Industrial Ecology Thesis

# Water, Waste and Wisdom:

## Education for a Circular Water Future in Europe

The Role of EU Higher Education in Building a Circular Water Economy

By M.I van Mouwerik

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# Preface

This thesis marks the final step in my journey through the Master's program in Industrial Ecology—a joint degree offered by Technical University of Delft and Leiden University in the Netherlands. It investigates how higher education in the EU can support the transition to a circular water economy by developing a circular mindset through technical, systemic, interdisciplinary, and reflective competencies in future water engineering professionals.

My interest in this topic stems from a long-standing fascination with ecological principles and system behaviours—spanning over the ecological, social, and technical domains. At its core, this curiosity is driven by a desire to grasp life in all its forms. It is the dynamic relationship between the living and non-living that gives rise to one of the most pressing questions: to what extent can humans influence, coexist with and destruct their environment? Water, as a subject of inquiry, embodies the complex dynamics between humans and their environment, as it is essential to all life. That the topic of water unites diverse questions across scientific, societal, and ethical domains makes it a topic that transcends academic world, aligning with my drive to work interdisciplinarity and engage with challenges that extend beyond the academic sphere.

And if these weren't enough reasons to dedicate myself to this topic, the project also engages with education—an area I've become increasingly passionate about since I began teaching. Education provides a space to explore the world in dialogue with others, to organize and critically test one's thinking, and to navigate the challenge of exploring and communicating 'the complex' simple—and 'the simple' with depth. Being able to share your way of seeing the world, to have others listen and respond, is one of the most humbling and meaningful work I can think of.

This project allowed me to explore the intersection of water, education, and systems thinking—three areas I deeply care about. Writing this thesis has expanded my academic understanding while also challenging my assumptions and contributing to personal and professional growth. Surprisingly uniting, the conclusions I arrived at in the research mirror the insights I gained from the process itself: outcome and process are not separate. A the start of the project, I focused so intently on *what* content the thesis should cover that I overlooked the *how* of conducting research and crafting an academic work. The learning curve was steep, and at times stressful, yet grounded in a quiet confidence that, regardless of the outcome, everything would be all right.

Ultimately, this research reflects my belief that education is not merely about transferring knowledge. It is about cultivating the values, mindsets, and capacities needed to engage with uncertain, ambiguous, and complex futures—always aiming to do so with  trust, respect and joy.

M.I. van Mouwerik, (Mathilde)
Amsterdam, August 2025

# Content

# Abstract

In the face of escalating climate pressures and resource scarcity, the transition toward a circular water economy (CWE) has emerged as a critical sustainability strategy within the European Union. However, this transformation demands not only technical innovation; it also depends on education that prepares future water professionals to implement, upscale, maintain and adapt these emerging technologies. This thesis investigates the role of EU higher education in enabling that transition, examining how water engineering curricula can move beyond traditional linear paradigms to embrace the systems thinking, interdisciplinary collaboration, and reflective practice required for circularity practices.

Drawing on a systematic literature review, curricular analysis of EU Master's programs, and empirical insights from expert interviews, the research identifies gaps in current educational practices for educating water professionals. CE principles remain largely absent from mainstream water engineering education, while essential competencies to execute those practices—such as Interdisciplinary collaboration, systemic insight, and reflective practices—stay underdeveloped. The study synthesizes these findings into a comprehensive conceptual framework that outlines core education concepts and links them to learning objectives and teaching methods.

By reframing education as a key enabler of circular transformation, this research contributes to both education for CE and the operationalization of circular water systems. It provides practical guidance for educators, institutions, and policymakers aiming to align academic training with the needs of a resilient, resource-conscious water future—shaping not only professional practices but also the underlying ways we think about them.

# Acknowledgments

I would like to sincerely thank my supervisor, Dr. D. Xevgenos, for his valuable guidance and feedback throughout this process. I am also grateful to the members of my thesis committee: Dr. J. Manuel Duran, whose thought-provoking philosophical and fundamental questions enriched the depth of this work, and A. Bilyaminu, for his open and friendly approach of help and willingness to offer support whenever needed. My sincere thanks to all of you for your constructive input and encouragement.

I want to thank all the interview participants who generously shared their time and insights—your contributions were vital in shaping the empirical foundation of this thesis.

Besides, I would like to thank Dr. L. Kamp, the thesis course coordinator, whose support and availability, even from a distance, were greatly appreciated.

Last but not least, my deepest gratitude goes to those who have been my antidote to stress, my source of inspiration, and my unconditional support throughout this journey: my sister C.S. van Mouwerik, my partner S.W. Wanyonyi; and the people without whom I would not be here—my parents.

# List of Abbreviations

| | |
|---|---|
| CWE | Circular Water Economy |
| CWP | Circular Water Practice |
| EU | European Union |
| UNESCO | United Nations Educational, Scientific and Cultural Organization |
| IPCC | Intergovernmental Panel on Climate Change |
| CE | Circular Economy |
| ESD | Education for Sustainable Development |
| ECE | Education for Circular Economy |
| EDR | Educations Design Research |
| SLR | Systematic Literature Review |
| PRISMA | Preferred Reporting Items for Systematic Reviews and Meta-Analyses |
| STEAM | Science Technology Engineering Art Mathematics |
| TUD | Technical University of Delft |

# 1 Introduction

## 1.1 Background

Water security has historically been both a key driver of human development and a critical challenge for human survival. Throughout history, water management challenges in the Europe illustrate this dual nature of water, demonstrating how it can be both beneficial and detrimental. Water's indispensable role in human development is evident in all aspects of life, see its contributions to thermal stability and climate regulation provided by rivers (Caissie, 2006) and oceans (Bigg et al., 2003; Reid et al., 2009), the support of agriculture and food production (Ingrao et al., 2023), facilitation of transport and trade (Gupta & Prabhakar, 2024; Lane & Pretes, 2020), and contributions to energy production (Kaunda et al., 2012; Olsson, 2015; Sipahutar et al., 2013) and industrial processes (Han et al., 2024). At the same time, water management issues—such as preventing floods in coastal and inland areas (Mishra et al., 2022; Wesselink et al., 2015), mitigating and preventing pollution (Goel, 2006), and combating water scarcity (Dolan et al., 2021; Tzanakakis et la., 2020) — demonstrate the complex interplay of water's benefits and its risks. A persistent tension in water security lies in balancing the competing necessities of humans and ecosystems while preserving vital services such as biodiversity (Schindler et al., 2016; Vörösmarty et al., 2010; Reid et al., 2019). To address this, water professionals have introduced innovations across various sectors, ensuring water security through measures from securing water supply, managing urban drainage, treating wastewater, and handling sludge in urban and industrial areas (Brown et al., 2009), to regulating water levels (Moench, 1994) and managing nitrogen contamination from agriculture (Eickhout et al., 2006). Although the impact of these practices differs across municipal, regional, and national contexts (Daniell et al., 2014; Moss & Newig, 2010), water scarcity remains a global challenge (Du Plessis, 2022; He et al., 2021; Peydayesh & Mezzenga, 2024). At the same time, water scarcity is currently impacting approximately 11% of the European population and 17% of the EU's territory (European Commission, 2011; Koseoglu-Imer et al., 2023). Which underscores the transboundary nature of water systems (Earle et al., 2013) and reinforces the collective responsibility of nations in ensuring effective water management. At the European Union (EU) level, multiple directives and regulations are designed to overcome this transboundary challenge, aiming to protect both surface and groundwater resources across borders (Moss, 2003). Together, these innovations and policies—especially those in urban water management focused on safe drinking water, (urban) sanitation, and pollution control—have improved general public health (Akpor & Muchie, 2011; Brown et al., 2009; Ferriman, 2007) and enhanced the overall water security significantly (World Bank, 2009).

However, water security issues persist in the EU, many of which are exacerbated by climate change (Elsner, 2023). The Intergovernmental Panel on Climate Change (IPCC) report emphasizes that every additional degree of warming will make achieving water security increasingly difficult (IPCC, 2021). Besides, while the fundamental properties of water and weather systems remain unchanged, the scale of human manipulation and operations of these systems did (liu et al., 2007). For example, through extensive use of land with fertilizers (Craswell, 2021), over-extraction of freshwater resources for both consuming and irrigation (Richey et al., 2015; Mishra, 2023; Khorrami & Malekmohammadi, 2021), industrial pollution (Dwivedi, 2017) or other anthropogenic pressures

(Akhtar et al., 2021). Moreover, aging infrastructure (Poff et al., 2016), growing urbanization (Mcgrane, 2016), emerging contaminants (Das et al., 2023; Geissen et al., 2015; Petrie et al., 2015), competing water demands (Flörke et al, 2018; Giuliani et al., 2021; Zikos & Hagedorn, 2017) fragmented governance of the water sector national (Alaerst, 2021) and international (Nwokediegwu et al., 2024), and the need for climate adaptation measures (Larson et al., 2015) are examples of human behaviour that drives water crises as well and further complicate contemporary water management efforts. These anthropogenic pressures intertwine with climate impacts, only amplifying the complexity and consequences of water security issues within water and weather systems. These systems, with their intrinsic complexity, interconnectedness, and cyclical behaviour, foretell that simplistic short-term strategies are ill-suited to address the wicked problems inherent to modern water management (Reed and Kasprzyk, 2009). Strategies such as rising dikes or expanding sewage infrastructure, once sufficient, fall short of addressing the nuanced and interdependent dimensions of modern water security challenges (Ritzema et al., 2018; Thissen er al., 2017; Vlachos and Braga, 2001).

Besides, countries and communities that have yet to achieve water security are the most vulnerable to water shocks, while those that have attained some level of security may face growing challenges in maintaining it (Sadoff & Muller, 2009). In both cases, however, governance is needed to allocate additional resources to manage its treats and challenges (Julio et al., 2021; Julio et al., 2022; Molle et al., 2006). Therefore, addressing water security becomes more than just an engineering or infrastructure challenge—it demands social equity and justice considerations as well (Jepson et al., 2017; Yalew et al., 2024).

Thus, given today's challenges and pressures on water resources, water professionals must adopt sustainable approaches that balance human consumption with natural regeneration (Falkenmark & Rockström, 2004; Farrelly & Brown, 2011). Which marks the urgent need for resilient water management, where water professionals play a crucial role in shaping such sustainable practices that support life, well-being, and economic prosperity while minimizing environmental pressures.

CE has been proposed as an effective strategy for reducing such environmental pressure and promoting sustainable management, particularly in the water sector (Brears, 2020; Kopnina, 2020; Mbavarira and Grimm, 2021; O'Shea et al., 2021; Sauvé et al., 2021; Tahir et al., 2018). Also the EU's CE Action Plan underscores the importance to implement CE principles into water management and transitioning to circular water systems (Johansson, 2021). Principles such as closed-loop supply chains (Fathollahi-Fard et al., 2020), value retention by redesigning urban management (Kakwani & Kalbar, 2020), waste minimization through reuse of wastewater (Silva, 2023; Guerra-Rodríguez et al, 2020), and resource efficiency (Masi et al., 2018) align well within the water sector (Delgado et al., 2024; Smol et al., 2020; Vinayagam et al., 2024). Thus, by maintaining the value of resources, the circular water economy offers a strategic approach for water professionals to adapt their economic and operational systems in response to the growing challenges of water security.

However, transitioning from a linear water system to a circular one demands workforce training and education tailored to meet the operational complexities of circular practices (Guerreschi et al., 2023; Sánchez-García et al., 2024; Suárez-Eiroa et al., 2019). Tiippana-Usvasalo et al. (2023) emphasize the critical role of education in developing skills for the CE. Similarly, Serrano-Bedia and Perez-Perez (2022) identify higher education as a key driver in accelerating the CE transition. Smol et al. (2025) further advocate for institutional capacity-building to unlock the potential of circularity. Education is thus recognized as a vital enabler of the CE, supporting long-term vision and committed leadership (Mbavarira & Grimm, 2021). Higher education institutions, in particular, are viewed as strategic actors in advancing this transition (Renfors, 2023).

This recognition has led to the emergence of two closely related fields: ESD and ECE. While they share overlapping goals and approaches, While they share overlapping goals and approaches, ECE is increasingly being distinguished as its own field (Renfors, 2023; Kopnina, 2022; Kirchherr and Piscicelli, 2019), albeit with a still limited and fragmented body of literature (de la Torre et al., 2021; Giannoccaro et al., 2021). As Guerreschi et al. (2023) point out, educators often lack clear guidance on how to design CE-focused courses. In fact, only two studies have been found that explicitly examine CE courses at the university level (Kopnina, 2022; Kirchherr & Piscicelli, 2019).

Moreover, ideas of what the content of such courses should be remains limited too. Existing research has mainly concentrated on identifying key (sustainability) skills and competencies needed for the CE, name skills and competences like systems thinking, strategic thinking, collaboration, critical thinking, and self-awareness (Janssens et al., 2021; Giannoccaro et al., 2021; Straub et al., 2023; Wiek et al., 2011). Nevertheless, CE skills remain poorly defined and are rarely reflected in job descriptions or HR frameworks (Burger et al., 2019; Guerreschi et al., 2023; Giannoccaro et al., 2021). The CE sector itself remains fragmented and evolving (Burger et al., 2019; Garito et al., 2023; Renfors, 2023), making it difficult to anticipate future skill demands. The literature remains limited and is never specifically related to both ECE and the water sector.

While a growing body of literature addresses how to design educational programs and teaching strategies that enable competencies for sustainability and CE (e.g., Ab Hamid et al., 2024; Kirchherr & Piscicelli, 2019; Mesa & Esparragoza, 2021; Renfors, 2024; Vidal et al., 2024), much of this work is rooted in ESD rather than ECE, and rarely considers the water sector specifically. Thus, despite technological innovations, policy initiatives, and educational efforts supporting circular systems, there remains a critical gap in the education and training of professionals equipped to implement a circular water economy (CWE). Overall, this highlights a significant shortfall in research concerning both the content ("what?") and teaching method ("how?") of education necessary to advance the circular water economy in practice.

## 1.2 Problem Statement

Although there is considerable literature on educational practices and pedagogical methods in general, even within the realm of sustainability education, a preliminary search from the introduction revealed minimal research on educational strategies aimed at equipping individuals with the skills and competencies needed to implement, maintain, and adapt CE principles in water management systems. Given the growing demand for applying CE principles to the water sector— there is a notable gap in both defining the learning objectives (what water professionals should learn?) and determining the most effective teaching methods to do so (how to best convey these concepts?). These knowledge gaps give rise to the need for new or customized educational strategies and frameworks to better equip water professionals for the transition to a CWE, yet there is currently no such specific conceptual framework available.

This results in the problem statement: Despite the growing recognition of the need to transition to a circular (water) economy, there is a significant lack of literature addressing the education required to support this shift (de la Torre et al., 2021; Giannoccaro et al., 2021; Guerreschi et al., 2023; Kirchherr & Piscicelli, 2019; Kopnina, 2022). Specifically, there is an absence of defined learning objectives and teaching approaches for equipping professionals with the skills and competencies necessary to implement, upscale, maintain, and adapt CE principles in water management systems.

## 1.3 Research Aim and Objective

The main objectives are specified as follows:

1. Assess the skills gap related to the implementation of CE principles in the water sector.
2. Identify the key knowledge areas, skills, and competencies necessary to support the development of circular thinking within water engineering education, with a focus on enabling the effective implementation of CWPs.
3. Identify teaching method and assessment techniques that best support the development of skills and competences needed for circular water practise.

The deliverable will be an conceptual framework for water engineering professionals. This includes the results from the literature review and empirical findings in the form of educational conceptual topics. The "what" (educational concepts and learning objectives), the "how" (teaching method), behind the circular water economy are presented separately

## 1.4 Research Question

*Main research question*

What subject-specific and generic competences, along with teaching approaches, are necessary for higher education in the EU to effectively embed circular thinking into water engineering curricula and prepare future water professionals for a circular water economy?

*Sub-questions*

1. Are current water engineering educational programs in the EU equipping graduates with the skills and competences required for implementing circular water economy practices in the water sector?
2. What are the critical CWPs to educate future water professionals for a circular water economy in the EU?

3. What skills and competences should young professionals have to execute these new CWPs?
4. How is circular thinking established through interdisciplinary, systems-thinking, and reflective learning approaches used to support education on CWPs?
5. How are teaching and assessment methods designed for prompting this circular thinking within water-related education programs?

## 1.5 Scope

This research aims to develop a structured conceptual framework that integrates skills and competencies to equip future water professionals with the competencies needed to drive the transition to a circular water economy. The study will be conducted between February and August 2025. A qualitative research approach will be used, focusing on case studies and interviews within the EU. The primary data sources will include interviews with case study holders and key experts in the CE and water sector.
The study is designed for a diverse audience, including academics, industry professionals, governmental organizations, and other stakeholders interested in the circular water economy and the role of education in advancing its implementation.

The study focusses on Master level water engineering education. This research explicitly excludes case studies outside the EU, and only academic or other sources available in English or Dutch will be considered. Additionally, the conceptual framework developed will not be empirically tested or evaluated within this study. Furthermore, the research will centre on technologically driven CE practices which operate on relatively small scale, rather than addressing larger-scale sustainability measures such as national flood protection. By defining these boundaries, the study ensures a focused and feasible approach to exploring the role of education in accelerating circular water economy practices.

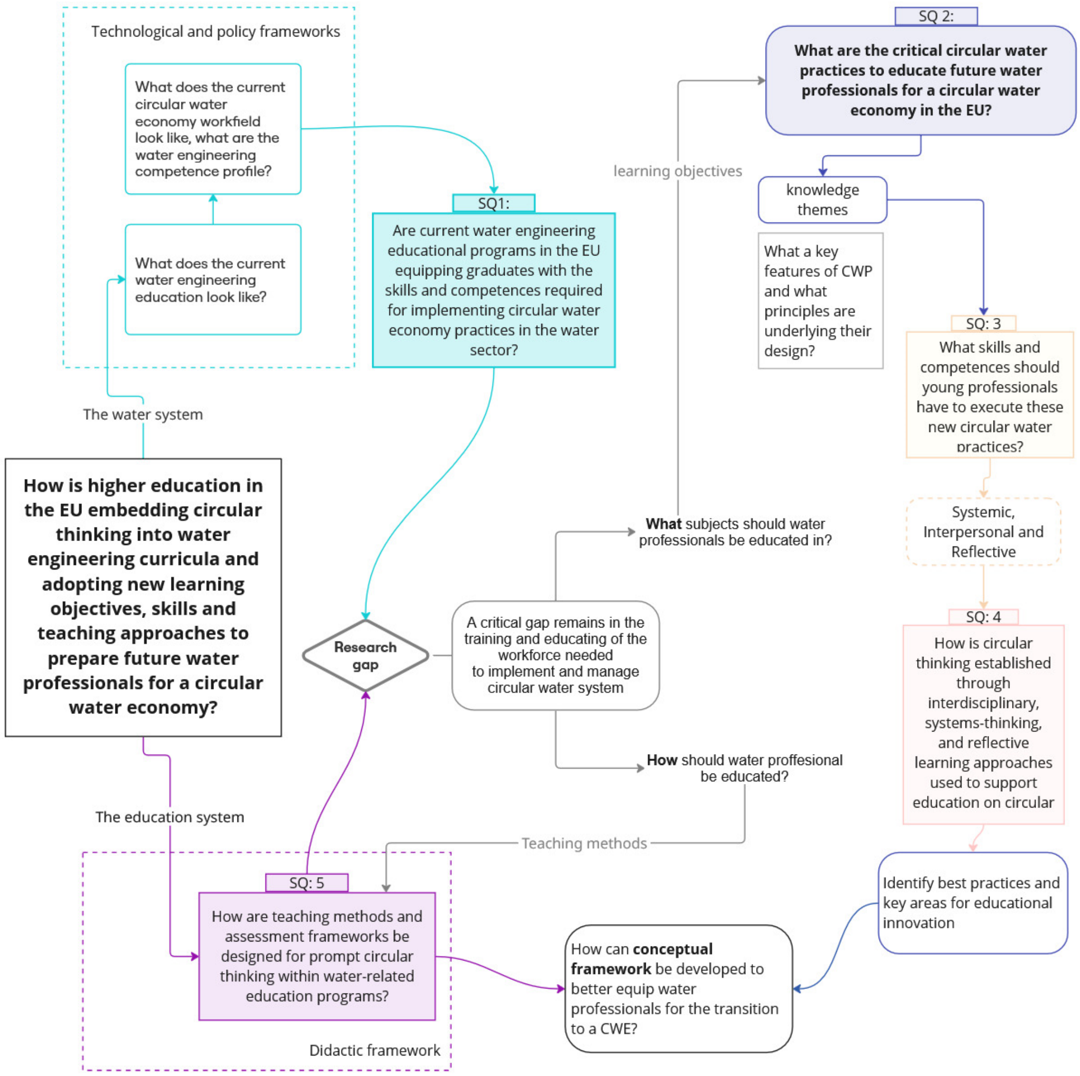
## 1.6 Scientific and Societal Relevance

Water security has been a central issue throughout human history, and with the increasing impacts of climate change and unsustainable resource management, it has become a critical global challenge. In the context of the EU, countries like the Netherlands, with its rich history of water management, and others grappling with floods and droughts, face pressing water security threats. These problems are exacerbated by climate change, over-extraction of resources, and environmental degradation. However, addressing these challenges requires more than traditional water management solutions—it necessitates an integrated and more sustainable approach such as CE. The scientific relevance of this research lies in its contribution to bridging a critical gap in knowledge: the lack of an conceptual framework tailored to preparing water professionals to manage circular water systems. While CE principles offer a promising pathway to sustainable water management, the literature lacks comprehensive studies on how to educate and train the workforce needed to implement these principles. This research will identify essential learning objectives and teaching methods to enable the intellectual and technical skills required for a circular water economy. By doing so, it provides a foundational contribution to the academic discourse on both CE theory and sustainability education.

