 'regime shift' by the authors.

In our opinion, Domènech et al. (2015) clearly showed that policies in Catalonian municipalities changed as a result of experimentation with innovative technologies and associated policies in one municipality (i.e., the 'regime shift'), but not how learning precisely led to those changes. The authors provided some pieces of the puzzle by writing that "much technical learning has been generated by trial-and-error" and that "interactions and communication between actors [...] proved to be essential to generate social learning amongst policymakers" (p. 38). However, even though they did not quality the relationship between learning and change, the authors argued that "learning processes determine the direction and speed of [a] transition" (p. 27). Moreover, they attributed a lack of change to the absence of learning: "no water quality standards have been approved by any competent authority in Catalonia or Spain which suggests that social learning processes still need to take place at this level" (p. 37).

In similar vein, Vangansbeke et al. (2015) argued that forest management in Flanders changed as a result of "collective search and learning processes" (p. 106), but their description of these processes was rather limited (even though they used a 'learning history' approach). Cuppen et al. (2019) analysed the Dutch societal debate on shale gas and showed in much detail how change in the public opinion occurred (e.g., through specific events, published reports) but were less detailed on what and what not they viewed as learning. In sum, rather strong claims on how learning leads to change and contributes to transitions (through niche-regime interactions) often lacked a thorough analysis of learning processes and are not yet supported by convincing empirical evidence.

3.4.2. Learning in regimes and by incumbents

The papers we discussed in the previous section were optimistic about achieving change at the regime-level through learning (e.g., Cuppen et al., 2019; Domènech et al., 2015; Vangansbeke et al., 2015). However, a few papers that focused on learning at the regime-level showed that learning in regimes and by incumbents remained superficial, and instead of system transformation, the existing system was often reinforced (Johannessen et al., 2018; Johannessen and Mostert, 2020; Medema et al., 2015; Wolfram, 2019). For example, in water governance systems, this superficial learning was found in sectoral specialisation and siloed organisations and was strengthened by a lack of risk perception amongst stakeholders (Johannessen et al., 2018; Johannessen and Mostert, 2020).

Based on an analysis of urban water governance systems in different countries and continents, Johannessen et al. (2018) argued that superficial learning can become a barrier for deeper learning as it prevents learning beyond dominant paradigms (a 'learning lock-in'). Based on similar findings in the South Korean energy system, Wolfram (2019) underscored the importance of 'unlearning' dominant paradigms but did not elaborate on how this can be accomplished. Moreover, Medema et al. (2015) and Johannessen et al. (2018) argued that deeper learning in regimes and by incumbents require proactive approaches and efforts to facilitate and foster learning.

Bryant and Thomson (2021) highlighted the role of individual 'change agents' in regimes. They evaluated an internal education program for municipal employees that accompanied the introduction of sustainable policies in Perth, Australia, and found that this educational program had considerable impact (measured as new sustainability initiatives) within a short time frame. Therefore, Bryant and Thomsen (2021) argued that "even within apparently rigid bureaucratic structures such as government departments, bureaucrats have agency" ('Conclusions' paragraph 3).

In sum, we found in many papers an underlying, sometimes implicit, assumption that learning in regimes and by incumbents remained superficial and a few papers provided evidence of this (e.g., Johannessen et al., 2018; Wolfram, 2019). This superficial learning was generally considered as insufficient for regime-change and system transformation (see Section 3.2.2). Niches, as (radical) alternatives of dominant regimes, were viewed as place where deeper leaning occurred, although the development of niches may also include much superficial learning (e.g., Aboytes and Barth, 2020). Moreover, some papers had high hopes of niche-regime interactions (e.g., Domènech et al., 2015), but have not convincingly showed how learning led to change. Therefore, we argue that learning in regimes and by incumbents is still understudied.

3.4.3. Learning to find shared understanding

We discussed earlier that a 'change in understanding' is seen as an essential ingredient of a social learning process (see Section 3.2.1). Many papers focused on developing a 'shared understanding' between actors as a basis for novel, collaborative action. When actors interact in a multi-actor setting, mutual learning helps to overcome differences in actors' perspectives and goals and may lead to a better understanding of a problem and eventually to a shared understanding. For example, Scholz and Methner (2020) found that learning between members of a transdisciplinary research project for sustainable agriculture in South Africa, helped to develop a more comprehensive understanding of the sector, the vulnerabilities, and the opportunities.