The societal relevance of this research lies in its potential to directly impact the workforce and industries involved in water management. By developing an conceptual framework that focuses on equipping professionals with the necessary knowledge and competencies for a CWE, this study addresses an urgent need for sustainable solutions to water security threats. The framework can serve as a model for educational institutions, policymakers, and industry leaders seeking to enable a more resilient and sustainable water management system. In doing so, it contributes to societal well-being by promoting water security, environmental protection, and economic stability, all of which are essential for adapting to the complex and uncertain future shaped by climate change and human activity.

## 1.7 Concept Map

*Figure 1 Concept map with main research question and sub-questions*



## 1.8 Educational Theories

This research is informed by several theoretical frameworks that together provide a comprehensive lens to understand learning processes, system change, and collaborative practices.

*Constructivist and situated learning theories*

At the core of the theoretical foundation is constructivist learning theory, which posits that learners actively construct knowledge through their experiences and interactions with the world around them. Rather than passively receiving information, students are seen as active participants in their learning process, building on prior knowledge and engaging in problem-solving activities that promote deep understanding (Piaget, 1973, as cited in Leung et al., 2024; Ausubel, 1963, as cited in Scalabrino et al., 2022).

Situated learning theory, developed by Lave and Wenger (1991 cited in Handley et al., 2006), extends constructivism by emphasizing that learning is deeply embedded in the social and physical context in which it occurs. In contrast to traditional learning environments, situated learning focuses on authentic, context-specific experiences that occur in real-world situations. Core to situated learning theory is the concept of Communities of Practice (CoP), introduced by Wenger (1998), which offers a valuable insight for understanding how learning and knowledge-sharing take place within groups that are collectively engaged in a common domain of interest. A CoP is formed when individuals with shared concerns or passions come together regularly to deepen their understanding through interaction, collaboration, and shared practice. Situated learning theory suggests, therefore, that learning is most effective when it is grounded in the actual practices and activities of a community or culture, where learners participate in legitimate peripheral learning environments (Handley et al., 2006), gradually moving toward full participation in a community of practice.

*Transformative learning*

Transformative learning theory, primarily associated with Jack Mezirow, addresses the process by which individuals critically examine and subsequently alter their existing frames of reference. This theory posits that significant learning occurs when individuals reflect on and challenge their previously held assumptions, leading to a transformation in their worldview and actions (Mezirow, 2018). Transformative learning is often facilitated through critical reflection, dialogue, and disorienting dilemmas, prompting learners to adopt new perspectives on personal, professional, and societal issues.

*Triple-loop learning and Bateson's learning theory*

Closely related to transformative learning is the concept of triple-loop learning theory, which extends beyond single- and double-loop learning. In single-loop learning, individuals correct actions based on feedback to achieve existing goals more effectively. Double-loop learning involves questioning and revising the assumptions and goals themselves. However, triple-loop learning—although less consistently defined—entails a more profound epistemological shift in how individuals perceive systems, value structures, and their own roles within them (Tosey et al., 2019). Transformation learning and third-loop learning is often referred to when it comes to sustainable and CE education (Scalabrino et al., 2022; Leung et al., 2024; Kioupi et al., 2022; Kirchherr and Piscicelli, 2019). Possibly, because both refer to transition of systems for which another set of value and beliefs are necessary. This will be explained in more depth in the next part. To explain the third loop learning the thesis follow's the paper of Tosey et al. (2019) and uses the work of Gregory Bateson the ecology of mind (1972, 2000). Bateson's perspective is rooted in systems theory and influenced by biology, anthropology, and cybernetics. He posits that the mind is a dynamic system of relationships involving organisms, their environments, and each other.

In this view, knowledge is not just something that exists on its own and in the individual but is relational and distributed across multiple systems between individuals and environments. It is not merely a collection of isolated facts but rather the product of cognitive interactions within these systems. In this sense, knowledge is continuously evolving, not as the accumulation of facts, but through the expansion and adaptation of cognitive patterns in response to new experiences and insights. Learning thus becomes the recognition of relational patterns rather than isolated facts, and it is embedded within continuous interaction with the environment.

Bateson distinguishes between various levels (not hierarchical) of learning. Learning 0 entails reflexive responses to stimuli without adaptation. Learning I involves acquiring known patterns of behaviour in order to optimize an outcomes—akin to single-loop learning. How we get familiar with this package of fact and methods, is often a unconscious process. Only when we are confronted with paradox and contraries in thinking about these fact and methods, we can questioning of assumptions. This is the process of Learning II, which is concerned with the context and process of learning itself. Bateson refers to "punctuating" experience differently which is not a matter of to be true or false (Bateson 1973: 271 cited in Tosey et al., 2019). This is associated with second-loop learning. Learning III, comes most close to triple-loop learning, involves a fundamental reconfiguration of meaning frameworks and belief systems. Though, Bateson warns against instrumentalizing this level of learning, as it transcends language and rational analysis, and is better understood in terms of wisdom rather than knowledge acquisition (Tosey et al., 2019).

*Instructional design frameworks*

To effectively apply these theories and create a more concrete educational design, it is essential to incorporate detailed didactic and pedagogy principles and translate these theories into classroom level practice. Educational design should therefore incorporate instructional strategies that make learning processes visible and meaningful. For instance, Ebbens et al. (2020) identify three critical elements that support learner engagement:

1. Meaning-making: Encouraging connections between new knowledge and existing experiences.
2. Individual accountability: Ensuring active participation and contribution from all learners.
3. Visibility of learning: Making thinking processes explicit through dialogue and reflection.

Complementing this approach, Merrill's (2002) First Principles of Instruction offer a practical, evidence-based framework for designing effective learning experiences. His model emphasizes that meaningful learning is inherently problem-centred, engaging learners in tasks that reflect real-world challenges. The process begins with the activation of prior knowledge, allowing learners to connect new information to what they already know. This is followed by the demonstration of new skills or knowledge, which helps to model desired outcomes in a concrete context. Learners are then encouraged to apply what they've learned through practice and feedback, reinforcing understanding and building competence. Finally, integration into real-life contexts ensures that learners can transfer and adapt their knowledge to authentic situations. In the context of CWE, Merrill's principles provide a useful scaffold for aligning instructional methods with circular thinking—linking theory with practice and enabling deep, applied learning that supports the development of essential competencies.

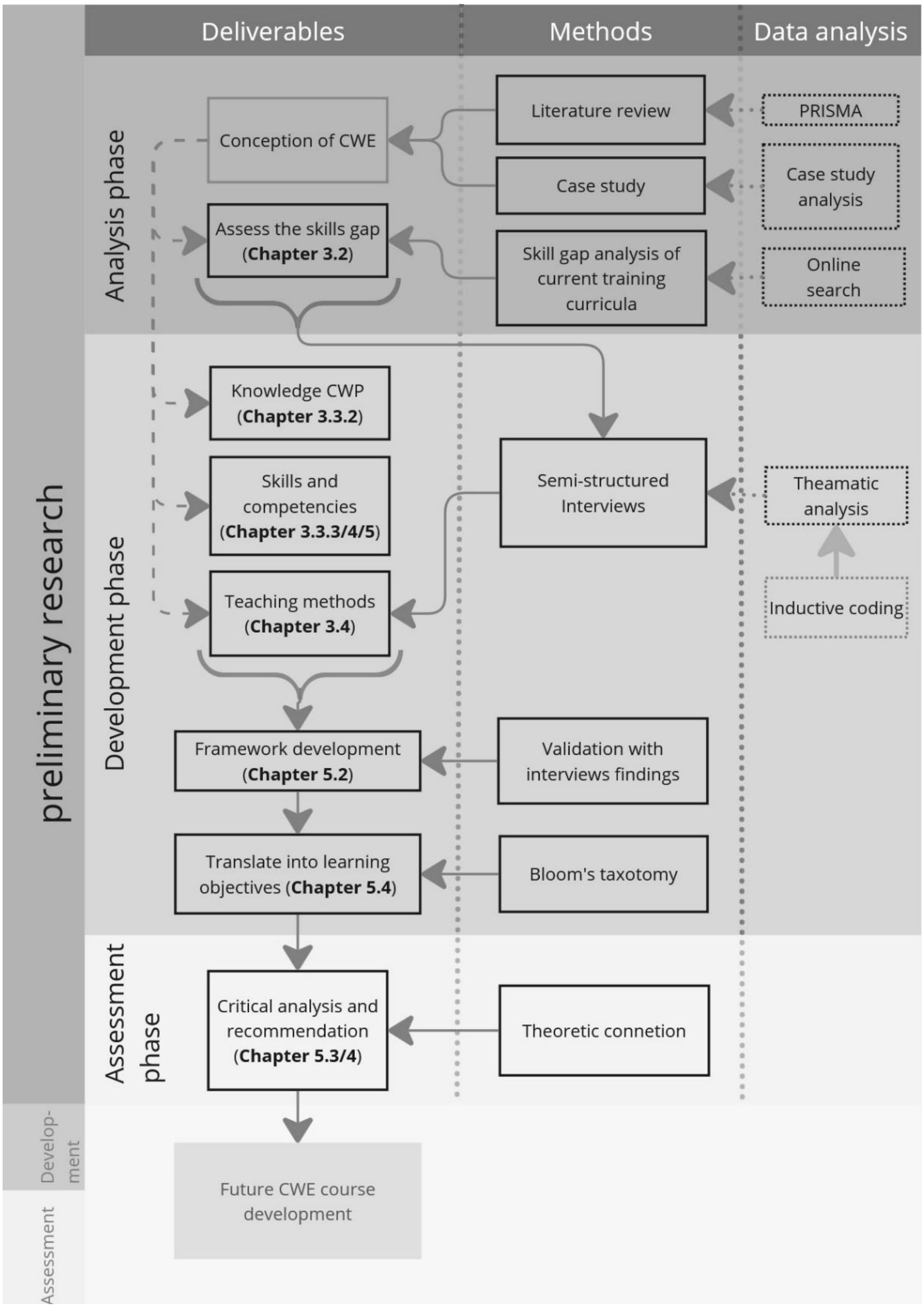
*Conclusion*

Collectively, the theories and frameworks discussed advocate for an educational paradigm in which knowledge is not transmitted but co-constructed through social participation, critical reflection, and contextual engagement. While many of these pedagogical strategies originate from secondary education, their emphasis on classroom-based interaction which makes them equally applicable in higher education contexts, including bachelor's and master's level programs. Therefore, this literature can meaningfully inform the educational design for a circular water economy at Maters level. As explored further in Chapter 5, these theories provide a foundation for constructing critical analysis and recommendation for circular water economy educational design.

# 2 Research Approach and Methodology

## 2.1 Research Flow Diagram

*Figure 2 Research flow diagram*

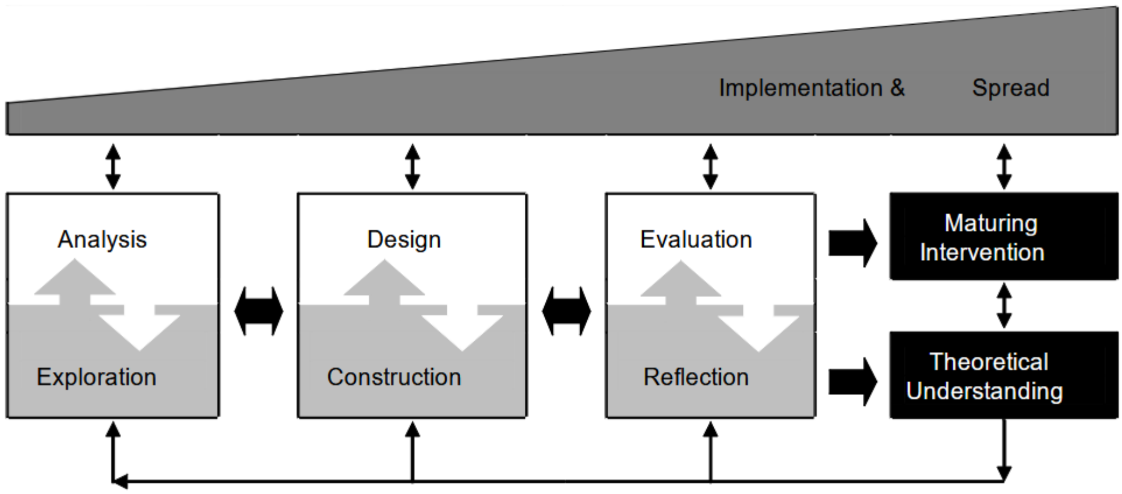


## 2.2 Research Approach

To address the research objectives, this study adopts a design-oriented research approach, which is appropriate given the aim to develop a scientifically grounded educational artifact. In the context of this thesis, the ultimate aim is to design a course on the circular water economy. EDR provides a structured approach to guide the development of such an educational product.

Educational Design Research (EDR), situated within the broader Design Science paradigm, is considered particularly well-suited to this purpose, as it effectively addresses the complex interplay between theory and practice inherent in educational settings (Van den Akker et al., 2006). Within the EDR model (McKennay and Reeves, 2018), various methods are integrated to define competencies, teaching strategies and learning objectives.

Figure 3 Generic model for conducting educational design research (McKennay and Reeves, 2018)




As outlined by Plomp (2013), the Design Science Approach typically unfolds in three iterative phases: design, build, and evaluation. While variations exist in how these stages are described, there is general agreement on their structure:

- **Preliminary Research or Analysis**: This phase involves conducting a needs and context analysis, reviewing relevant literature, and constructing a theoretical or conceptual framework.
- **Development or Design**: Characterized by iterative refinement, this stage focuses on developing and improving interventions through cycles of formative evaluation. It may also include the assessment of existing solutions to identify areas for enhancement.
- **Assessment or Evaluation**: A (semi-)summative evaluation phase that examines whether the solution meets predefined criteria. It is often termed "semi-summative" because it frequently identifies areas for further improvement.

EDR also follows a three-phase process—analysis, design/development, and evaluation—as noted by McKenney et al. (2006). Although EDR has been implemented in diverse ways, Barab and Squire (2004, as cited in Plomp, 2013) offer a broadly applicable definition: "a series of approaches with the intent of producing new theories, artifacts, and practices that account for and potentially impact learning and teaching in naturalistic settings."

EDR contributes to both theoretical understanding and practical application. The theoretical outputs aim to describe, explain, predict, or inform educational phenomena (Jacobsen & McKenney, 2023), while the practical results may include educational product, processes, programs, or policies. Although EDR has traditionally been applied within primary and secondary education (Gravemeijer & Cobb, 2006), the researcher argues that is equally relevant in higher education contexts, which are also characterized by classroom-based learning environments. Besides, EDR is about effectively transferring knowledge from teacher to student, a basic in all learning environments.

From the perspective of course development as the intended educational product, this thesis is positioned within the theoretical dimension of EDR, placing itself in the preliminary research phase. Therefore, the study does not result in a fully developed intervention or specific learning activities. Instead, it offers practical guidance and proposes a set of learning objectives. Although the literature findings are validated through interviews and questionnaires, the conceptual framework itself is not subject to iterative prototyping or empirical testing. Due to its exploratory nature of this thesis such activities fall beyond the scope.

The primary aim of this study is to construct a conceptual framework and formulate recommendations for the future development of a course on circular water economy. To this end, the research remains aligned with the three-phase structure of EDR: Analysis, Development, and Assessment.

- **Analysis Phase:** This phase includes a comprehensive literature review, a case study analysis, and an online search for existing educational programs in Europe. Given the limited availability of literature specifically on circular water economy education, the review draws from adjacent fields such as CE, water management, hydrology, and sustainability.
- **Development Phase:** In this phase, a conceptual framework is developed and validated using empirical data from interviews and questionnaires with educators and professionals in relevant fields.
- **Assessment Phase:** This phase involves an critical analysis based on educational theory and the formulation of recommendations for the design and implementation of a future course on circular water economy.

However this process was not as linear as the research diagram (figure 2) might suggest. Instead, the literature review and the interviews proceeded in parallel, with both generating data to address the sub-research questions and ultimately the main research question. As such, the phases are not directly linked to the sub-research questions in a linear manner. The literature review and the interviews collectively contributed to answering the sub-research questions, the outcomes from both phases compared only at the conclusion of the research. To develop this conceptual framework, an iterative process was employed. Initial insights derived from the literature informed the framework's structure, which was then refined, validated, and expanded using empirical data gathered through interviews. sequential, where the outcome of one phase served as the input for the next. his conceptual framework forms the basis for recommendations regarding the future development of an educational intervention focused on CWE.

The final deliverables of this thesis include:

- An overview of existing educational programs in the EU that addresses elements of the circular water economy
- A synthesis of core concepts and themes derived from both the literature review and interview findings
- A conceptual framework that outlines core course-specific content, key skills and competencies (represent the “what? ), and appropriate teaching methods (represent the “How?”)
- A corresponding set of proposed learning objectives.

Together, these outcomes lay the groundwork for future educational interventions in the field of CWE and are accompanied by concrete recommendations to guide their further development.

## 2.3 Methodology

To answer the research question, the methods are threefold. First, we will conduct a systematic literature review (SLR) to analyse peer-reviewed scientific literature and build knowledge for conception of circular water economy. Second, we will be empirical knowledge through interviews and questionnaire in order to gain insights into the practice of circular water economy and broader education practices. Finally, the gathered knowledge can be integrated into framework that helps design learning activities for future water professional on CWE practices.

### 2.3.1 Systematic Literature Review

The SLR is based on the updated guidelines identified by Siddaway, Wood & Hedges (2019) and will be conducted to review the available peer-reviewed literature on education on CWE. Applying this method allows for a reliable, replicable, and transparent reporting and overview of the current knowledge in scientific literature (Siddaway et al., 2019). The preferred reporting items for systematic reviews and meta-analyses (PRISMA) outlines the steps needed to conduct a SLR, and the PRISMA diagram supports this systematic approach by visualising the number of selected and analysed papers after each phase of the approach: the identification, screening, eligibility, and inclusion phases (Page et al., 2021). The results from each phase will therefore be reported in a PRISMA diagram.

*Screening and eligibility of records*

The literature search is performed in the search engine and database Web of Science (www.webofscience.com). The exclusion and inclusion criteria identified for the eligibility of the records are reported in table 1.

*Table 1 Exclusion and inclusion criteria for selection of peer-reviewed papers*

| Inclusion criteria | Exclusion criteria |
|---|---|
| 1. Available in English & Dutch<br>2. Full-text is available<br>3. Case study of application of education on circular economy practices<br>4. Case study or application of circular water economy<br>5. Case study of application of water literacy | 1. Unavailable in English & Dutch<br>2. Duplicate papers & full-text is unavailable<br>3. Does not include application on education or circular economy<br>4. Does not include application on the water sector<br>5. Does not include application of water literacy |

*Analysis of the peer-reviewed literature*

The selected records are systematically analysed and categorised according to the following aspects:

- Date published with reference year - the last 5 years.
- Geographic location of case study (EU).
- Technical skills Domain: Application of CE principles in water management (e.g. sewer system management, water and resource reuse, and water consumption reduction).
- Soft Skills Domain: Key competencies for circular water management (e.g. interdisciplinary collaboration, systems thinking, complexity science, and circularity principles).
- Type of teaching method (e.g. Problem-based learning, Design-thinking, Case study learning)

*Search term identification*

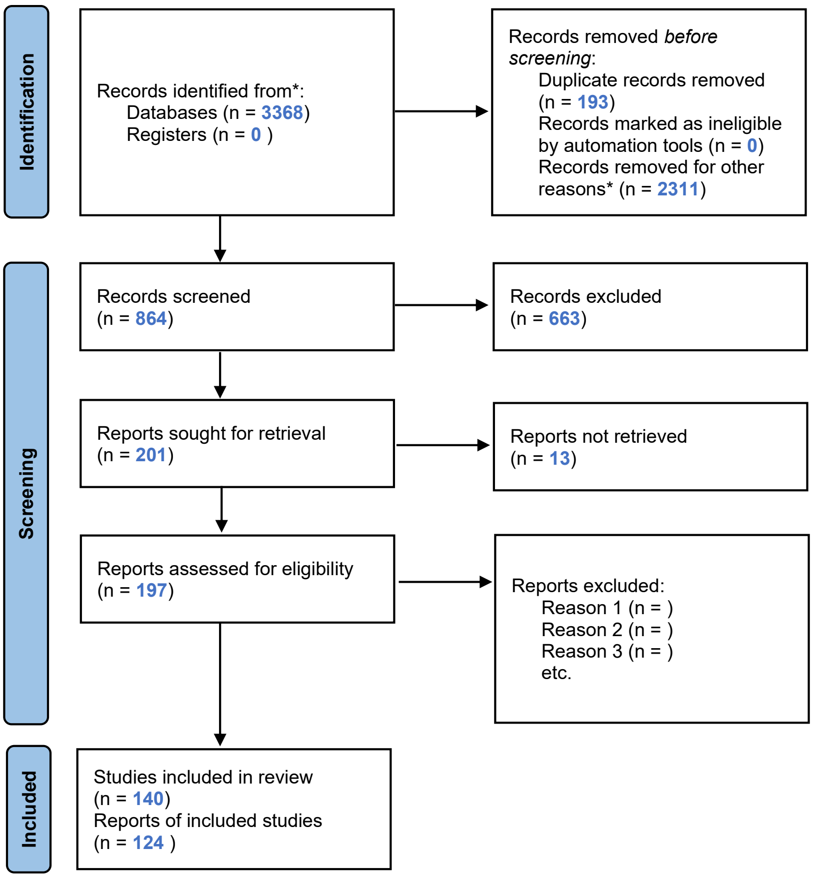
The search term that will be used are presented in table 2. The search terms are categorized by their objectives to demonstrate the rationale behind their selection, though this does not imply a strict division for discussion in the literature review.  The date on which the papers are extracted is marked down, after which no more papers were added to the review. The first two search terms generated the amount of results too high to be successfully reviewed in the duration of the project, therefore this input was narrowed down by selecting for keywords "CE" AND "water" in the first case, and "CE" AND "education" in the second case. This was done in EndNote application. Besides, because of the variety of amount of literature available with the different search terms, there was chosen to in some cases extent the search to ALL instead of ABSTRACT, see table 2 for which this implies.