Sol et al. (2018) defined this process as 'reframing': "the emergence of new, shared perceptions on the issues faced by a relatively heterogeneous group exploring a mutually perceived but somewhat ill-defined challenge" (p. 1388). Other papers used other concepts

to analyse the process of developing a shared understanding, including 'boundary crossing' (Souza et al., 2019), which was seen as fundamental for transdisciplinary problem-solving, and 'negotiation-of-meaning' (Beers et al., 2019).

Although the concept of shared understanding was widely used in the papers we reviewed, it was not always clearly defined. Scholz and Methner (2020) built on earlier work of Scholz (2016) where she argued that shared understanding refers to "convergence in the mental models of actors" (p. 29) which is part of a social learning process. Shared understanding is not the same as consensus: consensus implies that actors reached an agreement as a result of a discussion, while shared understanding can also imply an awareness of divergent opinions without reaching consensus (Scholz, 2016). Moreover, when actors learn, it does not necessarily mean that they also reach a shared understanding. Learning can also occur while positions harden and common ground decreases (Beers et al., 2006; Scholz, 2016). Scholz (2016) therefore suggested to distinguish between learning either being 'convergent' or 'divergent'. Convergent learning refers to "an increase in shared understanding and means that actors integrated new perspectives gleaned from each other and/or developed new shared concepts" (p. 44). We argue that developing a shared understanding is essential to make the step towards novel, collaborative action, but that reaching a shared understanding is not a straightforward process.

Shared understanding is thus crucial in learning for transitions. However, we also found that in many papers the problem was described but not questioned, and that the interaction in multi-actor settings focused on solutions to the problem. Put simply, in many papers, developing shared understanding of a problem did not mean that the problem itself was questioned (e.g., Mutahara et al., 2018; Scholz and Methner, 2020). Approximately one-third of the papers we reviewed questioned the problem. Those papers described, for example, situations and settings where problems were analysed, discussed, and eventually reframed (e.g., Baehler and Biddle, 2018; Frantzeskaki et al., 2018). Researchers can play a key role in questioning problems: half of the papers in which the problem was questioned were based on action research, engaged scholarship, or transdisciplinary approaches (e.g., Ely et al., 2020; Fazey et al., 2020).

3.4.4. Partnership conditions: trust, disagreement, and power

An important enabling condition for learning that was mentioned in the papers we reviewed was trust. Several papers showed that trust between the actors in a multi-actor setting provided a good starting point for learning to take place. For example, Eriksson et al. (2019) found that 'strong ties' (i.e., the well-connected individuals) facilitated trust in a group of academics and that trust fostered deeper learning from self-reflection (although the weak ties were also important for learning). Scholz and Methner (2020) found that trust created commitment to the project and vice versa. However, they also argued that this finding may be the result of an absence of more radical voices in the project. Rossi (2020) showed that low and decreasing trust-levels limited the opportunities for learning. Sol et al. (2018) highlighted the role of individual 'change agents' when trust-levels were low in the governance innovation networks in the Netherlands.

At the same time, trust was also described as an important outcome of a learning process. Papers that highlighted trust as an enabler of learning also provided evidence that learning together (and developing a shared understanding) is a process that creates mutual trust between the actors involved (Rossi, 2020; Scholz and Methner, 2020). We argue that an initial trust-base is an important precondition for learning and that the relationship between trust and learning is reciprocal: trust fosters learning from and with one another but learning together also creates trust.

A few papers emphasised the usefulness of having disagreement and conflicts (e.g., Beers et al., 2016), and especially Cuppen et al. (2019) who, based on an analysis of newspaper articles, focused on the role of 'normative conflicts'. They analysed the societal debate on the use of shale gas in the Netherlands and showed that a key role for shale gas in the energy transitions was initially taken-for-granted by the national government and associated organisations in the energy system. Societal unrest around the negative externalities of shale gas explorations shifted the attention to the use of shale gas, and the earlier taken-for-granted role of shale gas was gradually and increasingly questioned. Based on these findings, Cuppen et al. (2019) argued that disagreement, conflict and even polarisation may be, "counter intuitively, an important mechanism for learning through societal conflict" (p. 173).

Many papers also indicated the importance of power relations in learning processes, especially for learning in regimes and by incumbents (e.g., Medema et al., 2015). Incumbents are considered as powerful actors because they often have elevated levels of technological development, many financial resources, and influence on public policy (Imbert et al., 2019). Johannessen et al. (2018) argued that powerful actors can create and maintain a learning lock-in by preventing any learning that goes beyond dominant paradigms. However, they were less clear on how this power was exerted. Power also plays a role in niche-regime interactions. Powerful actors can influence to what extent regimes adapt to implement niche innovations. Put simply, they have influence which niche innovations are implemented and which are not. Ingram (2015) defined this as "selection power" (p. 66). However, learning is not the only factor involved in implementing niche innovations and the precise role of learning in the adaptive processes remained largely unclear.

In similar vein, Barrie et al. (2019) showed in the biotechnological niche innovation network in Scotland, that the intermediary actor exerted power of the knowledge flows (and thus the opportunities for learning) in the network and effectively played the role of knowledge "gatekeeper" (p. 217). In sum, our analysis suggested that power is related to learning (at the regime-level) in different ways, but that the relationship between power and learning is insufficiently analysed.

4. Discussion

In this paper, we presented a systematic review of empirical papers that addressed the role of learning in sustainability transitions. We focused our analysis on three main topics: how learning is defined, how it is studied, and how it is related to sustainability transitions. In this section, we reflect on the results of our analysis and describe the limitations of our work.

Based on earlier claims in exploratory reviews that there is a lack of conceptual clarity and a weak empirical knowledgebase in research on learning for transitions, we were initially positively surprised by the number of papers we identified ($n = 113$). However, through an in-depth analysis of the papers, we realised that not all papers deeply analysed learning processes and learning outcomes, and that their contribution to our understanding of learning was rather limited.

4.1. Perspectives, problems and prospects for future research

4.1.1. The complex relationship between learning and change

What is learning? Our analysis showed that learning was often seen as a process of acquiring new information through interaction in social networks and of meaning-making of this information. This perspective on learning was derived from definitions of social learning in natural resource management (e.g., Reed et al., 2010). In transitions research, this type of learning has been defined as 'discursive interaction' (Van Mierlo and Beers, 2020). This learning occurs in multi-actor settings where actors with different perspectives and goals discuss a sustainability problem. Learning then leads to a better (or rather, a more complete or more nuanced) understanding of this problem. Put simply, actors learn from and with one another to define problems from different viewpoints.

By striving to develop a shared understanding of a problem, multiple actors can form a collective basis for novel, collaborative action. In transitions research, this type of learning has been defined as 'reflexive action' (Van Mierlo and Beers, 2020), and is also reflected in a definition of learning provided by Van Mierlo et al. (2020) who defined learning as "a non-linear, iterative process in which ideas and possibilities for collaborative action are being developed, experimented with and pursued in a diversity of networks" (p. 253).

Our analysis showed that different views existed on whether novel, collaborative action is part of a learning process or is a learning outcome. Most papers saw novel action as an essential ingredient of a (multi-loop) social learning process, a transformative/transgressive learning process, or an expansive learning process. We share the view that developing a shared understanding of a sustainability problem is not sufficient in order to achieve a transition. Thinking and speaking of a problem alone is not enough, it is not only what actors think and say, but also how they translate their thoughts and talks into what they do (action) that leads to change and contributes to transitions. This resonates with the distinction in practical learning outcomes, relational learning outcomes, and conceptual learning outcomes made by Van Poeck et al. (2020), where the latter refer to broadening the scope of how problems are framed and defined and to 'skills' such as creativity, critical thinking, reframing, etc., which may contribute to achieve transitions.

Based on our analysis, we see that learning for transitions from prevailing studies have tended to be solution-orientated (i.e., directed towards action), and consequently studies have downplayed learning in relation to problem definitions. A (too) dominant focus on what actors do, neglects learning that occurs before novel, collaborative action is undertaken, since there can be many intervening conditions and constraints that shape how thinking and talking can be translated into action. This may especially apply to the regime-level, where dominant practices, structures, and cultures (deliberately) maintained by powerful incumbents, can restrict the room for action and learning in general (Johannessen et al., 2018).

The focus on action in solution-orientated perspective on learning found in many papers, also contributes to the lack of conceptual clarity already noted by Van Poeck et al. (2020). Our analysis showed that previous studies often blurred the lines between learning and change and treated both concepts as synonymous and interchangeable. Put differently, papers that showed change failed to convincingly demonstrate how learning occurred and how it led to change (e.g., Domènech et al., 2015; Vangansbeke et al., 2015). Learning processes (as discursive interaction and as reflexive action) and learning outcomes (as change) were often conflated in previous studies, and researchers have assumed that change was the result of learning, potentially ignoring other factors.

In conclusion, we share Van Poeck et al.'s (2020) assertion that "the complexity of the relation between learning and societal change is insufficiently acknowledged" (p. 303). Based on our analysis, we argue that, in future research, there is room to better distinguish between learning as discursive interaction (problem-orientated), learning as reflexive action (solution-orientated), and learning outcomes (as change in societal systems).