Table 2 Search term identification for selection of papers. * Records removed for other reasons: used keywords "CE" AND "water" and "CE" AND "education"

| Objective | Data | Search term | Specifics | Amount | Duplicates | Keyword* |
|---|---|---|---|---|---|---|
| 1. Skill gap to implement CWE | 12-mrt | "circular economy" AND "water" | ABSTRACT | 2438 | 38 | yes |
| 2. Learning objectives to develop skill gap | 12-mrt | "education" AND "circular economy" | ABSTRACT | 349 | 50 | yes |
| | 12-mrt | "education" AND "water management" | ABSTRACT | 162 | 10 | |
| | 12-mrt | AB="circular economy" AND ALL="education" AND ALL="interdisciplin*" | ALL | 60 | 26 | |
| | 18-mrt | AB="education" AND AB="interdisciplin* AND All="water" | ABSTRACT | 88 | 7 | |
| | 18-mrt | AB="circular economy" AND ALL="education" AND ALL="STEAM" | COMBINED | 18 | 3 | |
| | 18-mrt | AB="education" AND AB="STEAM" AND AB="interdisciplinary" | ABSTRACT | 72 | 13 | |
| | 18-mrt | AB="education" AND AB="STEAM" AND AB="university" | ABSTRACT | 92 | 13 | |
| 3. Teaching approach to achieve learning objective | 12-mrt | circular water economy AND education | ABSTRACT | 31 | 28 | |
| | 12-mrt | "water literacy" | ALL | 32 | 1 | |
| | 18-mrt | "water education" | ABSTRACT | 26 | 4 | |

The first step of the review will be to filter records by their appearance in the abstract, according to the exclusion and inclusion criteria identified. Once records have been selected based on their title, we will follow the same procedure by reading their abstract and verifying that they still fit the criteria for their selection and to be read in full. Finally, full text will be screened and excluded if they do not meet the inclusion criteria. For each step described above, the number of excluded and included records will be reported in the PRISMA diagram (figure 4).

*Figure 4 PRISMA diagram based on guidelines from Page et al. (2021), with 'n' the number of papers remaining after each step of the selection*




Reason 1: Different region, not EU

Reason 2: Too technical – detailed

Reason 3: Different sector (e.g. fashion, building, agricultural, health, energy)

Reason 4: To specific on other topic (e.g. water footprint)

Reason 5: Same author similar topic new version

Reason 6: primary or secondary school setting

*Writing the literature review*

The literature was sourced from the Web of Science database and imported into EndNote software, where it was categorized according to the search term categories. Duplicate (193) entries were removed. To narrow down the number of publications for screening, the filter function in EndNote was applied to select only papers that contained the relevant keywords similar to the search terms. This initial filtering process resulted in the removal of 2,311 papers. This was based on an extra filtering within Endnote, by using keywords “CE” AND “water” and “CE” AND “education”. A total of 864 papers were then screened based on their titles, and abstracts were reviewed when there was uncertainty. From this screening, four groups were created to organize relevant papers: Technical learning objectives; General learning objectives; Teaching methods; Outside the EU (to allow possible future discussion on cultural and contextual differences in the thesis). During this process, 663 papers were excluded. A second round of screening within these categories led to the removal of an additional 13 papers deemed irrelevant. Before assessing final eligibility, the remaining papers were uploaded to ResearchRabbit Website to identify strongly related works not captured in the initial Web of Science search and include highly relevant papers before 2019. This led to the addition of 9 potentially useful papers. Ultimately, 140 papers were uploaded to Zotero software, including their PDFs, for full-text review. Of these, 124 papers were used in the final literature review. The remaining 16 were gradually excluded throughout the writing process. Additionally, two papers from an earlier, preliminary literature search—Sauvé et al. (2016) and Whalen et al. (2017)—were manually added due to their relevance. To identify the teaching approaches and assessment techniques best suited for developing the system thinking and interdisciplinary skills and competences previously outlined, the literature review included the concept of STEAM education (Science, Technology, Engineering, Arts, and Mathematics). Notably, all relevant STEAM-related studies identified were conducted at the primary or high school level and therefore fell outside the scope of this thesis. Two exception where the paper of Owens et al. (2020) and of Murray et al. (2023). Remarkably, both papers which surprisingly are both critical about the level of interdisciplinarity and usefulness of STE(A)M education for modern sustainability practices, like CWE practices. These two paper are included in the literature review.

## 2.3.2 Skills Gaps in Water Engineering Education

The online search was meant to identify the integration of CE content within water engineering courses, explicitly excluding hybrid programs such as sustainable water management ( https://www.uu.nl/en/masters/water-management-for-climate-adaptation accessed on 10 June 2025)) or water and climate management (https://www.uu.nl/en/masters/water-management-for-climate-adaptation (accessed on 10 June 2025)). Although such courses are designed to promote sustainable and circular thinking and play an important role in educating young professionals, they fall outside the scope of this research, which is centred on students in water engineering. Moreover, broader reviews of these types of programs have already been conducted (Guerreschi et al., 2023).

A representative sample of Master’s programs in water engineering was selected from a range of European countries to ensure geographical diversity. While the primary focus was on EU member states, programs from the United Kingdom and Switzerland were also included to provide broader context. The analysis focused on

Master's-level programs, with additional attention given to elective courses related to the CE and broader programs that included relevant content.

The selection process began with a general Google search using the keyword: Masters EU water engineering and using the website (educations.com), which resulted the first four programs (Institute national des sciences appliqées Toulouse; University of Wageningen; University of Faro; Newcastle University). To further structure the curriculum review, the selection continued with reference to the QS World University Rankings by Subject 2023: Engineering & Technology, prioritizing top-ranked institutions (https://www.topuniversities.com/university-subject-rankings/engineering-technology/2023?region=Europe ). Five Master's programs were selected based on the following criteria: location within the EU, UK, or Switzerland; classification as engineering Master's programs; and inclusion of water-related coursework. These were selected in order of descending QS ranking. To expand the scope of the analysis, an additional set of 41 Master's programs was identified using a database filter that included all engineering and environmental Master's programs containing the keyword water (https://www.topuniversities.com/programs/europe/masters/engineering-and-technology?region=[4010]&study_level=[3]&subjects=[477,482]&globalsearch=[water]).Only programs actively accepting applications for the 2025/2026 academic year were considered.

To assess the inclusion of circular (water) economy topics, each program's official website was visited and reviewed. Where full curriculum documents were available, these were examined directly. In other cases, descriptive information provided on program pages was used to evaluate content relevance. For the inventory of elective courses and programs related to the CWE, the AI tool ChatGPT was used to conduct targeted searches. Two specific query's guide this search:

1. "Look for master programs that include CE course, I want you to focus on water engineering and hydrology master."
2. "Before you looked for CE courses, can you find more that I can add to the Inventory of CE elective courses for Master programs across EU (and UK)?"

The AI-generated suggestions included external links to course pages, which were subsequently reviewed for reliability and relevance. If the link did not work, Google search engine was used to for the programs original webpage. In total, 16 course suggestions were generated, of which 10 were selected based on their utility for this study.

### 2.3.3 Case Study Analysis

The theoretical analysis of online literature search will provide interpretative guidance for the examination of case studies. Case studies are selected based on their application of circular water principles in water management within the EU context. These cases, sourced from the CIRSEAU cluster with the WATER-MINING/ULTIMATE projects in specific (granted within the H2020 call topic CE-SC5-04-2019 entitled "Building a water- smart economy and society"). The case studies will be examined to prepare for the interviews with the assigned case study holders.

## 2.3.4 Semi-Structured Interviews

To identify the most suitable educational approaches for the CWE, expert interviews were conducted to explore participants' perspectives, experiences, and motivations. The interviews served multiple key purposes: first, they validated and refined the knowledge, skills and competencies initially identified through a comprehensive literature review. While the literature provided a foundational understanding of relevant objectives and challenges, direct practitioner input was essential to ensure these elements were both relevant and tailored to the specific needs of the CE transition within the water sector. Second, the interviews aimed to uncover additional knowledge, skills and competencies related to CWE practices that were not addressed in the literature or case study analyses. This process ensured that the educational content would be comprehensive and aligned with real-world demands. Finally, the interviews helped identify and select effective teaching methods that support the achievement of the previously established knowledge, skills and competencies, ensuring that the educational approaches are practical and impactful. The interview questions were tailored to the participants' backgrounds and divided into two distinct questionnaires (Appendix A & B). The version for case study holders focused more specifically on identifying competence gaps, while the version for education emphasized methodologies for effectively engaging students in acquiring these competencies.

*Participant Selection*

Interview participants are professionals working in water engineering and/or education. They were selected primarily from case-study holders involved in the CIRSEAU projects, including WATER MINING, ULTIMATE project with contact details provided by the project supervisor. Educators were recruited from TU Delft and the IHE Institute for Water Education. The participants from the case studies were provided by the supervisor. Contact information of the educators was gathered from official institutional websites. Additionally, some participants were employed using a snowball sampling approach, where initial participants recommended others to join. All participants were invited via email with a formal project introduction. Inclusion criteria required participants to have multiple years of experience in either education or the water sector, with a direct connection to water education or the CE. Fluency in English or Dutch was required. Participants unavailable during the research period (May - July 2025) were excluded. 34 participants were invited.

*Interview protocol*

The qualitative interview protocol was designed with an initial panel size of 10 to 15 key informants. While this number does not meet the typical minimum of 30 participants required for statistical rigor, the highly specialized nature of the topic and the expert status of the interviewees justify this smaller sample size. 11 participants were interviewed, which is argued to be sufficient to provide relevant insights for this research. One participant was excluded from the study because the interview was cut short due to technical issues, and no relevant transcript could be produced. Another participant did not take part in a face-to-face interview but instead provided written responses to the questionnaire via email; this document was directly used in the thematic analysis. This leads to a discussion of the interview findings derived from 10 participants.

*Participant Demographics*

All participants are based in Europe (Netherlands, Italy, England, Germany and England) and are academics holding doctoral degrees or with over 10 years of experience in their fields. Their expertise spans a range of disciplines including industrial ecology, water ethics, water governance, and water engineering. Most participants have an educational background, except the case study holders, who, while affiliated with universities, were not selected based on their educational roles (see table 3).

*Table 3 Overview of the interview participants and related characteristics*

| Interview participant | Background | Questionnaire | Country |
|---|---|---|---|
| **1** | Water engineer | Case Study Holder | Italy |
| **2** | Water ethics | Education/Academic | The Netherlands (TUD) |
| **3** | Industrial Ecology, CE | Education/Academic | The Netherlands (TUD) |
| **4** | Water governance | Education/Academic | The Netherlands (IHE) |
| **5** | Water engineer | Education/Academic | The Netherlands (IHE) |
| **6** | Water engineer for CE | Education/Academic | The Netherlands (IHE) |
| **7** | Water engineer, System thinking and modelling | Education/Academic | The Netherlands (IHE) |
| **8** | - | Case Study Holder | Spain |
| **9** | - | Case Study Holder | England |
| **10** | Water engineer | Case Study Holder | Germany |
| **11** | Water engineer | Educator/Academic | The Netherlands (IHE) |

*Interview Procedure*

The interviews were semi-structured, allowing for follow-up questions and elaboration on responses. Each interview lasted between 30 minutes and one hour. One participant chose to respond to the interview questions in writing. Interview questions and project context were communicated in advance via email. At the start of each interview, participants were asked if they could allow potential extensions beyond the scheduled time. Interview questions were shared in the chat during video calls to enable participants to read along. Questions were occasionally adapted or reformulated to better fit the flow of conversation.

*Logistics and Ethical Considerations*

All interviews were conducted remotely via Microsoft Teams, enabling efficient scheduling and participation compared to paper-based methods. Prior to participation, it was confirmed that all experts had adequate internet access and technological proficiency. Interview invitations and responses were tracked in an Excel spreadsheet. Once a date was confirmed, a Teams meeting link was sent by email. The primary researcher conducted all interviews. Participants signed consent forms prior to the interview, and verbal consent was recorded at the start of the session. Anonymity was assured via information provided in the consent form and emails. Notes were taken during interviews to capture interviewer observations and facilitate follow-up questions. The participant group was not considered a high-risk or vulnerable population.

*Data Privacy*

Personal data collected in this study is limited to signed consent forms (including names and signatures) and contact details for administrative purposes. To protect confidentiality, all personally identifying details in transcripts were replaced with pseudonyms: “Interviewer” for the researcher and “Participant n” for interviewees. Personal images and identifying content were removed. Files were labelled by number and topic, with a single Excel file linking identifiers stored securely on TUD OneDrive for administrative use only.

Participation is entirely voluntary, with no incentives or penalties. Each interview invitation includes a plain-language information sheet and consent form, explaining the study’s purpose, procedures, and participants’ rights, including the right to withdraw at any time. Data were de-identified at or shortly after collection, using numeric codes. Indirect identifiers (e.g., names, dates, job titles, locations) were removed or generalized before transcripts were shared.

Only aggregated data will appear in the thesis. Any quoted material will be carefully reviewed to avoid re-identification. De-identified data (transcripts and thesis) will be stored in the TU Delft repository. All confidential files will be destroyed after the study. Consent forms clearly explain how data will be used, who can access it, and retention timelines.

### 2.3.5 Transcription and Data Preparation

Interviews were recorded using Microsoft Teams’ built-in recording feature, Steam, and saved as MP4 video files on TUD OneDrive. To assess transcription accuracy, the first transcript was cross-checked with an alternative transcription software, Otter.ai. Although Otter.ai produced a more accurate transcript, Microsoft Teams’ Steam was ultimately chosen for consistency and convenience, as Otter.ai’s free account limited transcription to only three sessions. Besides, Otter.ai might also give difficulties related to data protection security. One interview is transcribed from the teams audio with Turboscribe, because the audio was recorded in the wrong language, this transcription needed translation too.

After each interview, the recording was compared against the interviewer's notes to verify accuracy. Any content before and after the first interview question was removed to exclude personally or irrelevant information. When essential information was missing or unclear, the recordings were reviewed again and transcripts were adjusted accordingly. In most cases, the transcripts were deemed sufficiently accurate, requiring no significant edits. Given that the interviews aimed to capture participants' conceptual understanding necessary for competency development, transcription conventions (e.g. fillers, pauses or other sounds produced) were not included, as they did not contribute meaningfully to the analysis. Some interviews were conducted in Dutch and required translation. This was performed using Microsoft Word's built-in translation tool. The translated texts were carefully compared to the originals to ensure consistency and accuracy of meaning across languages.

### 2.3.6 Data Analysis Approach

Once transcribed, the qualitative interview data were analysed using thematic analysis, a method aimed at identifying, analysing, and reporting patterns (themes) within the data. Thematic analysis can be conducted in various ways, but the most widely used approach follows a six-phase process outlined by Clarke & Braun (2024). These steps include familiarization with the data, generating initial codes, searching for themes, reviewing themes, defining and naming them, and finally producing the report. This structured method not only ensures a systematic analysis but also helps reduce the risk of confirmation bias by encouraging a thorough and reflective engagement with the data. The analysis was facilitated by the qualitative data analysis software ATLAS.ti, which supported the systematic process of coding and theme development. Each interview lasted approximately 30 to 40 minutes, with most transcripts extending to about 30 pages. Before coding the transcripts and notes were re-read in order to gain a deep understanding of the content, context, and possible meanings. Each interview was in total analysed individual, not per question.

*Code development*

While the sections of the questionnaire provided an organizing structure, they did not inform a predetermined coding framework. Instead, a inductive coding process was applied, where codes emerge from the data itself a short phrase or word that captures a key idea, concept, or feature of a segment of the interview mentioned by participants were coded as individual codes. Yet, two key topics from the literature review—interdisciplinary collaboration and systems thinking—were already incorporated into the interview questions, providing some direction for the discussions. The transcripts were read line by line, with significant sentences, phrases, concepts, or words highlighted based on the researcher's judgment of their relevance to the study. While the literature review provided foundational knowledge, it was not used to create a predefined coding framework. This approach allowed new and unexpected themes to emerge beyond those identified in the existing literature. To support a structured analytical process, the goal was to code nearly all discussed concepts and topics, which were later reviewed, merged, and aligned to form coherent code categories. To stay close to the data first codes were coded ‘in vivo’, meaning that concept mentioned by the participants were directly copied into code. As follow up, coding was broadened by also including a longer phrase and sentence and self-made code name were assigned. This most often resulted sentences containing the concept were coded twice: once for the key concept and once for the full supporting sentence, both under the same code name. This was done to account for conversational patterns in which participants referred back to earlier points, making meaning only fully clear when viewed in the flow of the dialogue. In some instances, when a concept had overlap with multiple thematic ideas, it was assigned more than one code. When individual codes lacked sufficient clarity or context, memos were added to briefly explain what the code referred to. Only the participants’ words were coded; the interviewer’s contributions were excluded to avoid skewing the dataset. When a response could not be categorized using existing codes, new codes were created. In the first round of analysis little particular concepts or topics were excluded from coding, this results in 111 codes in total.

During the coding process, several methodological decisions were made to ensure clarity, coherence, and contextual integrity in the development of themes. A reflexivity journal was made to keep track on the code decisions that were made. These decision included how you coded your data, why you coded your data in that particular way, and what the outcomes of this data coding are. Concepts that were closely related but semantically different (such as multidisciplinary and interdisciplinarity) were grouped under a single code. This decision aimed to capture the shared conceptual intent behind different terminologies while maintaining thematic consistency. It is important to note that participants came from diverse professional backgrounds and disciplinary domains. This meant that certain themes were more prominent in specific interviews, and some thematic divisions naturally followed the structure of individual interviews due to participants’ specialized knowledge.

Additionally, two participants provided written responses. In one case, these written answers were submitted in support of the recorded interview and were added to the transcript. In the one case where the participant provided written text to accompany the interview, concepts from the written responses were only coded if they introduced new insights not already present in the interview, to avoid duplication in the coding process. In a few instances, responses or parts thereof were inaudible or unclear and were therefore excluded from the analysis.

*Theme Development*

After the initial coding phase, codes were grouped into three overarching code groups to allow more structure for later theme development, these groups aligned the sub-research questions and literature insight: Circularity Concepts, Skills and Competencies and Teaching Methods and Assessments. Building on insights from the literature, the initial code group labelled “Skills and Competences” was further refined into three distinct categories: Ethics, Interdisciplinarity, and Systems Thinking. All 111 codes were subsequently grouped into one of the following overarching categories: Circularity Concepts, Ethics, Interdisciplinarity, Systems Thinking, or Teaching Methods and Assessment. In cases of uncertainty, codes were revisited within the Atlas.ti software, and relevant quotations were re-examined to ensure accurate categorization. No codes were found to be sufficiently ambiguous to require assignment to multiple categories.

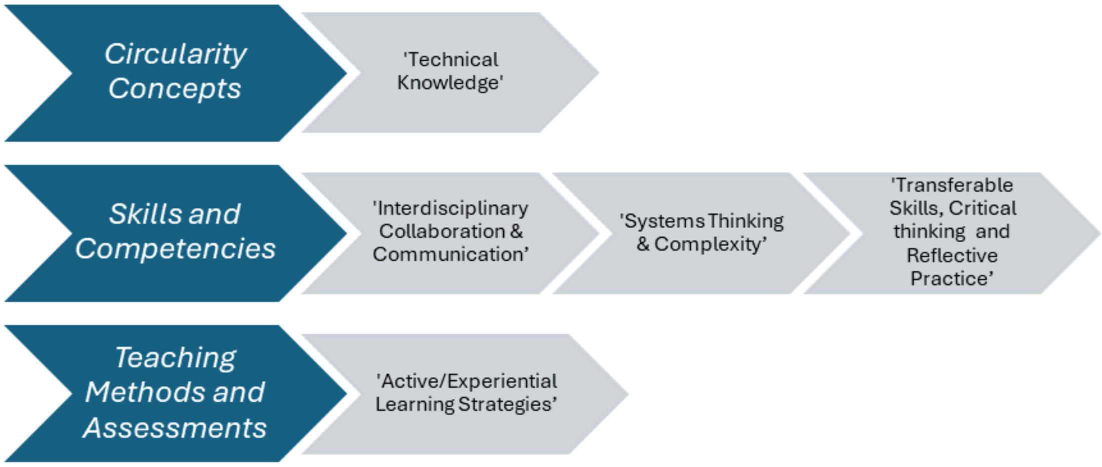
During a second round of analysis, several codes were either removed or merged with others. The excluded codes generally lacked supporting quotations, were conceptually redundant, or held limited analytical relevance (e.g., common yet vague phrases such as “it depends,” which—while reflecting complexity—offered little interpretive value). Although specific records of these changes were not retained, the list of a total of 56 codes and their respective groupings were saved (see appendix E).