4.1.2. Learning in regimes and by incumbents

Many papers we reviewed analysed learning in an experimental setting, such as a pilot project, living lab, or innovation initiative. In transitions research, these settings have been defined as niches (e.g., Kemp et al., 1998). Although learning is not central in the multi-level perspective on transitions, it has been suggested that learning for transitions mainly occurs in niches (Geels and Deuten, 2006; Van Mierlo and Beers, 2020). Other papers we reviewed focused on niche-regime interactions and defined these as adaptive learning processes in which incumbents need to adapt to implement niche innovations (e.g., Ingram, 2015). These findings do not mean that learning cannot take place at the regime-level, or that incumbents do not learn (see also Grin, 2020; Hoes et al., 2016). Rather, our analysis showed that learning in regimes and by incumbents is still understudied in transitions research.

That said, there is growing acknowledgement that learning at the regime-level is crucial. Some papers described regime-change and argued this change was the result of learning (Cuppen et al., 2019; Domènech et al., 2015; Vangansbeke et al., 2015), although this relationship is still inconclusive (see Section 4.1.1). Other papers showed that learning in regimes and by incumbents remained superficial and did not lead to transformation but instead strengthened the existing system (Johannessen et al., 2018; Johannessen and Mostert, 2020; Medema et al., 2015; Wolfram, 2019). Wolfram (2019) underscored the importance of 'unlearning' at the regime-level, but this idea has not been examined in the papers we reviewed.

It has been argued that incumbents tend to be resistant to change (Fischer and Newig, 2016). Some papers we reviewed suggested that incumbents deliberately resisted deeper learning (Johannessen et al., 2018; Medema et al., 2015), while others were more optimistic about learning in regimes and by incumbents (Domènech et al., 2015; Vangansbeke et al., 2015). Based on these findings, we

argue that it is a key prospect for future research to better understand learning in regimes and by incumbents. Earlier work by Hoes et al. (2016) and more recently by Grin (2020) on doing system innovation from within the heart of the regime have centred the attention on how (urban) experiments have developed where incumbents such as (local) governments and other established organisations play a leading role in driving regime-change.

Recently, Costa et al. (2022) developed an analytical framework to analyse regime-level learning. This framework consists of a 3 × 5 matrix with three learning-loops (single-, double-, and triple-loop learning) and five learner-levels (individual, group, organisation, network, and system). The first four learner-levels are described as 'learning-in' regimes and the fifth learner-level as 'learning-by' regimes. The latter corresponds with the transformation of societal systems. This framework thus also blurs the boundaries between learning and (institutional) change, which we also identified in our analysis. Costa et al. (2022) tested their framework in an initiative in the Belgian food system in which various stakeholders (both niche- and regime-actors) participated to promote local products in supermarkets. They found evidence of learning-in the regime but no evidence of learning-by the regime. In other words, the learning-in the regime did not (yet) lead to a transformation of the Belgian food system.

Our analysis showed that papers often made a distinction between superficial and deeper learning and used a 'multi-loop learning' perspective rooted in the work of Argyris and Schön on organisational learning. These papers associated single-loop (superficial) learning with incremental change and system reinforcement, and double- and triple-loop (deeper) learning with radical change and system transformation. We argue that, in future research, there is room to approach this as an (important) empirical question and not as an assumption. Is it only deeper learning that makes a difference, or can multiple steps of superficial learning to incremental improvements also contribute to regime-change? The type of learning in regimes and by incumbents may also depend on different transition pathways (Geels and Schot, 2007).

4.1.3. Multi-actor settings and partnership conditions

Although interaction and networks are keywords in definitions of social learning, both received little attention in the papers we reviewed. Papers often assumed that learning took place in interactions but did not focus on the interaction itself (with Beers et al. (2016) as a notable exception). Regarding networks, our analysis showed that a network perspective proved its value to understand the knowledge flows in niche innovation networks (e.g., Barrie et al., 2019; Ward and Butler, 2016). We also found that it was commonly assumed in previous studies that a larger number and diversity of actors would increase the opportunities for learning (e.g., Medema et al., 2015). We argue that applying a network perspective on regime-level learning can shine new light on this assumption and can help to better understand learning in regimes and by incumbents.

Moreover, we argue that it is important to consider trust and power relations in learning processes and in networks, especially when analysing learning in regimes and by incumbents. It has been acknowledged that power and trust dynamics are important in transitions (Avelino and Wittmayer, 2016; Koole, 2020). For learning, power relations are relevant because powerful actors can deliberately enable or constrain learning beyond dominant paradigms and often have control over knowledge flows within a network (Barrie et al., 2019; Imbert et al., 2019; Johannessen et al., 2018). For trust, we found that an initial trust-base is an important precondition to facilitate (deeper) learning. In addition, the relationship between trust and learning is reciprocal: trust fosters learning from and with one another, but learning together also creates trust (Eriksson et al., 2019; Scholz and Methner, 2020; Sol et al., 2018).