This process was iterative and evolved alongside the ongoing writing and discussion of the related quotations. As the analysis progressed, some sub-themes were reassigned to alternative categories to ensure stronger conceptual alignment. Quotations that had been reviewed and discussed were highlighted in yellow to avoid repeated analysis. Ultimately, once all codes and their associated quotations had been examined, 31 sub-themes were distilled from the text and emphasized in bold text. These sub-themes were then compared across categories, and group names were revised to better reflect the thematic content, though, there was already closely aligned. A deliberate decision was made to maintain broader, more generalizable theme categories in order to facilitate clearer comparison with findings from the literature.

The Circularity Concepts group directly informed the theme ‘Technical Knowledge’, covering general insights on what content students should be taught. The Skills and Competencies group was divided into two distinct themes: 1) ‘Interdisciplinary Collaboration & Communication’, encompassing stakeholder engagement, perspective-sharing, and teamwork. 2) ‘Systems Thinking & Complexity’, which included codes on systems thinking and related methodologies. And 3) ‘‘Transferable Skills, Critical Thinking and Reflective Practice’, encompassing critical thinking, linear vs. circular thinking and metacognitive development. Teaching Methods and Assessments group was translated naming the more specific method ‘Active/Experiential Learning Strategies’, covering general insights on how the specific nature of learning activities should look like (see figure 5).

The most illustrative and explanatory quotes were selected for inclusion in the results. The quotes were adapted to fit the text and simple words (such as huhh, okay, mmh) were deleted, without changing the meaning. Themes are discussed in chapter 4: Empirical Result, in the order deemed most compelling by the researcher, there is no order of importance.

*Figure 5 Overview code groups translated into the 5 theme names*




## 2.3.7 Conceptual Framework: Design and Validation Process

The conceptual map was developed by validating and integrating theoretical concepts from the literature review with practical concepts from the interviews, with both sources being brought into analytical dialogue during the interpretation of results. This dialogical engagement between theory and practice enabled a more grounded and adaptive analysis, ensuring that the resulting conceptual framework is not only theoretically robust but also empirically relevant and responsive to the needs of educators and practitioners.

Literature and interviews data were seen as equally valuable, with neither treated as inherently more authoritative. As a first step, the interview data were systematically compared with the literature and categorized into three groups: confirmed (concepts present in both sources), conflicted (concepts with differing perspectives), and not covered (concepts emerging only from the interviews). No conflicted concepts were found. The comparative analysis used the concept overview tables from the literature (table 6, 7 and 8) and the interview data (Appendix C). Concepts were color-coded for clarity: : blue indicates alignment between literature and interviews, yellow represents only found in the literature and purple marked concepts emerging exclusively from the interviews. This process revealed that not all sub-themes emerging from the interview data aligned neatly with the thematic structure established in the literature review. For instance, the sub-theme "Environmental & Ecosystem Awareness" was categorized under the "Interdisciplinary Collaboration & Communication" section in the interview analysis, whereas similar discussions in the literature were situated within the domain of knowledge competence. This discrepancy was addressed by reviewing the full list of sub-themes and literature-derived topics holistically, allowing for a more flexible and conceptually coherent integration of concepts across both data sources. To show this discrepancies the concept were coloured in grey.

Besides, this validation process may be somewhat confusing for the reader, as not all concepts are expressed using the same terminology. For example, the literature review refers to "reflective competence," while the interviews mention "transferable skills," even though they essentially describe the same concept. This process produced a consolidated set of concepts, encompassing knowledge, systemic, interpersonal, and reflective competences, which served as the foundation for the conceptual framework.

The structure of the conceptual framework follows the literature-based distinction between subject-specific and generic competences, and integrates the final outcomes on knowledge and skills and competences (see overview Appendix D). into a circular visual model. All the competences in from the conceptual framework are translated into one or more learning objectives following the Bloom's Taxonomy (Krathwohl, 2002) (see table 9).

# 3 Literature Review Results

## 3.1 Introduction

This chapter begins by examining the skills and competence gaps in water engineering education, addressing this through a review of the literature on water engineers' competence profiles, followed by a gap analysis of current training curricula, thereby answering the first sub-research question. The central section of the chapter focuses on the knowledge, skills, and competencies required to bridge these gaps, answering the second, third, and fourth sub-research questions. The final section explores the teaching methods that enable the development of these competencies necessary for implementing CWPs, addressing the last sub-research question. All research questions are reiterated at the beginning of each chapter. Chapter [3.2] focusses on the first research objective: Assess the skills gap related to the implementation of CE principles in the water sector. And the chapter [3.3] focusses on the second: to identify the essential knowledge concepts, skills, and competences required for executing circular water management.

The linear and circular value chains differ fundamentally in both structure and purpose (Kirchherr & Piscicelli, 2019). The linear economy predominantly pursues economic goals, often at the expense of ecological and social considerations, particularly the internalization of environmental costs (Sauvé et al., 2016). In contrast, the CE offers a new model for sustainable development, which has been defined as the "simultaneous achievement of economic performance, social inclusiveness, and environmental resilience for the benefit of both current and future generations" (Elkington, 1997; Geissdoerfer et al., 2017, as cited in Kirchherr & Piscicelli, 2019). While sustainable development is generally conceptualized at the macro level, the CE is typically applied at the micro level, focusing on production and consumption systems (Sauvé et al., 2016). The European Commission (2018) highlights that CE helps reduce the risk of resource shortages and enhances resilience (Bellver-Domingo & Hernández-Sancho, 2022). The EU has further formalized this direction through the CE Action Plan (2015), which defines the CE as one "where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised." A concrete example of this is Regulation 2020/741, which promotes water reuse in agriculture as part of the broader action plan (Berbel et al., 2023).

In a widely cited study analysing 114 definitions, Kirchherr et al. (2017) describe the CE as "an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes." This view implies a flow in which the end-of-life stage of one product becomes the starting point for another, reflecting the regenerative principles of ecological systems. To increase resource productivity and overall system sustainability, systems are (re)designed to be regenerative, allowing materials to cycle back after use (Murray et al., 2017). Through such closed-loop systems, the CE aims to prevent final disposal in landfills (Sauvé et al., 2016).

As Sauvé et al. (2016) write, the CE seeks to imitate natural processes "where little is wasted and most is recuperated by another species." However, unlike ecosystems, circular loops in human economies face

physical and socio-economic constraints. These include thermodynamic limits (De Man & Friege, 2016, cited in Kopnina, 2022) and diminishing returns where the costs of closing loops may outweigh the benefits (Anderson, 2007, cited in Sauvé et al., 2016). At its core, the CE seeks to decouple economic prosperity from the extraction of virgin resources (Ghisellini et al., 2016; Sauvé et al., 2016; Ellen MacArthur Foundation, 2017). However, definitions vary. Some scholars emphasize resource efficiency (Ghisellini et al., 2016), while others stress the importance of reducing overall consumption (Tiippana-Usvasalo et al., 2023; Kopnina, 2022). As a result, some scholars argue for deeper systemic change including nature-based solution and biomaterials (Nika et al., 2020), while others advocate for incremental improvements within current systems. Still, many agree that an overall cultural transformation is needed (Lacy, 2015, cited in Marouli, 2016).
Strengthening ECE is seen as a key strategy for facilitating this transformation by preparing future CE specialists and supporting sustainable development amid the growing demand for green jobs (Guerreschi et al., 2023). Education plays a central role in enabling circularity, enabling long-term vision and committed leadership needed for systemic transitions (Mbavarira & Grimm, 2021). Also, Smol et al. (2025) emphasize the importance of institutional capacity-building to unlock CE potential. Education is widely recognized as one of the most effective starting points for moving from a linear to a CE (Mannina et al., 2022; Tiippana-Usvasalo et al., 2023), with higher education institutions acting as strategic actors and key drivers of this transition (Renfors, 2023).

However, policy initiatives often narrowly emphasize technical or green skills while overlooking essential social, systemic, and collaborative competencies necessary for successful CE implementation (Burger et al., 2019). To establish such transformation and transition to CE ‘21st-century skills’ education is needed. This discourse refers to a set of abilities considered essential for learners to thrive in today’s complex, uncertain, ambiguous and rapidly changing world (Rotherham and Willingham, 2010). In education, this has led to a shift toward competence-based learning, where the focus is not only on knowledge acquisition but also on the development of transferable skills (Burger et al., 2019; Janssens et al., 2021; Marouli, 2016). These include, among others, critical thinking, system thinking creativity, interdisciplinary skills and adaptability (Alaerts and Kaspersma, 2022; Guerreschi et al., 2023; Kopnina, 2022; Marouli, 2016; Wan Rosely and Voulvoulis, 2023). To encourage these set of abilities, approaches like game-based learning (Lange et al., 2022; De la Torre et al., 2021) and project-based learning (Ab Hamid et al., 2024) are developed to support this shift in thinking, in many cases by trying to engage students in real-world problems. These methods align well with sustainability education and the goals of the UNESCO Education for Sustainable Development framework (2020), which promotes holistic, transformative education. Similarly, the EU GreenComp (European Sustainability Competence Framework) provides a structured set of sustainability-related competences to guide educators and policymakers (Bianchi et al., 2022).

In this context, ESD and ECE are viewed as closely aligned, sharing overlapping goals and approaches. Therefore, the literature reviewed extends beyond CE-specific education to include broader perspectives from sustainability education, aiming to establish a foundation for CWE. A total of 129 literature articles were reviewed for this study. Of these, 76 were categorized as 'technical', 34 as 'teaching methods', and 8 were directly related to skills and competences associated with sustainability in CE and water education. The remaining 6 articles were classified under the topic of 'water literacy'. As indicated by the preliminary literature search, no studies specifically focused on CWE were identified. Only two papers addressed courses directly related to the CE (Kirchherr & Piscicelli, 2019; Kopnina, 2022). Although the initial search included numerous papers related to STEAM education, most were excluded, as they primarily focused on primary or secondary education, which fell outside the scope of this thesis. Interestingly, the two included papers (Owens et al., 2020; Murray et al., 2023) both critique the current limitations of STEAM education, arguing that it lacks sufficient interdisciplinarity and does not fully align with sustainability goals. They advocate for teaching approaches grounded in reflective practice, stakeholder inclusion, and ethical reasoning.

## 3.2 Skills gaps in water engineering education

This chapter explores how the concept of circularity is reflected in current job market demands, how educational programs respond to these needs, and where disconnects remain. The subchapter focus on the first research objective: Assess the skills gap related to the implementation of CE principles in the water sector. And answers the sub research question: “Do current water engineering educational programs in the EU equip graduates with the skills and competences required for implementing CE practices in the water sector?” Drawing on literature and EU Master program analysis the chapter highlights the need for CWE to become part of water engineering programs.

### 3.2.1 The Water Engineer’s Competence Profile

As large EU-based firms increasingly align with environmental goals, energy transitions, and CE principles—often in response to Green Deal regulations—a growing skills gap is emerging. Many companies face a shortage of professionals equipped with the technical and adaptive competencies needed for the green transition (OECD, 2023). To meet policy demands and sustainability targets, firms must build dynamic capabilities, placing greater expectations on young professionals to enter the workforce with both strong technical knowledge and future-oriented mindsets (Vischi, 2018; Marrucci et al., 2021, as cited in Guerreschi et al., 2023).

Despite the growing momentum behind the CE, the skills required to support its implementation remain poorly defined and inconsistently integrated into professional practice. CE-related competencies are rarely reflected in job descriptions or human resource frameworks (Burger et al., 2019), and there is no clear consensus on what constitutes a "CE expert" (Guerreschi et al., 2023). Currently, most CE jobs are concentrated in conventional sectors such as waste management and recycling, while broader, interdisciplinary roles—such as CE managers—remain underdeveloped (Giannoccaro et al., 2021). The CE sector itself is still fragmented and lacks cohesion, making it difficult to predict future skill demands (Burger et al., 2019; Garito et al., 2023; Renfors, 2023).

In an effort to address this gap, Burger et al. (2019) conducted one of the first empirical studies mapping CE-related skills using European labour market data. Their findings revealed a wide spectrum of competencies, ranging from low-skilled logistics roles to high-skilled positions in eco-design and sustainability consultancy. These roles require not only technical and cognitive abilities but also strong soft skills. Nevertheless, current education and training programs often fail to meet these diverse and evolving demands, highlighting a persistent mismatch between academic curricula and labour market needs (Burger et al., 2019; Guerreschi et al., 2023). Janssens et al. (2021) reinforced these findings through a regional case study in Limburg, Belgium, which resulted in a CE competence recommendations. Their work revealed similar gaps between required job competencies and existing educational offerings.

Although efforts to integrate CE into education are increasing, they continue to face significant challenges. Some initiatives have attempted to incorporate 21st-century skills—such as systems thinking, collaboration, and adaptability—into CE education (Kirchherr & Piscicelli, 2019; Kopnina, 2022). However, structural issues within higher education remain pervasive, including fragmented curricula, underprepared faculty, and a lack of cohesive institutional strategies (Garito et al., 2023). These limitations are further compounded by scarce teaching resources, disciplinary silos, limited faculty expertise, and inadequate assessment tools (Renfors, 2024). Guerreschi et al. (2023) also highlight the lack of clear guidance for educators tasked with developing CE courses, particularly regarding how to balance foundational principles with emerging topics. A further challenge lies in the limited collaboration between academia and industry, which significantly hampers the co-design of practice-oriented training programs (Guerreschi et al., 2023). Without these partnerships, educational institutions struggle to align learning outcomes with the interdisciplinary and applied demands of the CE job market. This is reflected in how CE is often treated by higher education as a theoretical concept, disconnected from real-world complexity and professional application (Giannoccaro et al., 2021). This disconnect is particularly obvious in water management and engineering education, where rigid, technocratic approaches struggle to engage with the complex, uncertain realities of today's sustainability challenges (Alaerts & Kaspersma, 2022) and where the absence of systems thinking can lead to superficial solutions that overlook root causes (Wan Rosely & Voulvoulis, 2023). These water engineering programs tend to focus heavily on technical content while overlooking critical behavioural, institutional, and collaborative competencies essential for circular and sustainable transitions (Alaerts & Kaspersma, 2022).

To address these issues, Guerreschi et al. (2023) recommend standardizing learning objectives, defining job expectations, improving communication, and developing benchmarks to track progress. They also stress the need for interdisciplinary, critical, and collaborative learning environments. Kirchherr and Piscicelli (2019) add that CE education must also critically engage with CE's limitations, including risks of greenwashing. Kopnina (2022) similarly highlights the importance of embedding critical thinking, noting that students often focus narrowly on course completion rather than deeper learning experiences.

Thus, literature shows that a significant disconnect persists between CE educational offerings and the demands of the workforce. The next section looks into outlines the online search for educational offerings related to the CWE aimed at training future water professionals.

### 3.2.2 Gap Analysis of Current Training Curricula

While some courses related to CE exist, their integration into EU Master's level water programs remains limited. Notably, none of the programs identified offer courses explicitly named “circular water economy”.

Although water-related education presents a promising entry point for teaching CWE principles, the current inventory reveals that few water engineering programs incorporate CE content. Examples include two electives on CWPs at the Karlsruhe Institute of Technology (Germany), a course referencing circular practices at Aalto University (Finland), and a “Sustainability for Engineers” course at the University of Greenwich (UK) that explicitly mentioned CWPs, highlighted in blue (see table 4). While some websites listed electives, the search did not systematically include all elective options. A few standalone electives (also outside the university) were found that focus on water within broader CE education (see table 5).

One notable exception, not captured in the online search but mentioned during interviews, is the final water project course at IHE Delft (exact course name unknown), although there is no explicit mentioning of CWE, it aligns closely with CWE principles. This course is discussed in more detail in Chapter 4: Empirical Results. The next section reviews literature on how circular thinking can be cultivated through specific teaching methods.

*Table 4 Inventory of water engineering Master education programs across EU (and UK, CH). * Explicit mentioning of skills and competencies related to circular water economy practices in detail discussed in the next section*

| Region | Institute | Program | Curriculum description | CWE skills available* | Source |
|---|---|---|---|---|---|
| France | Institute national des sciences appliqées Toulouse | Water Engineering and Water Management | Core courses on wastewater treatment and wastewater management/Water production and water resource management/Graduation Internship (5-6 months) in academic Laboratories | NO | https://www.educations.com/institutions/insa-toulouse/msc-water-engineering-and-water-management?fl=2 |
| The Netherlands | University of Wageningen | Water Technology | 1 course on 'water technologies in global context' where broader water challenges are mentioned/ Multidisciplinary between engineering topics. | NO - related skills or topics | https://www.wur.nl/en/education-programmes/master/msc-programmes/msc-water-technology/programme-of-water-technology.htm |

| | | | | | |
|---|---|---|---|---|---|
| Portugal | University of Faro | Urban water cycle | Risk and Resilience of Water Infrastructures/Water Reuse Technologies | NO - related skills or topics | https://www.educations.com/institutions/university-of-algarve/master-in-urban-water-cycle |
| England | Newcastle University | Hydrology and Water Management | "the course offers a global perspective on hydrology in the context of sustainability" Does name sustainability education. | NO | https://www.ncl.ac.uk/postgraduate/degrees/5408f/ |
| The Netherlands | TU delft University | Environmental Engineering: the track Water Resources Engineering | Elective on ' design nature based solutions in water management'/ interdisciplinary group project/ water treatment technologies mention sustainability - NO CE | NO - related skills or topics | https://www.tudelft.nl/onderwijs/opleidingen/masters/enve/msc-environmental-engineering/programme/track-water-resources-engineering |
| The Netherlands | TU delft University | Complex system engineering and management | "But do you want more than 'just' technical skills" but no specific focus on water systems | NO - related skills or topics | https://www.tudelft.nl/en/education/programmes/masters/cie/msc-civil-engineering/programme |
| Germany | Karlsrule Institute of Technology | Water science and engineering | interdisciplinary, research-oriented education. sustainable management of water resources → 2 specific course elective on CE project work and CE Water Energy Environment: Research Proposal Preparation | YES | https://www.sle.kit.edu/english/vorstudium/master-water-science-engineering.php |
| Sweden | KTH Royal Institute os Technology | Enviromental Engineering and Sustainable Infrastructures | interdisciplinary tools. properties and functions of water and ecosystems. LCA course. There is a track on social side of engineering: Sustainable societies | NO - related skills or topics | https://www.kth.se/en/studies/master/environmental-engineering-sustainable-infrastructure/courses-environmental-engineering-sustainable-infrastructure-1.268175 |
| Italy | Politecnico di Torino | Chemical and Sustainable process engineering | considering their environmental impact of design | NO | https://www.polito.it/en/education/master-s-degree-programmes/chemical-and-sustainable-processes-engineering/specialist-tracks#par_1860 |
| The Netherlands | Joint degree University of Groningen and Twente | Water Technology | Courses on technical practices of wastewater treatment, algae use, biofouling, resource recovery, source separation sanitation – No mentioning of interdisciplinary work of system thinking | NO | https://www.rug.nl/masters/water-technology-joint-degree/#!programme |

| | | | | | |
|---|---|---|---|---|---|
| Belgium | University of Leuven | Water Resources Engineering | Mentioning of project-based learning activities, sustainability development goals | NO - related skills or topics | https://www.kuleuven.be/programmes/master-water-resources-engineering |
| England | University of Cranfield | Water and wastewater Processes | Mentioning of sustainability challenges. Interdisciplinary courses. | NO - related skills or topics | https://www.cranfield.ac.uk/courses/taught/water-and-wastewater-processes-environmental-science#Coursedetails |
| England | University of Cranfield | Research in water | Mentioning of natural based solution, | NO - related skills or topics | https://www.cranfield.ac.uk/research/msc-by-research/water |
| England | University of Hertfordshire | Water and environmental management | Sustainability, course in both technical and environmental social and political. Includes field and lab-based elements | NO - related skills or topics | https://www.herts.ac.uk/courses/postgraduate-masters/msc-water-and-environmental-management |
| England | Cardiff University | Water, climate change and sustainability | Interdisciplinary master. | NO - related skills or topics | https://www.cardiff.ac.uk/study/postgraduate/taught/courses/course/water-climate-change-sustainability-msc |
| England | Newcatle University | Hydrology and water management | Flood protection. Focus technical skill but also mentioning transferable skills. Field trips and problem-solving exercises | NO - related skills or topics | https://www.ncl.ac.uk/postgraduate/degrees/5408f/ |
| Finland | University of Aalto | Water and environmental engineering | Explicit mentioning of CE. " also to reduce the environmental impact through a CE recovering nutrients and energy" "combines a strong technical basis with a sound understanding of broader societal contexts" mentioning of project work, stakeholder and industry collaboration, use of case studies | YES | https://www.aalto.fi/en/study-options/water-and-environmental-engineering-master-of-science-technology |
| Hungary | University of Debrecen | Agricultural Water Management Engineering | Environmental courses, flood protection. Field visits. | NO - related skills or topics | https://edu.unideb.hu/p/agricultural-water-management-engineering-msc |

| | | | | | |
|---|---|---|---|---|---|
| England | University of Greenwich | Water, waste and environmental engineering | Mentioning CE in one specific course 'sustainability for engineers' | YES | https://www.gre.ac.uk/postgraduate-courses/engsci/wat-was-env-eng |
| England | Oxford University | Water science, policy and management | Sustainable water management | NO - related skills or topics | https://www.ox.ac.uk/admissions/graduate/courses/msc-water-science-policy-and-management |
| Sweden | University of Lund | Water resource Engineering | Technical water courses. Course on water society and sustainability | NO - related skills or topics | https://www.lunduniversity.lu.se/lubas/i-uoh-lu-TAWRE |
| Spain | University of Viog | Sustainable water management | Sustainability issue. No CE | NO - related skills or topics | https://www.educations.com/institutions/universidade-de-vigo/masters-degree-in-sustainable-water-management |
| England | University of Swansea | Desalination and Water Re-use | Water Advanced Technology (e.g. AOPs, Hazardous substances, Modelling membrane processes) | NO - related skills or topics | https://www.swansea.ac.uk/postgraduate/research/engineering-applied-sciences/chemical/msc-by-research-desalination-and-water-re-use/ |
| England | Queens Mary University of London | Water and environmental management | Mentioning work on interdisciplinary solutions, work with people outside academic world, fieldwork, real world application Mentioning nature-based solution, natural climate solutions | NO - related skills or topics | https://www.qmul.ac.uk/postgraduate/taught/coursefinder/courses/water-and-environmental-management-msc/ |
| France | Institute Polycentric de Paris | Water, Air, Pollution and Energy | Technical and environmental courses sustainable development, Climate change | NO - related skills or topics | https://www.ip-paris.fr/en/education/masters/mechanics-program/master-year-2-water-air-pollution-and-energies |
| Ireland | University College Dublin | Waste, water and Environmental Engineering | Sustainable Development | NO - related skills or topics | https://hub.ucd.ie/usis/!W_HU_MENU.P_PUBLISH?p_tag=COURSE&MAJR=T277&KEYWORD=t277 |

| | | | | | |
|---|---|---|---|---|---|
| Denmark | University of Aalborg | Water and Environmental Engineering | Solve environmental problems including waste water, drinking water supply, storm drainage. Problem-based learning. Collaborate with industry | NO - related skills or topics | https://www.en.aau.dk/education/master/water-environmental-engineering |
| France | Institute Polycentric de Paris | Water, Soil, Waste Management and Treatment | Multidisciplinary and multi-partner program. "Active teaching methods: audits, study trips, presentations, case studies." By product recycling, waste water purification and sludge treatment | NO - related skills or topics | https://www-rec.ecoledesponts.fr/en/masters-water-soil-waste-management-treatment |
| Germany | Berlin school of management | Engineering and International Business - Focus on Renewable Energy, Water and Waste Management | Interdisciplinary program. active learning by applying directly to projects and your future career. "soft and social skills are crucial in addition to hard skills and expertise" Environmental life cycle assessment | NO - related skills or topics | https://www.srh-university.de/en/master/engineering-international-business-renewable-energy-water-waste-management/e/ |
| Spain | Rey Juan Carlos University | Hydrology and Water Resource Management | Technical and environmental courses | NO - related skills or topics | https://www.uah.es/en/estudios/estudios-oficiales/grados/Hydrology-and-Water-Resource-Management-Face-to-face-modality/ |

*Table 5 Inventory of circular (water) economy elective courses or programs for Master programs across EU (and UK, CH). * Explicit mentioning of skills and competencies related to circular water economy practices in detail discussed in the next section*

| Region | Institute | Program | Curriculum | CE skills available* | Source |
|---|---|---|---|---|---|
| Italy | University of Bologna | Civil Engineering: Circular-Green Management of Urban Drainage | The concept of circular water resources management | YES | https://www.unibo.it/en/study/course-units-transferable-skills-moocs/course-unit-catalogue/course-unit/2023/454141?utm_source.com |
| Slovenia | University of Ljubljana | Business and management: Circularity and water management | Elaborate course on CE from social and economic perspective | YES | https://www.ef.uni-lj.si/en/uvoz-predmetov/kroznost-in-upravljanje-z-vodo-2?utm_source.com |

| | | | | | |
|---|---|---|---|---|---|
| Belgium | University of Leuven | Sustainable Water Management | resource recovery and the CE, water-food-energy nexus, water from a social science perspective | YES | https://onderwijsaanbod.kuleuven.be/syllabi/e/I0K20AE.htm#activetab=doelstellingen_idp11868720 |
| Finland | Turku University of Applied science | Water, Waste, and Material Management | principles of a CE for water digital CE, technologies for enabling a CE | YES | https://opinto-opas.turkuamk.fi/realization/C-10126-AT00DC36-3001?lang=en |
| England | University of Cranfield | Water Engineering MSc | Waste Management in a CE: Reuse, Recycle, Recover and Dispose | YES | https://www.cranfield.ac.uk/environmentalengineering?utm_source.com |
| Belgium | University of Ghent | International Master of Science in Environmental Technology and Engineering | Introduction to the CE, Economics and Management of Natural Resources | YES | https://studiekiezer.ugent.be/2025/international-master-of-science-in-environmental-technology-and-engineering-IMETEB-en/programma?utm_source.com |
| Denmark | Private group: AVK Group linked to Aarhus University | Advanced Water Cycle Management | Courses on circularity & sustainability integrated into water cycle: Waste water as resource. | YES | https://www.avkvalves.com/en/gain-knowledge/water-worldwide/advanced-water-cycle-management?utm_sourc.com |
| Hungary and Spain | University of Prague and Ovideo | Environmental Technology and management. Track: CE | Technology of CE with also water specific courses | YES | https://www.imatec-mundus.eu/curriculum/?utm_source.com |
| Austria | Technical University of Leoben | Circular Engineering | No courses on water related topics | YES | https://www.unileoben.ac.at/circular-engineering/en/master?utm_source.com |
| - | Online (1.5 hours) | Circular Water Management: A framework for the transition | "This course aims to address the transition of the water sector to the CE paradigm" | YES | https://circulareconomyalliance.com/product/circular-water-management-a-framework-for-the-transition/?utm_source.com |

## 3.3 Knowledge, skills and competence concepts

### 3.3.1 Introduction

The literature review continues with the second objective: to identify the essential knowledge concepts, skills, and competences required for executing circular water management. And begins by clarifying key knowledge concepts to provide conceptual grounding of CWPs. The literature review continues by analysing the skills and competence need to execute these practice and based them on the three categories systemic, interpersonal and reflective (see table [6]). The next sub chapter will give the findings on the main teaching methods for advancing CWE. In summary, this chapter highlights the integrated set of knowledge, skills, and reflection future water professionals need—and how education can support their development—to enable the transition toward a CWE. Before presenting the findings from the literature, the structure and discussion of the following chapter is first outlined.

Figure 6 Overview literature review and align with research questions

| | | |
|---|---|---|
| Subject-specific competences | **Knowledge Concepts**: Directly related to circular water practices and identifies the knowledge concepts that circular water education should address | |
| | *RQ 2: "What are the critical learning objectives and key challenges in educating future water professionals for a circular water economy in the EU?"* | |
| Generic competences | **Skills and Competences**: Directly relate to the abilities to translate technical expertise into societal and economic value | *Systemic competences* (e.g., systems thinking, complexity awareness) |
| | | *Interpersonal competences* (e.g., communication, stakeholder collaboration) |
| | | *Reflective competence (*domain-independent attributes such as critical thinking, creativity, adaptability, and reflectivity*)* |
| | *RQ 3: "What skills and competences should young water professionals have to execute new circular water practices?"* | |
| | *RQ 4: "How is circular thinking established through interdisciplinary, systems-thinking, and reflective learning approaches used to support education for circular water management?"* | |
| **Teaching Method:** explores the pedagogies and assessment approaches that best support the development of the aforementioned knowledge concepts, skills and competences | | |
| *RQ 4: "How are educational activities and assessment frameworks designed to prompt circular thinking within water-related education programs?"* | | |

*Conceptual distinction*

Before engaging with the literature, it is necessary to first clarify the key concepts employed in this thesis. Learning objectives, skills, and competences differ in scope and function, particularly in how they relate to student achievement and the processes that support learning. Learning objectives are specific, measurable statements that define what a learner should know or be able to do by the end of a learning activity, guiding both instruction and assessment (Harden, 2002). Skills refer to applied, often task-specific abilities that draw upon knowledge and form the foundation for broader competences (Kennedy et al., 2009). Competences are more comprehensive, integrating knowledge, skills, and attitudes into context-specific and transferable capabilities (Klieme et al., 2008; Kennedy et al., 2009). As Calenda and Tammaro (2015) argue, competences reflect not only outcomes but also the dynamic, iterative nature of the learning process. Beyond being knowledgeable and skilled, competences involve action and personal orientation—how to be—as part of professional identity formation and citizenship preparation (Wagenaar, 2014). However, Wagenaar (2014) points out the "fuzziness and conceptual confusion" surrounding the term competence, highlighting that its use often overlaps or varies in meaning when compared to related concepts such as learning outcomes and skills.

*Other frameworks*

This fuzziness is evident in the wide range of conceptual frameworks scholars have used to define and communicate learning objectives, skills, and competences in sustainability and CE education. Wagenaar (2014) itself, distinguishes between subject-specific and generic (or transferable) competences, with the latter further divided into instrumental, interpersonal, and systemic skills. Instrumental competences refer to core cognitive and methodological abilities such as analytical thinking, problem-solving, and information literacy. Interpersonal competences encompass skills related to teamwork and communication, while systemic competences involve adaptability, creativity, and awareness of sustainability.

Janssens et al. (2021) speaks of competences too and classifies them into three categories: technical competences (skills directly linked to CE principles), valorisation competences (the ability to translate technical knowledge into societal and economic value, including systems thinking, interdisciplinary collaboration, and design skills), and transversal competences (domain-independent abilities such as critical thinking, creativity, responsibility, and communication across stakeholder groups). This last category also includes interpersonal and self-regulatory abilities such as emotional intelligence, teamwork, and the capacity to adapt and transfer knowledge across contexts. Interestingly, competences such as “interdisciplinary skills to create shared problem definitions and shared solution perspectives” were classified as valorisation competences, while others like “skills to communicate with different stakeholders” and “interpersonal skills” were placed under transversal competences. This overlap highlights the conceptual fuzziness and fluid boundaries that often exist between the different categories and the use of these concepts.

Burger et al. (2019) organize competences into technical skills (e.g., eco-design, process engineering), cognitive skills (e.g., problem solving, analytical reasoning), and soft or non-cognitive skills (e.g., communication, collaboration, and adaptability). Additionally, Li et al. (2024) and Garito et al. (2024) make a simpler distinction between knowledge, skills, and attitudes. Where knowledge refers to what a learner knows—the concepts, facts, and theories acquired through study. Skills describe what a learner can do—the ability to apply knowledge in practical or cognitive tasks. Attitudes reflect how a learner approaches learning or action, including values, motivation.

The framework of Scalabrino et al. (2022) is quite different as they speak of dimensions and element. The authors propose a three-dimensional framework for sustainability education, combining cognitive, socio-emotional, and behavioural/action-oriented. The cognitive dimension focuses on the aims and learning outcomes. It emphasizes the development of knowledge and intellectual capacities needed to understand complex environmental and socio-economic challenges. This includes clearly defined learning outcomes, as well as broader "qualities for sustainable living," such as critical thinking, complexity awareness, and creativity. Besides, this part highlights specific competences for sustainable consumption and production. The socio-emotional dimension addresses thematic content that enables values, empathy, and ethical reflection. The behavioural dimension is based on transformative pedagogies and active learning methods and addresses specific teaching methods.

*Literature review as structure for the conceptual framework*

Together, these frameworks shape the structure of the upcoming literature review and form the foundation for the conceptual framework. This approach builds on the competence models of Li et al. (2024) and Garito et al. (2024), who advocate for distinguishing between knowledge, skills, and attitudes. While adopting this structure, the current framework primarily differentiates between knowledge and skills. The dimension commonly referred to as "attitudes" is instead addressed under the category of reflective competences, as explained in the following paragraph. Besides, it adopts the distinction between subject-specific and generic competences as proposed by Wagenaar (2014), which is reflected in dividing the chapter in two main sub chapter: 'knowledge' and 'skill and competence development'. These knowledge chapter gives an overview of current CWP and topics. The concepts discussed are translated into learning objectives correspond to the 'to know' dimension of the UNESCO framework (Delors et al., 1996).

The subsequent chapter on skills and competences addresses learners' abilities to apply technical expertise in real-world, societal, and economic contexts (aligning with the valorisation competences as defined by Janssens et al., 2021). The chapter is subdivided into three parts, the first two part follow Wagenaar's (2014) categorization of systemic and interpersonal skills, which reflect the capacities required to operationalize knowledge and adopt circular thinking. These are expressed as learning objectives at the level of 'to do' (Delors et al., 1996). Instrumental competences (Wagenaar, 2014) are not examined in detail, as they are considered foundational and are assumed to be inherently covered in any technical Master's programme; therefore, they fall outside the course-specific focus of this thesis.

A third subchapter, on reflective competences, is included to address domain-independent attributes such as critical thinking, ethical awareness, and value formation. This correspond with the concept of transversal competences (Janssens et al., 2021), attitudes part (Li et al., 2024; Garito et al., 2024), and the socio-emotional dimension of learning (Scalabrino et al., 2022). The emphasis of this chapter is not on transmitting fixed values through specific learning activities, but on enabling the capacity to recognize and reflect on the plurality of values, which in turn influences design processes and decision-making practices. The learning objective related to the outcomes of this chapter are associated with the ‘learning to be’ and ‘learning to live together’ dimensions (Delors et al., 1996).

In addition, a separate chapter is dedicated to teaching methods and assessment strategies, which explores the pedagogies and assessment approaches that best support the development of the aforementioned learning objectives and competences. These methods are examined in light of how they enable students to engage with systemic, interpersonal, and reflective competences needed to execute CWP.

## 3.3.2 Knowledge Concepts

The CE offers a valuable framework for rethinking how water is used, recovered, and regenerated. At its core, a CWE seeks to close the loop, not only through water treatment and reuse but also by recovering and reintegrating remaining outputs, such as nutrients and energy, into productive systems (Kehrein et al., 2020). While the water sector aligns with circular principles, it also presents distinct characteristics and challenges. Water is a dynamic, flowing resource—heavily regulated and intricately woven into complex socio-technical systems. Its governance demands an integrated understanding of engineering, ecology, economics, and social structures (Wan Rosely & Voulvoulis, 2023). Unlike other materials, water is both a public good and an economic commodity: essential to life, yet traded and sold. These biophysical and socio-economic dynamics require sustainable strategies suited to water’s complex role in society.

The complexity of the CWE highlights the need to equip young water professionals with a robust and interdisciplinary set of competencies. This chapter responses to the research question: What are the critical CWPs to educate future water professionals for a CWE in the EU? Drawing on an extensive literature review, the chapter identifies and recommends key knowledge areas relevant to professional water practitioners. While curriculum design ultimately remains the responsibility of education providers, the findings offer a guideline to inform and support educational development. Findings from the chapter are summarized in the table [7] at the end chapter.

What the former chapter (3.2) already suggested, to engage with CWPs effectively, young professionals must understand both the technical and socio-political dimensions of water systems. Technical competencies include familiarity with advanced circular technologies, such as anaerobic digestion for biogas recovery (Zhang & Liu, 2022), membrane filtration (Issaoui et al., 2022), and algae–bacteria consortia (Bhatt et al., 2022). These are complemented by knowledge of applied reuse strategies, including nature-based solutions like rainwater harvesting (Novaes & Marques, 2023), integrated urban-industrial reuse chains (Neri et al., 2024), and decentralized systems (Al-Azzawi et al., 2022). Moreover, practitioners must acknowledge that circular solutions need to be resilient and adaptable to future uncertainties (Bouziotas et al., 2023), with wastewater treatment plants (WWTPs) increasingly positioned as key actors in this shift by evolving into Water Resource Recovery Facilities (Capodaglio, 2023; Smol, 2023; Mannina et al., 2022).

Effective education for the CWE begins with an understanding of learners' existing conceptions. A foundational pedagogical principle holds that assessing prior knowledge is essential before defining new learning objectives (Merrill's, 2002). Nevertheless, literature suggest that students often enter water education with fragmented or inaccurate mental models which limits their ability to effectively engage with water-related challenges (LaDue et al., 2021). Beyond student understanding, enhancing water literacy is also essential for enabling public participation in decentralized, community-based water management (Boon, 2024), which is typical for CWPs. In this context, the concept of water literacy emerges as a critical educational concept. Water literacy refers the knowledge and skills needed to make informed decisions about water use, conservation, and management, including an understanding of water systems, related challenges, and the factors influencing water sustainability (McCarroll & Hamann, 2020). Studies on water literacy emphasize the importance of interdisciplinary (Mostacedo-Marasovic et al., 2022), constructivist learning (Imaduddin and Eilks, 2024), Socio-scientific reasoning (Owens et al., 2020), experiential (Ceccaroni et al., 2023) and active learning strategies (Moreno-Guerrero et al., 2020). Without more interdisciplinary research and the development of tailored educational programs, the workforce may be inadequately prepared to handle the complexities of circular water systems, potentially impeding the widespread adoption of sustainable water management practices.

Moreover, successful implementation of CWPs requires the ability to navigate beyond technical systems. As Kehrein et al. (2020) argue, the primary constraint is often not technological feasibility of CWP but the lack of market integration for recovered products. Scholars increasingly critique the dominant technological focus in circular water literature, calling for more attention to institutional, ethical, and socio-political dimensions (Fernandes et al., 2023; Mannina et al., 2022; Parada et al., 2022). The viability of circular solutions also depends on their alignment with local conditions. Practices vary widely between urban, rural, and industrial contexts, each with distinct infrastructure, regulation, and cultural dynamics (Fidélis et al., 2020; Peydayesh and Mezzenga, 2024). The selection and upscaling of technologies must consider local context, not just technological legitimacy (Afghani et al., 2022). Thus, understanding that circular strategies must be adaptable and tailored to specific sectors, geographies and social contexts is crucial.
These findings confirm that learning objectives for CWE must extend beyond technical skills. A broader range of competencies is needed, including systems thinking (Mbavarira & Grimm, 2021), policy integration (Cipolletta et al., 2021), stakeholder engagement (Mannina et al., 2022), and cross-sectoral collaboration (Kehrein et al., 2020; Vinayagam et al., 2024; Frijns et al., 2024).

Taken together, these insights show that the complete learning objectives for CWE extend well beyond technical training and need broader recognition of skills and competencies. These professionals must not only design and operate complicated reuse systems, but also lead circular transitions in complex, real-world environments. Before we discussed those generic skills and competence in the next chapter, first show the main knowledge findings identified from the literature are summarized in table 6.