4.1.4. Research approaches and the role of the researcher

The problems and prospects for future research we described in the previous section provide challenging questions that are not easy to answer. First and foremost, it will require longitudinal methodological approaches, which are rare in previous studies on learning for transitions. It is likely that existing research funding structures influence research approaches that do little to promote longitudinal studies, as academic research is characterised by short-term project approaches covering a few years (e.g., Trimble and Plummer, 2019). This may provide an explanation as to why so many studies tend to focus on short interventions like a co-creation workshop or interviews and surveys with participants in experimental settings as the basis for research on learning for transitions.

Another possible reason for the short-term focus in prevailing studies is that studies were often designed as action research where researchers had multiple roles: they did not only observe and analyse learning, but were also actively engaged as, for example, a facilitator or knowledge broker. Bulten et al. (2021) showed that these distinct roles can conflict with each other and that it can be difficult to combine action-orientated roles with knowledge-orientated roles, while researchers can also run into limitations of where (space) and when (time) they are involved. However, a deeply engaged researcher can also contribute to better understand learning processes (e.g., Souza et al., 2019).

4.2. Limitations of our systematic review

The systematic approach we used to review the literature has important strengths, such as the robustness of the evidence-base and transparency about methodological choices, but also has some critical limitations. Because we focused on papers that were published between 2015 and 2020, we missed some seminal papers by the founding mothers and fathers of research on sustainability transitions. Based on our inclusion and exclusion criteria and the keywords we used to search in Scopus, we also missed relevant papers on 'system innovations' (e.g., Grin, 2020). A quick search in Scopus including the keywords 'system innovation' and 'learning' showed that there were relevant papers here. Therefore, we nuance our claim of being as inclusive as possible. Nevertheless, we maintain that our findings are based on a solid evidence-base.

Our approach of using a broad, open scope including a wide variety of empirical settings and geographical regions resulted in a wide selection of papers ($n = 113$). This brought some limitations in time and capacity to analyse all the papers. However, not all

papers deeply analysed learning and contributed much to our understanding of learning for transitions and therefore we were able to deeply analyse the most relevant papers.

Another limitation of our work is that we focused on peer-reviewed journal papers written in English. Grey literature sources may provide additional knowledge on the topic, especially since mutual learning processes between academic and non-academic actors were common practise in the papers we reviewed. In a systematic literature review of multi-stakeholder platforms in sub-Saharan Africa, Van Ewijk and Ros-Tonen (2021) found that grey literature sources were more critical about the role of researchers than journal papers. Our analysis showed that the role of the researcher was often perceived as positive, although Collins (2020) argued that experiences of learning can diverge: academics may see a successful learning experience, while non-academic actors may see a project that has failed to 'deliver'.

Despite the limitations of our work and nuancing our claim that we were as inclusive as possible in our search strategy, this review paper has presented a solid contemporary and comprehensive overview of how learning is defined and studied in transitions research and of how learning is related to sustainability transitions. Moreover, we highlighted several thematic areas related to learning that constitutes knowledge gaps in the study of learning for transitions, including networks, trust, disagreement, and power.

5. Conclusion

This systematic review addressed the question: ***how is learning defined and studied in transitions research, and how is learning related to sustainability transitions?*** We addressed this question because our understanding of the role of learning in sustainability transitions has been based on exploratory reviews of the literature and there was a lack of an integrative review of empirical evidence on learning for transitions. Based on an analysis of 113 empirical papers, we conclude that only a limited number of papers deeply analysed learning processes and learning outcomes.

In the papers, a 'multi-loop social learning' perspective was dominant. Strong claims that learning contributed to change were made, but our results show that previous studies have not convincingly demonstrated how learning led to change. We argue that there is a need to better distinguish between learning processes and learning outcomes, and to deeply analyse how learning leads to change and contributes to transitions.

Papers displayed a dominant focus on learning in an experimental setting and learning in regimes and by incumbents is understudied. This is related to the short time horizon that papers often had, which is likely to be influenced by existing research funding structures. Analysing learning in regimes and by incumbents is a key prospect for the field of transitions research and will require more longitudinal approaches that are rare in previous studies on learning for transitions. Finally, networks, trust, disagreement, and power are important aspects related to learning that will require further examination, especially when analysing learning in regimes and by incumbents.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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Appendix A. Included studies

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