*Table 6 Core topics for understanding circular water practices (CWP)*

| | Subject | Key Insight | Reference |
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| 1. | **Water domain specificity** | For example, water is a regulated public good and economic commodity, embedded in complex socio-technical systems. | Wan Rosely & Voulvoulis, 2023 |
| 2. | | Water should be seen as 'a service, input, energy source, and material carrier'. | Delgado et al., 2023 |
| 3. | **Circular principles** | Circular principles include source protection, reuse, and waste minimization. | Ramírez-Agudelo et al., 2021 |
| **4.** | | *Close the loop:* Recovery of water, nutrients, and energy must include repurposing | Kehrein et al., 2020 |
| 5. | | Circular strategies must prioritize sustainable uses. | Sauvé et al., 2021; Smol et al., 2020 |
| 6. | **Water literacy** | Water literacy includes understanding systems, scarcity, and governance. | McCarroll & Hamann, 2020 |
| **7.** | | Public understanding is essential for local water management. | Boon, 2024 |
| 8. | **Water/pollutant refusal (prevention)** | Preventing pollution and water abstraction reduces treatment needs. | Wan Rosely & Voulvoulis, 2023; Issaoui et al., 2022; Ramírez-Agudelo et al., 2021 |
| **9.** | | Eco-design reduces pollutant entry at the source. | Borah et al., 2023 |
| **10.** | | Infrastructure optimization helps prevent water loss. | Koseoglu-Imer et al., 2023 |
| 11. | **Water reuse** | Includes nature-based and engineered solutions. | Koseoglu-Imer et al., 2023; Nika et al., 2020 |
| **12.** | | Urban RWH systems aid treatment and hydrological balance. | Novaes & Marques, 2023; Ghafourian et al., 2021 |

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| **13.** | | Industrial RWH reduces demand on municipal systems. | Dias et al., 2024; Neri et al., 2024 |
| **14.** | | Reuse systems must be tailored to specific cultural and environmental contexts. | Peydayesh & Mezzenga, 2024; Antiñolo Bermúdez et al., 2022; others |
| 15. | **Reuse of products** | *Case study:* Sludge can be reused in agriculture or construction (e.g bricks), but faces logistical and legal challenges. | Jakubus, 2024; Nguyen et al., 2022 |
| 16. | **WWTPs** | Traditionally focused on pollutant removal; now evolving into recovery facilities. | Mbavarira & Grimm, 2021; Capodaglio, 2023, Smol, 2023, Mannina et al., 2022; Wan Rosely & Voulvoulis, 2023; Jakubus, 2024 |
| **17.** | | WWTPs can contribute to climate resilience and produce valuable materials (e.g bioplastics, biofuels, fertilizers, and construction materials). | Capodaglio, 2023; Guerra-Rodríguez et al., 2020; Renfrew et al., 2024 |
| 18. | **Emerging contaminants** | ECs like pharmaceuticals and surfactants are hard to remove with conventional WWTPs. Choice of treatment method is critical for posing risk to human and ecosystem health. | Das et al., 2023; Borah et al., 2023; Koseoglu-Imer et al., 2023 |
| 19. | **Transformative technologies** | *AOPs* degrade non-biodegradable compounds | Mannina et al., 2022 |
| **20.** | | *Anaerobic digestio*n recovers energy from sludge - a key pathway for making WWTPs energy-positive | Smol, 2023; Castellet-Viciano et al., 2022; Zhang & Liu, 2022 |
| **21.** | | *Membrane Technologies:* ultrafiltration, nanofiltration, and reverse osmosis | Abidli et al., 2022 |
| **22.** | | *Biotech solutions* like MES and and algae–bacteria consortia show promise but are not yet mainstream. | Bhatt et al., 2022; Abidli et al., 2022; Dhanker et al., 2023 |

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| **23.** | | *Hybrid Systems:* combine biological treatment with membrane separation | Yadav et al., 2021 |
| **24.** | | *Adsorption-Based Methods:* Low-cost, low-energy adsorbents such as graphene oxide, biochar, and hydrochar.- face challenges with regeneration, performance variability, and integration into existing infrastructure, making them difficult to scale commercially | Khajvand et al., 2022; Das et al., 2023; Padhye et al., 2022; Abidli et al., 2022 |
| 25. | **Economic and environmental benefits** | Resource recovery reduces emissions, saves energy, and adds revenue streams. | Yadav et al., 2021; Smol, 2023 |
| 26. | **Sectoral diversity** | Water reuse differs by use case (e.g., potable, industrial), each with unique barriers. | Fernandes et al., 2023 |
| **27.** | | Urban areas: often characterized by dense populations and diverse/aging infrastructure, tend to focus on stormwater harvesting and wastewater reuse | Al-Azzawi et al., 2022; Ramírez-Agudelo et al., 2021 |
| **28.** | | Industrial environments: circularity often centres on internal recycling and the recovery of water from highly polluted streams, requiring complex treatment and integration into production systems | Dias et al., 2024; Hernández-Chover, Castellet-Viciano and Hernández-Sancho, 2022 |
| 29. | **Spatial diversity** | International, National and regional: diverse pathways are required to reflect the varied institutional, geographic, and climatic | Fidélis et al., 2020; Khoury et al. (2023); Voulvoulis (2018); Afghani et al., 2022; Peydayesh and Mezzenga (2024) |
| 30. | **Rethinking Infrastructure Through Decentralization** | Decentralized systems are adaptable, reduce transport energy, and increase local resilience. | Arora et al., 2022; Smol, 2023; Al-Azzawi et al., 2022; Ramírez-Agudelo et al., 2021; Al-Azzawi et al., 2022; Vinayagam et al., 2024 |

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| **31.** | | Social and institutional benefits : They enable community involvement and innovation. | Ghafourian et al., 2022 |
| **32.** | | Case studies: decentralized city infrastructure at the neighbourhood scale; Sewer mining | Al-Azzawi et al. (2022); Plevri et al., 2021 |
| 33. | **Resilience thinking** | Underused in circular water planning; critical for long-term adaptability. | Marques et al., 2023; Bouziotas et al., 2023 |
| **34.** | **Metrics and tools and methodologies** | Data Envelopment Analysis (DEA) can improve performance evaluation in WWTPs;; circular economic and environmental indicators; Water Circularity Index (WCI); broader circularity assessment framework; circularity framework specifically for WWTPs; PESTEL framework; Payment for Ecosystem Services (PES); tariffs model | Hernández-Chover et al. (2023); SSmol et al. (2025); Kakwani and Kalbar (2024); Nika et al. (2020); Samberger et al. (2024); Smol et al. (2025); Antiñolo Bermúdez et al., 2022; Bellver-Domingo and Hernández-Sancho, 2022 |
| **35.** | | Method: Scenario modelling; Mathematical optimization frameworks; life-cycle costing (LCC), net present value (NPV), and return on investment (ROI); material flow analysis (MFA); Multi-criteria decision-making (MCDM) + Analytical Hierarchy Process (AHP); GIS-based decision model; Technology readiness levels (TRLs), life cycle assessment (LCA), and techno-economic analysis (TEA); LCA | Bouziotas et al., 2023; Smol and Koneczna (2021); Arora et al. (2022); Lee et al., 2023; Valenti and Toscano, 2021; Yadav et al., 2021; Zhang & Liu, 2022 and Harris et al. (2021) |
| 36. | **Technical barriers and Operational Complexity** | Technologies lack commercial maturity, scalability, cost, and are often energy-intensive, cost-prohibitive, or poorly adapted for small and rural systems | Castellet-Viciano et al., 2022; Koseoglu-Imer et al., 2023; Kehrein et al., 2020; Abidli et al., 2022; Yadav et al., 2021; Jakubus, 2024; Mannina et al., 2022 |

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| 37. | | Efforts to operate multiple recovery pathways within a single WWTP also introduce additional complexity and maintenance burdens | Kehrein et al., 2020; Castellet-Viciano et al., 2022 |
| 38. | **Technical challenges** | Monitoring and scaling reuse systems is hindered by the lack of standardized performance metrics, while WWTP operators face regulatory uncertainty, infrastructure gaps, and weak economic incentives despite their willingness to innovate | Mannina et al., 2022; Frijns et al., 2024; Ramm and Smol (2024) |
| 39. | **Socio, political and economy challenges** | *Economic and Market Challenges :* The initial high capital investment costly retrofitting of existing WWTP's pose significant obstacles, absence of financial incentives for further industry uptake; Uncertain long-term returns | Kakwani & Kalbar, 2020; Smol et al., 2023; Smol et al., 2025; Vinayagam et al., 2024; Kehrein et al., 2020; Koseoglu-Imer et al., 2023; Frijns et al., 2024; Mannina et al., 2022 |
| **40.** | | *Institutional and Regulatory Constraints:* institutional side, outdated, fragmented, or rigid regulatory frameworks; Complex permitting and compliance procedures; legal complexities; | Cipolletta et al., 2021; Kehrein et al., 2020; Mbavarira & Grimm, 2021; Mannina et al., 2022; Santos et al., 2024; Berbel et al., 2023 |
| **41.** | | In siloed management across the water, waste, and energy sectors | Gude, 2021; Jakubus, 2024; Mannina et al., 2022; ; Koseoglu-Imer et al., 2023; Wan Rosely & Voulvoulis, 2023 Smol, 2023; Cipolletta et al., 2021; Vinayagam et al., 2024; Frijns et al., 2024; Fernandes et al., 2023 |
| **42.** | | *Public Perception and Social Acceptance:* Policy inertia and limited awareness of circular solutions among both | Guerra-Rodríguez et al., 2020; Castellet-Viciano et al., 2022; Smol, 2023; Vinayagam et al., 2024; Fernandes |

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| | decision-makers and the public further obstruct progress | et al. (2023; Jakubus, 2024; et al., 2022; Parada et al., 2022; Santos et al., 2024 |

### 3.3.3 Systemic Competence

This chapter discusses skills and competences directly related to the abilities to translate (technical) knowledge into societal and economic value. It first discusses the systemic competences, then the interpersonal competences and end with the reflective competences. The final chapter concludes with a brief discussion on the implementation challenges of these skills and competences, highlighting that they are not yet fully integrated into current educational practices. Finding from all sub chapters are summarized in the table 7 at the end of reflective competence chapter.

As the former chapter on 'knowledge on CWP' showed, the CWE operates across and between multiple overlapping systems. This complexity demands not only technical proficiency but also the development of advanced systemic skills. Numerous scholars advocate for the integration of systems thinking in for water education (Alaerts & Kaspersma, 2022; Wan Rosely & Voulvoulis, 2023) and ECE (Cappellaro, 2024;; Janssens et al., 2021; Burger et al., 2019; Samberger, 2022; Lally & Forbes, 2020; Leung et al., 2024). For circular practice to work, solution should come from a system thinking where technological, organizational, and socio-political components are viewed as interdependent rather than isolated (Mbavarira and Grimm, 2021). These competences enable professionals to understand, navigate, and intervene in the interconnected and dynamic nature of water-related challenges embedded within broader socio- technical and environmental systems. Systemic thinking thus emerges as a cornerstone in educating future water professionals, enabling capacities such as complexity awareness, long-term strategic planning, integrative problem-solving, and adaptive planning. Although not every paper is situated directly within the context of CWE, each is conceptually aligned through themes of CE, sustainability, the water domain.

*Systems thinking as a foundational skill*

Wan Rosely and Voulvoulis (2023) provide a comprehensive review of systems thinking as both a conceptual and practical tool for transforming urban water systems. In their view, systems thinking enables professionals to understand non-linear dynamics within infrastructure, governance, policy, and user behaviour, and to identify leverage points for transformative change. Similarly, Cappellaro (2024) argues that effective change requires a foundational understanding of how systems work. Key features of systems thinking include an emphasis on whole systems over individual components, recognition of interdependencies and time delays, the use of multi-perspective problem framing, and application of analytical tools such as causal loop diagrams and system mapping. Cappellaro (2024) presents a framework that integrates complex thinking and systemic approaches into water education through a case study on the domestic water cycle in French curricula. The author critiques the traditional linear model of water education, which often isolates different components and fails to convey the interconnections inherent to water systems. This fragmentation hinders students' ability to comprehend the broader system.

Lally and Forbes (2020) contribute by analysing student engagement with socio-hydrologic system models. Their study demonstrates how interdisciplinary modelling exercises, though initially challenging, improve students' operational understanding of human-water interactions. In order to meaningfully change and influence both natural and human-made water systems—such as circular water systems—students need more opportunities and support to develop systemic skills associated with water literacy. These include exploring cause-effect relationships, unintended consequences, and feedback dynamics, all of which are essential for effective water-related reasoning and problem-solving. However, the authors caution that presenting students with problems that are artificial or of low relevance diminishes engagement and minimizes the pedagogical benefits of systems thinking. To enable authentic systems thinking, students must be engaged in real-world, high-impact learning scenarios where they can gain experience thinking about, explaining, and making decisions concerning complex, coupled human-natural systems.

Similarly, Samberger (2022) emphasizes water circularity within the broader food–water–energy (FWE) nexus. The paper critiques linear resource models and argues for integrated, circular strategies that embed water as a reusable resource within systemic feedback loops. This system-in-systems perspective serves as a strong conceptual foundation for integrating circular systems thinking into education.

*Adaptive capacity and long-term planning*

Alaerts and Kaspersma (2022) expand the discussion by linking systemic skills to adaptive capacity development. The authors explicitly discusses the evolving skillset required for water professionals. Wwhich are, in addition to technical expertise, soft skills such as strategic foresight, systems thinking, stakeholder engagement, communication, and reflective learning. The authors focus on 21 century challenges that characterize by uncertainty, complexity, and rapid change and requires system-oriented policy-making and iterative learning. Unlike normative policies based on predictability, adaptive approaches acknowledge knowledge gaps and conflicting stakeholder values. Systems thinking underpins these approaches, supporting strategic goal setting and ongoing learning. Long-term visioning, accompanied by peer learning and interdisciplinary collaboration, becomes essential for sustainable transformation.

Moreover, Hoffman et al. (2021) emphasize the need for what they term a “futuring” mindset, engaging students in long-term scenario planning to help them explore the consequences of decisions across time. This helps learners develop systems thinking and moral imagination, allowing them to reason through unintended future effects of interventions in water systems.

### 3.3.4 Interpersonal Competence

As several authors have already indicated, systemic solutions for CWP require collaboration across diverse fields and sectors. This requires a foundation of interpersonal and interdisciplinary skills. Renfors (2024) emphasizes that the interdisciplinarity of course implementation, particularly through mixed student groups, needs to be enhanced in order to strengthen systems thinking competencies and to enable appreciation of diverse perspectives and values. To guide this process, students and professionals must master communication, collaboration, interdisciplinary awareness, and stakeholder engagement (Alaerts & Kaspersma, 2022; Li et al., 2024; Renfors, 2024). Collaboration among sectors and institutions is equally vital. Cross-sector partnerships helps scale innovations and build public trust (Mbavarira and Grimm, 2021; Kehrein et al., 2020; Vinayagam et al., 2024; Frijns et al., 2024).

*Interdisciplinarity and collaborative competence*

Many studies highlight the need to equip learners with the ability to work across disciplinary boundaries (Mokski et al., 2023; Xia & Peng, 2022; Murray et al., 2023; Podgórska & Zdonek, 2024). Renfors (2024) succinctly states: "Interdisciplinarity is the key characteristic in education for the CE." These competencies allow students to integrate and apply knowledge from different domains to address complex water-related challenges. Li et al. (2024) similarly argue that water is inherently interdisciplinary and its presence across multiple curricular domains provides opportunities to embed collaborative, cross-sectoral thinking. However, their study reveals that in practice, geographic education often presents water in fragmented ways, undermining the potential for systemic understanding. In a broader curriculum review, Renfors (2024) found that only 29% of examined articles on CE education introduced interdisciplinary courses with mixed student cohorts, illustrating a significant gap in current educational practice. Leung et al. (2024) emphasize that systems thinking and interdisciplinary awareness are intertwined, requiring open-mindedness and a willingness to understand differing perspectives. This mindset is essential for students to engage meaningfully with real-world problems and to generate innovative solutions.

*Stakeholder engagement and real-world interaction*

Engagement with external stakeholders is a recurring theme in the literature. Hoinle et al. (2021) show how universities can successfully collaborate with local actors to create transdisciplinary teaching environments. However, they caution that such initiatives require skilled facilitation and strong commitment from both academic and non-academic partners. Renfors (2024) critiques the lack of workplace interaction and stakeholder co-learning in current CE education, despite these being central to transformative learning. Burger et al. (2019) and Guerreschi et al. (2023) also highlight the importance of public-private partnerships in aligning educational experiences with professional realities. According to Guerreschi et al. (2023), effective training must be hands-on, dynamic, and rooted in collaboration with firms and organizations. These interactions help students develop key competencies such as adaptability, communication, and cross-sector collaboration. In educational contexts, structured reflection and dialogue are crucial for developing this communication competence. Murray et al. (2023) addressed this through formal learning objectives that include presentations to both academic and non-academic audiences. These activities enhance students' abilities to communicate research and ideas clearly across disciplinary and stakeholder boundaries.

Besides, in the study of Janssens et al. (2021), the most important valorisation competences were not system thinking or interdisciplinary collaboration. The authors found that competences relate primarily to business, economics, and management were rated with highest importance. The three highest-rated were: "being able to come up with customized business models," "knowledge about the economic aspects of the environment and ecology," and "skills about project management and implementation". As one expert in the focus group noted, the main barriers are no longer technical but economic in nature: "the technical possibilities are not the biggest challenge anymore, but are replaced by economic challenges".

Zimmermann (2024) further emphasizes the importance of end-user participation in water management by presenting a three-tier model—awareness, education, and resources. This framework shows how enabling end-users with the right knowledge and tools can enable more inclusive and effective water partnerships, reinforcing the value of community engagement as a driver of circular water governance. By cultivating interpersonal skills through interdisciplinary collaboration, stakeholder engagement, and mindset development, education for the CWE can prepare students to navigate complex, interconnected challenges. Embedding these approaches across curricula will not only strengthen professional readiness but also accelerate the broader systemic transformation toward sustainability.

### 3.3.5 Reflective Competence

While technical expertise, systems thinking and interdisciplinary collaboration are foundational to managing circular water systems, a set of broader, cross-cutting abilities (commonly referred to as transversal competences) is equally critical. These include ethical reasoning, creativity, critical thinking, adaptability, responsibility, and life-long learning. Unlike domain-specific knowledge, transversal skills apply across disciplines and are particularly important for navigating the uncertainty, ethical decisions, and interdisciplinary collaboration inherent 21-century problem-solving (Alaerts and Kaspersma, 2022).

*Developing Circular Mindsets*

As Guerreschi et al. (2023) note, the CE demands a fundamental reconfiguration of how individuals think, collaborate, and take responsibility. This includes cultivating interdisciplinary literacy, adaptability, resilience, and a cooperative mindset. The authors argue that education must prepare students not only to act within existing systems but to challenge and transform them. Thus, transversal competences are not just “soft skills” or supplemental to technical learning—they are transformative capacities that shape how knowledge is applied, how challenges are approached, and how individuals engage with society and the environment.

Deda et al. (2022) underscore the need for a shift from linear to circular thinking, framing the CE as a redefinition of growth that emphasizes system-wide benefits and the decoupling of economic activity from resource depletion. This transformation demands a rethinking of production and innovation processes.

Janssens et al. (2021) identify top-ranking transversal skills for the CE as “innovative and open-minded,” “creative thinking,” and “being visionary.” These abilities allow learners to generate solutions, create direction, and strategize effectively. these competences have in common that they deal with finding creative solutio ns, give direction and create a strategy for the circular economy. Besides, “life-long learning” competence was ranked long among surveyed experts, although the experts did not mentioned it as important with the focus group. The authors explanation is that they were convinced that more and more recent graduates have this skill and extra attention for this is not essential.

Critical thinking emerges as a foundational transversal skill in teaching CWE practices, enabling learners to question dominant paradigms and engage with complex, interconnected systems. Kopnina (2022) emphasizes the need for pedagogies that transcend anthropocentric and linear economic thinking, advocating instead for a posthuman ethical framework within CE education. This approach challenges students to critically examine the socio-ecological implications of human-centred resource use and to envision alternative futures that respect non-human agency and ecological boundaries. In this context, critical thinking is not merely evaluative but transformative, encouraging learners to deconstruct existing norms and imagine regenerative, equitable water systems aligned with circular principles. Besides, ethical awareness is a crucial component of transversal competence. It involves the ability to make moral judgments, assess trade-offs, and act responsibly (Kopnina, 2022). Skills particularly relevant in managing complex water-related decisions where conflicting interests and long-term impacts are involved. Besides Kopnina (2022) as one of the two authors that discusses a CE course, emphasized the importance of linking CE practices to sustainability issues. “If the CE is to be truly ecologically beneficial or at the very least, less harmful, its contribution to the environment, especially in the case of consumables, needs to be better understood.” And later she writes: “In the case of CE, one may inquire which types of economic activities can give back or contribute (in a sense of regenerative or reciprocate interaction) to greater-than-human-word” (Kopnina, 2022).

Leung et al. (2024) highlights system thinking is not merely about following structured frameworks and following methods but about cultivating a mindset that embraces non-linearity, openness, and divergent thinking. Their study critiques procedural approaches to systems education that may reduce creativity and engagement. Particularly in engineering contexts, students are often trained to generate well-defined models, making the open-ended nature of systems thinking appear daunting. To counter this, the authors recommend cultivating the "habits of a systems thinker," such as recognizing interconnections, thinking holistically, questioning assumptions, and enabling continuous learning. These competencies help students address wicked problems, characteristic in water management. The authors curriculum incorporates creative exploration, tolerance for failure, and opportunities for experimentation. Learning activities are designed based on the Waters Center for Systems Thinking framework (Waters Center For Systems Thinking, z.d.), which includes skills like identifying dependencies, defining system boundaries, and embracing adaptability (Leung et al., 2024). In this context, systems thinking operates not only as a practical competency but also as a guiding mindset that informs how actions are understood, designed, and executed.

The shift from reductionist to systemic thinking represents a paradigm change in sustainability education. Scalabrino et al. (2022) argue that sustainability education must move beyond the inclusion of environmental content (as in traditional environmental education) toward enabling epistemological and ethical transformation. Drawing on work from Meadows (1982) and Mayer (1998), they emphasize the need for learners to confront the world as a complex, interconnected, and infinite system. Systems thinking, in their view, goes beyond analytical tools to include value-driven reflection and action-oriented learning. This means that education must help students construct ways of feeling, thinking, and acting that bring together knowledge, affect, and ethical commitment. The authors continue to advocate for dialogic learning environments that enable students to explore how consumerism, industry practices, and socio-cultural values intersect with environmental sustainability. This integrative approach helps learners understand not only systemic interdependencies but also their agency in shaping them through personal and collective action.

*Implementation challenges and future directions*

While the value of systems thinking in sustainability education is widely acknowledged, its implementation within curricula remains inconsistent and fragmented. Cappellaro (2024) identifies persistent barriers such as insufficient teacher training, rigid curricular frameworks, and limited interdisciplinary collaboration. These structural issues constrain educators' capacity to enable complex systems understanding. In parallel, Lally and Forbes (2020) report that many students continue to hold inaccurate or overly simplistic conceptions of the water cycle, which hampers their ability to engage meaningfully with the systemic nature of CWPs. Procedural and overly formulaic approaches to systems thinking—highlighted by Leung et al. (2024)—further dilute its transformative potential, often suppressing creativity and critical engagement. With a broader view, Renfors (2024) critiques the prevailing focus of ECE on micro- and meso-level applications, noting a lack of emphasis on macro-level themes such as consumer behaviour, policy frameworks, and social change. The author calls for a shift toward multi-scalar thinking and real-world engagement, suggesting the use of tools such as simulations, stakeholder interactions, and problem-based learning to build systemic competence. Importantly, the authors also advocates for the integration of social objectives—such as shared economies and social entrepreneurship—that remain underrepresented in current programs but are essential for enabling holistic understanding. Interdisciplinary communication remains another critical challenge. Sauvé et al. (2016) emphasize that divergent disciplinary meanings can create misunderstandings and hinder collaboration across teams, particularly when shared terminology is lacking. Building mutual understanding and developing common vocabularies are thus essential interpersonal skills for those working within the CWE. Several recent studies highlight structural and institutional barriers to integrating interdisciplinary and systems-oriented approaches. Ab Hamid et al. (2024) point to a general absence of coordinated curriculum design and limited faculty preparedness, urging investment in faculty development and institutional strategies that promote cross-departmental collaboration. Xia and Peng (2022) describe interdisciplinarity as "inevitable" in groundwater science, yet constrained by deeply entrenched departmental silos. They propose forming interdisciplinary mentorship teams to bridge these divides and promote integrative learning experiences. These structures include supervisors from different department, enabling cross-pollination of ideas and bridging gaps between disciplines.

Mokski et al. (2023) add that fragmented knowledge production further undermines interdisciplinary collaboration. Barriers such as limited understanding of ESD, perceived irrelevance of sustainability content, and structural limitations—including funding constraints—are common across institutions. These challenges resonate strongly with those faced in CWE education. Jones et al. (2008, cited in Mokski et al., 2023) also note that sustainability is often viewed by faculty as an "add-on" rather than a core curricular element. Similarly, Podgórska and Zdonek (2024) emphasize the ongoing lack of actionable strategies for embedding the Sustainable Development Goals (SDGs) into university activities, underscoring the need for more pragmatic and integrative approaches to curriculum reform.

*Table 7 Core skills and competences for executing circular water practices (CWPs)*

| | Subject | Key Insight | Reference |
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| 1. | **System thinking** | Components are viewed as interdependent rather than isolated levers, emphasizing whole systems over individual components. This perspective includes recognition of interdependencies and time delays, the use of multi-perspective problem framing, and the application of analytical tools such as causal loop diagrams and system mapping. | Alaerts & Kaspersma, 2022; Cappellaro, 2024; Wan Rosely & Voulvoulis, 2023; Janssens et al., 2021; Burger et al., 2019; Samberger, 2022; Lally & Forbes, 2020; Leung et al., 2024; Mbavarira and Grimm, 2021; Cappellaro (2024) |
| 2. | water literacy | Without fundamental knowledge about water cycles, system thinking, including an understanding of cause-effect relationships, unintended consequences, and feedback dynamics, becomes difficult. | Lally and Forbes (2020); Cappellaro (2024) |
| **3.** | Food–water–energy (FWE) nexus: | Understanding that water systems are interconnected with other domains is essential. | Samberger (2022) |
| 4. | Adaptive Capacity Long term thinking | Challenges characterized by uncertainty, complexity, and rapid change necessitate strategic foresight, long-term thinking, stakeholder engagement, communication, and iterative learning. A “futuring” mindset involves long-term scenario planning that helps individuals explore the consequences of decisions across time. | Alaerts and Kaspersma (2022); Hoffman et al. (2021) |

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| | **Interpersonal** | | |
| **5.** | Interdisciplinary collaboration | It is important to equip learners with the ability to work across disciplinary boundaries. Interdisciplinary approaches in course implementation, particularly through mixed student groups, are highlighted. | Ab Hamid et al., 2024; Mokski et al., 2023; Xia & Peng, 2022; Murray et al., 2023; Podgórska & Zdonek, 2024Renfors (2024) |
| **6.** | Developing Collaborative Mindsets | A shared understanding, interdisciplinary awareness, willingness to understand differing perspectives, and the need for innovative solutions are essential. The concept of "embracing empathy" and understanding others is crucial. | Alaerts & Kaspersma, 2022; Li et al., 2024; Renfors, 2024; Leung et al. (2024) |
| 7. | Stakeholder Engagement/ Cross-sector partnerships and Real-World Interaction | Stakeholder engagement and collaboration with partners outside the academic sphere are necessary to create real-world interactions and presentations for non-academic audiences. Collaboration among sectors and institutions is equally vital for scaling innovations and building public trust. | Alaerts & Kaspersma, 2022; Li et al., 2024; Renfors, 2024; Hoinle et al. (2021); Burger et al. (2019) and Guerreschi et al. (2023); Mbavarira and Grimm, 2021; Kehrein et al., 2020; Vinayagam et al., 2024; Frijns et al., (2024); Murray et al. (2023) |
| 8. | End-user participation in water management | Engaging end-users through education and resource provision enhances inclusive and effective water management practices, reinforcing community-driven circular water governance. | Zimmermann, 2024 |
| 9. | Entrepreneurial skills | Business, economics, and management-related skills are essential. | Janssens et al. (2021) |
| | **Reflective competence** | | |
| **10.** | Developing Circular Mindsets | This requires a fundamental reconfiguration of how individuals think, collaborate, and take responsibility. It embraces non-linearity, openness, holistic thinking, creative exploration, and opportunities for experimentation. | Guerreschi et al. (2023); Deda et al. (2022); Leung et al. (2024) |
| 11. | Allow creativity | Innovative and open-minded thinking, creative solutions, and the creation of strategies for the CE are emphasized. The | Janssens et al. (2021); Leung et al. (2024) |

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| | | encouragement of divergent thinking is essentials. | |
| **12.** | Critical thinking | Critical thinking involves challenging what is suggested by the teacher, peers, (academic) study material and claims you make yourself. I should embracing ambiguity and uncertainty in order to explore new possibilities. | Kopnina (2022); Scalabrino el at. (2022); Leung et al. (2024) |
| **13.** | Ethical awareness | Ethical awareness is crucial for assessing trade-offs and enabling epistemological and ethical transformation. | Kopnina (2022); Scalabrino el at. (2022); |
| **14.** | Reflection | "Learning to learn" involves embracing failure as valuable opportunities for growth and challenging assumptions to uncover new insights. | Scalabrino el at. (2022); Leung et al. (2024) |
| **15.** | Self confidence | Personal confidence involves enabling a growth mindset, believing in one's ability to learn, and understanding the agency in shaping oneself through personal and collective action. | Leung et al. (2024); Scalabrino el at. (2022); |
| 16. | **Implementation Challenges and Future Directions** | Challenges include insufficient teacher preparation and a lack of understanding among teaching staff. | Cappellaro, 2024; Mokski et al., 2023 |
| 17. | | Engineering contexts often lead to the training of students in well-defined models, making the open-ended nature of systems thinking appear daunting and neglecting broader systemic perspectives. | Alaerts and Kaspersma (2022); Cappellaro, 2024; Leung et al. (2024); Renfors (2024) |
| **18.** | | A lack of interdisciplinary collaboration in educational settings is a challenge. | Alaerts and Kaspersma (2022); Cappellaro, 2024 |
| **19.** | | The presentation of water systems is often fragmented, impeding a holistic understanding. | Li et al. (2024); Lally and Forbes (2020) |
| **20.** | | Divergent interpretations and meanings within interdisciplinary teams present challenges. | Sauvé et al. (2016) ; |

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| **21.** | Resistance to system thinking and circular practices often arises from perceptions of irrelevance. | Mokski et al., 2023 |
| **22.** | There is a lack of practical solutions for incorporating sustainability topics into curricula. | Podgórska and Zdonek (2024 |

## 3.4 Teaching methods and assessment approaches

This chapter addresses the third objective of the thesis: to identify teaching approaches and assessment techniques that best support the development of skills and competences needed for circular water practise. It responds to the sub-question: How are educational activities and assessment frameworks designed for prompting circular thinking within water-related education programs? By examining didactic strategies, pedagogical models, and assessment practices, this chapter explores how education can effectively enable interdisciplinary, systems-based, and reflective learning aligned with CE principles. All findings are summarized in table 8 at the end of the chapter.

Educating future professionals for sustainability demands a shift from traditional, content-based instruction toward more dynamic, experiential, and integrative teaching approaches (Fang & O'Toole, 2023 cited in Podgórska and Zdonek, 2024). These must equip students not only with technical and systemic knowledge but also with critical thinking, adaptability, and ethical reasoning. Accordingly, the literature highlights a range of teaching methods—project-based learning, experiential education, game-based strategies, and reflective assessment models—as essential to cultivating the competences necessary for executing CWE practices.

*Project-Based and experiential learning*

Project-Based Learning (PBL) is widely recognized as an effective methodology to enable interdisciplinary collaboration, critical thinking, and real-world problem-solving (Kirchherr and Piscicelli, 2019). Ab Hamid et al. (2024) explore dominant pedagogical approaches in Malaysian institutions, identifying project-based and case-based learning as prevalent. Podgórska and Zdonek (2024) underscore PBL's role in integrating sustainability into higher education by actively engaging students in complex design, decision-making, and research processes. Their research found that indeed, most teamwork at the polish university, was interdisciplinary teamwork with two or more different academic backgrounds. Some projects also involved collaboration with expert from business and industry.

The paper of Leung et al. (2024) contest design and systems thinking instruction, which as they often relies on standardized steps and tools. Many short modules or crash courses overly emphasize tools and procedures while neglecting the deeper values, mindsets, and adaptive qualities at the heart of design and systems thinking.

As a result, they argue, students often struggle to conceptualize and transfer these "thinkings" to other, more complex contexts. As alternative they present a first-year engineering project-based course, intentionally avoids overly strict and conventional approaches. The course follows a three-phase model designed to cultivate mindsets through experiential learning. Each phase focuses on a different domain—design, systems, and integration. Integration is argued as most important to encourage students to develop insights that are transferable to real-world applications. The framework draws on principles from Experiential Learning Theory (ELT), which posits that learners gain knowledge most effectively through active engagement and reflective observation (Kolb, 1984 cited in Leung et al., 2024). Leung et al. (2024) noted that research findings support the use of ELT in engineering education, showing it promotes hands-on learning, improves problem-solving skills, and enhances long-term knowledge retention by linking theory to action.

In parallel, the course design is also rooted in constructivist principles, which hold that learners build new knowledge by integrating it into their prior experiences and mental models (Piaget, 1973 cited in Leung et al., 2024). Leung et al. (2024) argue that such education allows learner-centred instructional design, "where students can construct their own understanding from their learning experiences". This setup allows students to co-construct understanding through interaction with both their peers and real-world challenges. This approach supports the development of flexibility, pattern recognition, iterative learning, and critical systems thinking—skills that are directly needed for circular water management and sustainability challenges more broadly.

Similarly, Oyewo et al. (2022) present a compelling case of PBL in a chemistry course where students designed natural water coagulants as example of nature-based solutions. By addressing a real-world water quality issue through interdisciplinary problem-solving, students developed scientific knowledge alongside societal awareness, illustrating how environmental, technological, and ethical considerations intersect in CWPs.

*Educational approaches to enhance water literacy*

Several studies suggest that experiential, interdisciplinary, and context-specific methods are most effective for building water literacy: Imaduddin and Eilks (2024), which identifies a growing but fragmented body of educational research on water literacy. call for more integrative pedagogies that adapt to local contexts and connect water issues to learners' everyday experiences. They emphasize the importance of embedding circular thinking within broader sustainability education. Socio-scientific reasoning: Owens et al. (2020) explored how structured reasoning around water-related socio-environmental dilemmas can deepen students' understanding of hydrologic systems and their societal relevance. Citizen science in schools: Ceccaroni et al. (2023) demonstrated how hands-on, inquiry-based approaches (such as water sampling and environmental monitoring) can enable engagement and knowledge retention in younger learners. Flipped learning models: Moreno-Guerrero et al. (2020) found that active learning strategies, where students engage with water topics through pre-class materials and in-class discussions, significantly improve comprehension and critical thinking.

*Interactivity, games, and simulations*

Several studies highlight the power of game-based learning and interactive tools for teaching complex systems and circularity. De la Torre et al. (2021) highlight the value of simulation games in teaching CE and sustainable energy, showing they boost student engagement and help explain complex feedback loops—though additional guidance may be needed for abstract concepts. Lange et al. (2022) similarly found that game-based learning improves understanding of resource loops and sustainability trade-offs. Their games were integrate real-world dilemmas, requiring players to balance environmental, economic, and social considerations. By simulating stakeholders with differing priorities, such as investors, consumers, and regulators, students experience the complexity of circular transitions, gaining practical insight into negotiating competing interests across the value chain. These examples are not specific to the water sector in the game itself, but the types of complexities, trade-offs and stakeholder dynamics modelled circular practices and can provide an inspiration for circular water management, as case games and examples can be translated to the water engineering context.

Khoury et al. (2023) and Evans et al. (2023) provide a water-specific example through their development of the NEXTGEN serious game, which introduces players to CE principles within the urban water cycle. The game is designed to help users deal with the trade-offs and benefits of CE solutions by illustrating the interconnections between water systems and other factors such as energy use, material recovery, environmental impact, and costs. It responds to the need for a holistic understanding of how circular principles—reducing waste and pollution, reusing materials, and regenerating natural systems—apply to urban water cycles, including stormwater intake, groundwater use, conveyance, treatment, and discharge. Unlike other serious games that mention water in passing, NEXTGEN uniquely allows players to explore how specific components such as household reuse systems, wastewater treatment technologies like biogas generation and sewer mining, and nature-based solutions impact water quality, energy consumption, and emissions. The game aims to raise public awareness, enable systemic thinking, and promote debate through a pedagogically grounded method rooted in constructivism, experiential learning, and the Socratic method of inquiry. Participants begin with limited knowledge and must hypothesize initial strategies to improve their CE Score. They are gradually introduced to concepts across five hybrid learning stages while exploring realistic challenges such as rainfall, population growth, and the financial and environmental dynamics of water systems. The three core learning goals are: understanding the urban water cycle, assessing the influence of external factors, and identifying effective actions to reduce stress and promote circularity. The game has proven to be engaging and impactful in classrooms and public settings, helping sensitise policymakers, businesses, and citizens to climate-related water issues. It has also shown unexpected value as a debate facilitation tool, bringing multidisciplinary perspectives into discussions—for instance, around the potential of metal-mining wastewater to reduce exergy use and carbon emissions.

The study by Kioupi et al. (2022) highlights the effectiveness of active learning, including serious games and project-based learning, in enabling essential sustainability competences. The use of self-assessment questionnaires and reflection sessions enables students to evaluate their competence development and connect learning to real-world contexts, enabling self-awareness and transformative learning. Moreover, the study underscores the value of working in heterogeneous, interdisciplinary groups. By integrating digital tools and game-based learning experiences, such teaching pedagogies help students engage with complex systems and develop practical skills that are crucial for sustainability. Ultimately, these approaches align well with the need for interdisciplinary, action-oriented education in the CWE.

Whalen et al. (2018) similarly found that simulation games helped students understand the roles of diverse actors and the business strategies central to material sustainability. Such lived-experience learning contributes to deeper engagement and cognitive retention by mirroring real-world decisions. Deda et al. (2022) explore educational contests as an innovative teaching method to raise awareness and motivation. In their case study, students participated in a contest that required them to propose and design sustainability-focused solutions, allowing for creative expression and critical engagement. The contest format encouraged competition and provided students with a platform to showcase their ideas, and that visibility made them more engaged and enthusiastic. Increased exposure not only boosted motivation but also enabled a stronger sense of ownership and pride in their learning. However, the authors caution that while contests can successfully generate initial enthusiasm, they should be supported by deeper instructional content and guided reflection to ensure long-term learning gains and avoid superficial engagement with complex sustainability concepts.

*Transformative and constructivist pedagogies*

As established in the previous section, CE education goes beyond the mere transmission of knowledge. Drawing on the work of Sterling (2011), Scalabrino et al., (2022) advocate for transformative pedagogies that enable learners to examine their assumptions and worldviews. This type of learning moves from information transfer (first-order learning), to the questioning of assumptions (second-order), and finally to fundamental shifts in perspective (third-order). Such pedagogical strategies are particularly relevant for addressing sustainability challenges, including those within the CWE, where learners are required to engage with new levels of complexity, navigate uncertainty, and confront ethically ambiguous situations. Scalabrino et al. (2022) identify a range of methods to support transformative learning, including "adaptation, pre-conceptions and conflict with new knowledge; action-reflection oriented learning; values clarification and feelings mobilisation; continuous evaluation and feedback; systemic view from local to global, and across past, present and future; complexity, uncertainty, and critical thinking; seeing the interconnections between socio-environmental-economical-cultural challenges, personal daily choices, and individual values and interests. In the business context, this includes recognizing the links between global challenges, business risks, and sustainable solutions; action research; problem-solving, change, conflict management, and collaboration; emphasis on promoting empathy and facilitating the recognition of others' and one's own perspectives; and reinforcing motivation to inspire action and leadership".

The methods mentioned by Scalabrino et al., (2022) engage both affective and cognitive dimensions of learning, prompting students to connect personal values with systemic environmental challenges. The authors further argue that education should produce not just knowledge, but wisdom. They stress that meaningful learning happens when students can relate new concepts to existing experiences, and so building long-term understanding. They critique environmental education that treats students as blank slates and call for constructivist pedagogies that draw on learners' prior knowledge. Such approaches allow learners to reflect critically, think independently, and integrate sustainability values into their identity.

Lally and Forbes (2020) demonstrate that systems thinking can be effectively developed through scaffolded instruction, model-building, and iterative feedback. Students progressed from simple water cycle representations to more complex socio-hydrological models, helping them identify feedback loops, unintended consequences, and systemic interactions. Visualizing systems eased cognitive load, and tools that allowed rapid modification of components and interactions enhanced understanding. However, students tended to focus more on system components than on underlying mechanisms or patterns, and prioritized problem identification over recognizing unintended effects. More scaffolded instruction is needed to deepen their awareness of feedback and long-term impacts. The study also found that students who critically evaluated their model limitations performed better in written assignments. Finally, systems thinking supported students' understanding of personal responsibility in water use, encouraging reflection on human roles within socio-hydrological systems as future decision-makers.

Kirchherr and Piscicelli (2019) emphasize the importance of non-dogmatism in enabling critical thinking within the context of ECE. By introducing both the strengths and challenges of the CE concept, the aim is to encourage students to reflect critically on the topic, avoiding rigid adherence to fixed beliefs or ideologies. Non-dogmatism, as advocated in their approach, promotes an open-minded attitude that welcomes diverse perspectives, new ideas, and alternative solutions. Rather than becoming “overly committed to unrealistic optimistic win-win scenarios that might be unrealistic or to all-down skepticism”, (Kopnina, 2017, as cited in Kirchherr & Piscicelli, 2019) students are encouraged to engage in balanced, critical thoughtful analysis.

Kopnina (2022) advocates for the inclusion of posthuman ethics in CE education and introduces a new pedagogical approach based on ‘post-qualitative inquiry’. Such analysis emphasizes “thinking with theory” (Jackson & Mazzei, 2017, as cited in Kopnina, 2022). This pedagogical approaches offer alternative ways of learning “for and about circularity”, seeing, thinking, and engaging with the world at the level of ontological imagination (Kopnina, 2022), thereby encourages educators to move beyond anthropocentric frameworks and incorporate ethics-based, reflective inquiry. This approach encourages students their critically thinking through engaging with case studies, as data, in ways that challenge and refine theoretical assumptions. For instance, by questioning whether the CE is truly feasible, realistic or desired (Kopnina, 2022).

*Integration of real-world contexts*

Despite the growing emphasis on experiential education—and the demonstrated need for real-life interaction as discussed in the Stakeholder Engagement and Real-World Interaction section—several authors critique the insufficient integration of real-world scenarios into sustainability and CE instruction, even though such integration is vital for meaningful learning. Garito et al. (2023) highlight the lack of mechanisms connecting classroom learning to policy and environmental challenges. Mbavarira and Grimm (2021) further emphasize that water utilities and professionals must be trained not through linear project models but through systemic, strategic approaches that reflect institutional, governance, and ecological complexities.

Mendoza et al. (2019) propose a whole-institution model where campus operations itself are included as case studies. Integrating operational practices into curriculum allowed students to directly apply circular thinking to their surroundings, deepening their understanding of sustainability at both practical and conceptual levels. For example, Whitehill et al. (2022) demonstrate how a real-world collaboration between design students and a manufacturing partner led to tangible CE innovations and practical learning experience. Similarly, Murray et al. (2023) describe a one-year doctoral program where students worked on real-world, interdisciplinary projects with guidance from faculty and non-academic stakeholders. Their assessment emphasized communication skills, team-based problem-solving, and practical impact.

Zhan et al. (2023) differentiate between “close” and “remote” association interventions to stimulate creativity. Close associations link related ideas, like connecting “river pollution” with “water filtration,” reinforcing existing knowledge and supporting structured problem-solving. Remote associations, on the other hand, involve combining distant or unrelated concepts. For example, students in a role-playing simulation with stakeholders (e.g., farmers, policymakers) negotiate water reuse in a drought-affected region. Using both types of associations, students develop novel solutions (e.g., linking "music festivals" with "greywater reuse" for temporary sanitation) while mapping perspectives through empathy tools to enhance design and systemic awareness. The study found that remote associations enabled more original solutions, while close associations built confidence in technical tasks. These strategies are crucial in CWE education, helping students build expertise and generate creative, cross-disciplinary solutions.

*Addressing Assessment*

When the fundaments of teaching change (transformative; constructivist, experimental learning), assessment practices must align with those new pedagogies. Lally and Forbes (2020) show that students’ ability to articulate the limitations of their systems models correlates with higher performance, underscoring critically evaluating a model’s constraints, unintended consequences, and complexity encourages critical systems thinking. Kirchherr and Piscicelli (2019) propose core pedagogical principles for CE education, including constructive alignment, problem-based learning, interactivity, non-dogmatism, and reciprocity. These principles suggest that assessment should not aim to measure one correct solution but rather evaluate how students navigate ambiguity, integrate perspectives, and justify their decisions. The course was structured around four main components: introduction, applied theory, practice, and conclusion. The applied theory and practice sections were explored across three levels—micro, meso, and macro—based on the spatial differentiation of the CE as outlined by Fang et al. (2007, p. 316, cited in Kirchherr and Piscicelli, 2019). According to this framework, the CE operates across three distinct levels. At the macro level, it focuses on reshaping industrial composition and overall structural adjustments. At the meso level, it emphasizes the application of industrial ecology principles. At the micro level, the CE aims to ensure that individual business identify and make effective use of by-products. The educational approach was grounded in problem-based learning theory (Duch et al., 2001, cited in Kirchherr and Piscicelli, 2019), emphasizing collaboration in small groups to solve complex, real-world problems with opportunities for formative feedback. Additionally, the course introduced seven new interactive, game-based exercises: a drill game, buzzword bingo, a teardown lab, an eco-industrial park simulation, policy instruments, circular party, and circular futures. A field trip to BlueCity in Rotterdam—a co-working space for circular start-ups—was also included to provide practical, real-world insights.

Owens et al. (2020) introduce Social-Scientific Reasoning (SSR) as a powerful pedagogical and evaluative framework. SSR includes five key practices: recognizing complexity, considering multiple perspectives, valuing ongoing inquiry, scepticism of sources, and evaluating both scientific and non-scientific considerations. These align closely with the literature already discussed and summarize teaching method needed for prompt CWE thinking.

*Conclusion*

Effective teaching and assessment for ECE must transcend traditional, siloed instruction. The literature emphasizes project-based, experiential, and transformative learning as central to cultivating the skills required for sustainability: systems thinking, interdisciplinary collaboration, ethical reasoning, and adaptability. Assessment strategies should emphasize reflection, problem-solving, and stakeholder negotiation, encouraging students to think critically and act responsibly in the face of complexity and uncertainty. By aligning pedagogy with the dynamic and multifaceted nature of circular water systems, educators can better prepare students to become agents of systemic change.

*Table 8 Teaching methods for prompting systemic, interdisciplinary and reflective practices*

| | Subject | Key Insight | Reference |
|---|---|---|---|
| 1. | Project-Based/problem-based learning | Project-Based Learning (PBL) is an effective methodology for enabling interdisciplinary collaboration, critical thinking, and real-world problem-solving. It enables the integration of sustainability into higher education by engaging students in complex design, decision-making, and research processes. | Kirchherr & Piscicelli, 2019; Ab Hamid et al., 2024; Podgórska & Zdonek, 2024; Leung et al. (2024); Oyewo et al. (2022); |
| 2. | Field trips | Excursions bridge the gap between the university and 'outside' businesses and organisations. | Kirchherr and Piscicelli (2019) |
| 3. | Experiential Learning Theory (ELT) | ELT posits that learners gain knowledge most effectively through active engagement and reflective observation. | Leung et al., 2024 |
| 4. | Constructivist learning | Constructivist principles allow students to build new knowledge based on prior experiences, enabling learner-centred | Piaget, 1973; Leung et al., 2024; Kirchherr and Piscicelli (2019) |

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| | | instructional design that encourages flexibility, pattern recognition, and critical systems thinking. | |
| 5. | Socio-Scientific Reasoning (SSR) | SSR involves structured reasoning around water-related socio-environmental dilemmas, enhancing understanding of hydrologic systems and their societal relevance. | Owens et al., 2020 |
| 6. | Flipped Learning Models | Flipped learning, where students engage with materials before class and discuss in class, improves comprehension and critical thinking on water topics. | Moreno-Guerrero et al., 2020 |
| 7. | Transformative learning | Transformative pedagogies or non-dogmatic approaches move students from information transfer to critical reflection and fundamental shifts in perspective, which is crucial for addressing the complexities of circular water management. | Scalabrino et al., 2022; Kioupi et al. (2022); Kirchherr and Piscicelli (2019) |
| 8. | Scaffolded instruction, model-building, and iterative feedback | Gradually increase the complexity of tasks and reduce the level of assistance as students become more capable and confident in their learning. | Lally and Forbes (2020) |
| 9. | Visualization and interactive tools | Visualizing systems eased cognitive load. | Lally and Forbes (2020) |
| 10. | Posthuman Ethics | Posthuman ethics challenges anthropocentric frameworks, encouraging reflective inquiry and critical engagement with the CE's feasibility and desirability. | Kopnina, 2022 |
| 11. | Interactivity, Games, and Simulations | Game-based learning and simulations, such as the NEXTGEN serious game or contest-based learning, are effective in teaching CE and urban water cycle principles, allowing for interactive exploration of complex systems and stakeholder dynamics. | Deda et al., 2022; De la Torre et al., 2021; Lange et al., 2022; Kirchherr & Piscicelli, 2019; Khoury et al., 2023; Evans et al., 2023; Whalen et al. (2018) |

| | | | |
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| 12. | Active-learning pedagogies | Hands-on, inquiry-based teaching strategies actively engage students in the learning process through activities like discussions, problem-solving, and collaborative work, where learners explore real-world problems, experiment, and engage in critical questioning and problem-solving. | Kioupi et al. (2022); Ceccaroni et al. (2023) |
| 13. | Integration of Real-World Contexts and case-based learning | There is a need for greater integration of real-world contexts, such as campus operations or collaboration with external stakeholders, to bridge the gap between classroom learning and real-world environmental challenges.. | Ab Hamid et al. (2024); Garito et al., 2023; Mbavarira & Grimm, 2021; Mendoza et al., 2019; Whitehill et al. (2022); Imaduddin & Eilks, 2024; |
| 14. | Interdisciplinary Instructional Models | heterogeneous Group work, Interdisciplinary mentor groups in graduate education promote innovation and integrative thinking, bridging gaps between disciplines, “close” and “remote” association interventions | Kioupi et al. (2022); Xia & Peng, 2022; Murray et al., 2023; Oyewo et al. (2022), Zhan et al. (2023) |

# 4 Empirical Results

As one participant observed about CE, "not getting it done is even more complicated" - (Participant 2 – 24.55).

This chapter presents the findings from a thematic analysis of 10 expert interviews on education for the CWE. In line with qualitative reporting guidelines, each of the 5 key themes is addressed in turn, with illustrative quotations. From our interviews, 5 major themes emerged:

(1) Technical Knowledge;
(2) Systems Thinking & Complexity;
(3) Interdisciplinary Collaboration & Communication;
(4) Transferable Skills, Critical Thinking & Reflective Practice.
(5) Active/Experiential Learning Strategies

These themes represent core dimensions of knowledge theme, skills and competencies and effective didactics and pedagogy for circular water systems. The remainder of this chapter examines each theme in detail with supporting evidence and interpretation. Sub-themes are highlighted in bold and participant quotes are presented in italics to enhance readability. The overview of sub-themes with their description and example quotes are found in Appendix C.

## 4.1 Technical knowledge

Most educator interviews, and especially all case study holders, emphasized the critical importance of a strong **foundation in engineering** for students involved in circular water management. When asked about the skills and competencies water engineers need, the majority of interviewees prioritized specialized knowledge in water technologies. As one participant put it, "Good fundamental knowledge is crucial to understand the complexity of technology development" (Participant 6), similarly another stressed the need for "good knowledge of basic process engineering mathematical tools" (Participant 1 – 12.06).

In addition to foundational engineering skills, participants identified **key content** areas around which CWE should be organized, such as water reuse, emerging pollutant removal, nutrient recovery, and wastewater treatment plant design, water pinch analysis, ecotechnologies, nature-based solutions, industrial symbiosis, resource production within water treatment plants, and the focus on the water–energy–materials nexus. These concepts already show the interdisciplinary character of CWPs, encompassing biology (e.g., microbial community understanding), chemistry (e.g., green chemistry), and agricultural sciences (e.g., using wastewater to irrigate land while purifying it). These technological practices vary in their levels of development and maturity, but their technical advancement is not the most challenging aspect.

## 4.2 Systems thinking & complexity

Building on the prior theme, this section explores in more depth a systems-thinking approach that allows student to understand the broader context in which technologies are implemented. It involves understanding dynamic interactions between ecological, technological, economic, and political systems. However, one participant reflected that: “The implementation of these techniques [CWPs] is very complex. People often lack the skills for it” (Participant 4 – 41.28). Another engineer pointed to their own experience during execution of water reuse project: “We didn’t have that systems thinking from the start... that was a big limitation” (Participant 8). These reflections indicate a gap in current professional preparation for managing circular water challenges at the systems level.

Nevertheless, what the concept of CWPs binds is the integration of knowledge. **Integrality** was mentioned often by the participants. As one participant mentioned: “The realization is that by implementing different circular practices you have impact on other systems” (Participant 7). This integrality underpins the necessity for industrial symbiosis, as it encourages students to see how technologies, industries, and resources are interconnected within circular systems. Industrial symbiosis is a great way to establish the CE on a technical level where water, as transport medium, is essential to do so “Water is an ideal way to make connections between companies, often also the basis of industrial symbiosis” (Participant 3 - 3.32), and water “restore[s] elements that can be used in another industrial process” (Participant 9).

However, several participants noted that many promising circular initiatives remain trapped in the pilot phase, often due to policy constraints rather than technical shortcomings. “Many current circular projects... stay in pilots... and break down in scaling up, because the policy doesn’t allow it” (Participant 4 – 43.43). This highlights that the context or system in which a technology operates matters greatly, whether political, legal, social, economic, or environmental. Each discipline offers a different lens through which to interpret and respond to complex challenges. For instance, varying climates require different technical solutions, distinct institutional frameworks demand tailored policies, and diverse cultural settings call for adapted communication strategies. This insight connects to a broader challenge recognized in political science and captured in the concept of **policy mobility**: the understanding that technologies and policies are embedded in specific sociopolitical and institutional contexts. When transferred to new settings, they cannot simply be copied and pasted; instead, the receiving system must be carefully considered and adapted to. As participants noted, policy frameworks are not easily transplanted because they are shaped by the context in which they were created: “The technology was developed in a certain context, and the policy around it too.... You can’t copy one to the other purely because of the context” (Participant 4).

To help students navigate such complexity, several interviewees emphasized the importance of **layered thinking**—recognizing multiple system dimensions: physical, technological, behavioural, market, and regulatory. As one participant explained, “There’s a physical layer, a design layer, then a market layer, behavioural layers, regulation layers... So you realize you can design on different layers” (Participant 3 – 8.42).

The same participant added, “If you redesign the system, it results in new products, processes, and new chains” (Participant 3 – 10.42). Crucially, participants stressed that system redesign must involve engaging stakeholders across all these layers: “you have to speak to stakeholders at all those different layers” (Participant 3 – 11.48), in order to have your project successfully executed. “technical redesign does not mean at all that you will actually change behaviour or that you will actually create a different economy” (Participant 3 -8.42). This quote illustrates a **core systems thinking principle**: interventions cannot be isolated from the system they are implementing. What may appear as a sustainable solution at one level can create mismatches or inefficiencies at another. Addressing this requires designers and engineers to see beyond their immediate scope. As one participant articulated, “That is exactly the layer of discussion you have in a complex system. You redesign technology or choose different materials, but assume people will automatically live, think, and consume differently. That’s not the case. You have to redesign those social systems too. That’s the first layer—that's the systems layer” (Participant 3 - 9.29).

Another interviewee showed how such system layers also cross different sectors and domains and form **nexuses**, reusing wastewater may reduce water consumption but raises questions for other sectors like energy: “If you implement circular practices in the water sector—like recovering and reusing wastewater—what does that imply for energy demand, for example?” (Participant 7 - 1.44). Ultimately it comes down to “The realization is that by implementing different circular practices, you impact other systems” (Participant 7). And thus CWPs need to allow diversity of solution: “It's never gonna be like petroleum... one solution for all” (Participant 6 – 18.42).

When participants were asked about the specific role of education in establishing a systems mindset, they frequently referred to the importance of developing the skill of zooming in and out. Students need to be taught how to “take a step back” (Participant 6 – 7.55), “to think of all that as a system rather than as independent blocks” (Participant 7 – 10.57), and to “be aware to looked at the connectivity between different technologies” (Participant 8 – 17.45). Another participant argue the need to “see where the trade-offs are happening... and not just stay in your little box... you need to think a bit bigger” (Participant 7). In other words: to develop this kind of thinking, participants highlighted the need for education to train students to see **interconnections**, and shifting from viewing practices as isolated blocks toward understanding their interdependencies.

Besides, when you design for a system that is more circular and therefore more connected it create new complexities on all dimensions of a system. As one engineer noted, “Management capability and problem-solving skills become much more relevant, because the failure of one unit can disrupt the entire system” (Participant 1). Instructors should support students in developing the ability to build mental and visual models of circular systems, recognize dependencies across domains, and understand how interventions in one area may shift burdens or benefits elsewhere in order to increase their ability for problem-solving skills. These observations point to a set of key learning methods such **as systems mapping, scenario analysis, and trade-off evaluation**.

Multiple example of **trade-off** were discussed that might be interesting for cases when teaching CWE: water quality standards versus greywater reuse ("What do you take as a standard for our water quality?" – Participant 2), sustainability versus investment cost ("The initial investment can only be justified by long-lasting, continuous operation" – Participant 1), and the level of interdisciplinarity in educational preparation ("Generalists are as needed, but specialists are crucial" – Participant 6). Besides the approach to deal with such trade-offs is questioned too. Rather than seeking perfect solutions, one participant suggested the need to aim for **workable compromises** that reflect the priorities and constraints of different stakeholders: "Everyone talks about optimizing these trade-offs, but they don't really exist. You can optimize for one, but then another loses. What I try to do is find a compromise—something that may not be optimal for everyone but still works" (Participant 7 - 13.22).

Engaging in such compromise-driven discussions requires clarity about the **boundaries of the system** in question. Participants emphasized the need for engineering students to recognize the characteristics and openness of the systems they work with. As one raised the example: "To what extent is this a closed system or an open system? Around water and nutrients, these systems are very open. Completely different influences go in and out. If you're talking about plastic bottles, that might be a fairly closed system" (Participant 4 – 41.28). This distinction is crucial, as open systems are inherently more complex, shaped by a wide range of external inputs and interactions that must be accounted for in both design and decision-making processes. Systems thinking equips students and practitioners to embrace this complexity, navigate trade-offs, and design solutions that are adaptive, integrative, and fit for a circular future.

## 4.3 Interdisciplinary collaboration & communication

A recurring theme across the interviews was the recognition that circular water challenges inherently span multiple domains, including engineering, ecology, economics, sociology, and policy, and therefore demand interdisciplinary collaboration. Many of these disciplines were already mentioned. While the first theme discussion focused on the technical dimension of circular water systems, participants repeatedly emphasized the necessity of integrating additional perspectives. The three main perspectives that were discussed during the interviews included the economic, environmental and social/political one. A central insight across the interviews was that the technical ambitions are directly entangled with **economic** realities. Which leads to the issue of market uptake as a practical barrier to systems implementation. Even if nutrients can be recovered from wastewater, treatment plants are rarely equipped to function as market actors "Managing logistics, guaranteeing quality, and marketing those products is incredibly complex for a treatment plant operator" (Participant 7 – 13.22). Other participants underlined that in the current system the economic viability is not just a constraint, but often the determining factor: "the economic side of things, the market economic side of things I believe is very critical to be part of those [CE] projects, because if there's no market for it, well, you can produce as much as you want. You're not going to sell it" (Participant 8 – 10.10). One participants also noted that the economic perspective is highly relevant in designing your technology, when aiming at "a fully integrated circular scheme, the complexity of the process arises. And also the capital cost increases because you want to produce everything you need on site. And this leads to a much larger investment, initial investment that has to be justified only by long lasting operation of the continuous process" (Participant 1 – 5.58). Even when environmentally sustainable alternatives are available, financial logic still prevail in the current capitalistic system: "Ultimately, the finance side of things will dictate the answer at the end, because if they [industry] can do something sustainable but it's going to cost them a lot of money and then they will not do it" (Participant 8 – 14.38).

**Environmental** considerations also formed an important bases for discussion. As one participant observed, "We all should realise our ecosystem services are very important and we are very dependent on ecosystems for our services, but not a lot of people are concerned about ecosystems health" (Participant 6 – 15:44). Another participant noted: "some governmental support should be in place to ensure the safety of the environment, the ecosystem, the people, the animals, everyone" (Participant 11 – 6.45). This environmental perspective also showed that, outcomes are often system-wide and demand long-term thinking, which challenges short-term economic or operational goals. Therefore one participant mentioned realisation for students to be "responsible for managing the whole system" (Participant 7 – 6.19), reinforcing the need for cross-domain coordination.

Besides, as the system theme already showed, the **socio-political dimension** emerged as another crucial layer of system complexity. One participants highlighted that in any transition, practices, circular or not, can produce uneven impacts: "there is a group that benefits from it and a group that benefits less, there are winners and losers" (Participant 4 – 27.41). This reality makes idealistic claims of "win-win" outcomes suspect: "So when people talk about win-win situations, you have to be suspicious in itself, because they are trying to sell something" (Participant 4 – 27.21). In fact, system changes often disrupt existing power dynamics and forces the question: "What does this technology do, but also does it change the system...the status quo?" (Participant 4 – 27.21). Technological solutions can inadvertently reinforce inequality: "Maybe their application worsens the improvement that is proposed in a better environment or a safer food system can mean a deterioration for a group of people who were already not doing well. And that those who were already better off will get it even better.. And those who had it bad get it even worse" (Participant 4 – 29:51). This links to deeper institutional dynamics: "Those who already have power, also have the ability to get things done that is in their interest, making them even more powerful" (Participant 4 – 31.06). CWPs may not offer immediate benefits for everyone, making it important for students to critically examine their social and political impacts in order to support a just transition.

These examples of different disciplinary perspectives demonstrate that the CWE can be approached from multiple angles—each bringing its own challenges, assumptions, and potential solutions. As one participant noted: "There are just a whole bunch of issues where we really need all those perspectives" (Participant 2 – 10.55). To effectively navigate the accompanied complexity, students need to develop the capacity to engage with and integrate diverse forms of knowledge and become **interdisciplinary** trained: "You need decision makers. You need communities, you need professionals, you need operators. You need, everyone who's part of this [reuse wastewater for agriculture use] supply chain" (Participant 11 – 9.04). Another participant emphasized the need to ensure "team composition represents those different types of knowledge domains" (Participant 3 – 12.23). To adjust CWPs to 21-century problems: "We have to combine forces because usually the bottleneck that everyone sees his sector or subject as most important" (Participant 11 – 9.43). Besides, one participant emphasized the importance to notice that no single discipline holds “the absolute truth” when it comes to addressing such complex issues (Participant 4 – 17.17). This understanding is critical not only for solving technical problems but also for equipping students to work effectively in real-world contexts.

Nevertheless, several participants observed that, many project teams still lack disciplinary diversity. Most teams consisted entirely of engineers, with only one case including a social science (and even then, only toward the end of the project). As this participant admitted: “We assessed the social sciences, without knowing what we were doing…things have changed a little bit, so for future projects, we're working differently on that” (Participant 9).

Importantly, interdisciplinary collaboration was seen as a way to expand professional awareness and responsibility beyond one’s immediate technical role. This is especially true outside of academic settings, in the real-world, where interdisciplinary work becomes even more complicated: “It's a completely different ball game. Because you're not all studying for the same degree, you're work in different companies and different sectors, different industries. You have other commitments. It's very difficult. It's very intensive. It's very challenging to get these processes to work and I think quite often the effort is underestimated” (Participant 7 – 2.17). Moreover, while the value of interdisciplinarity was widely acknowledged, participants also questioned the ease with which it is pursued in practice, one participant asked “We’re all telling everybody, we should work more into interdisciplinarity… but what are you asking people?” (Participant 6 – 24.07), highlighting the often underestimated difficulty of navigating such collaboration. Interdisciplinarity was described not simply as desirable, but as essential to functioning within the complexities of circular systems. This goes beyond simple representation—it involves cultivating mutual respect and openness to other forms of knowledge: “Recognize that the other person's contribution is valuable” (Participant 1 - 4.48), and “keep in mind that you on your own can't give that last answer” (Participant 3 - 4.47). Another participant stressed, effective interdisciplinary practice with **stakeholders** involves building: “the relationship with the actors of the area, to understand what benefits this can bring to them, how this really fits into their operative life, and what they really need” (Participant 9). Through understanding other position and perspective, you can understand to deal with issues beyond your own daily responsibilities, instead of thinking “what happens over there is not my problem” (Participant 7 – 5.0). As modern challenges increasingly span multiple disciplines, stakeholders, and organizational levels, this shift in mindset is essential for addressing problems that cannot be solved by a single area of expertise alone.

This reflects the understanding that interdisciplinary collaboration depends on strong disciplinary anchors, brought into conversation through mutual respect and openness to learn. This attitude is important to be able to **communicate**, especially given the challenges of engaging across disciplines, each with its own specialized language and jargon. However, the same participant also notes that “people don't want to listen to each other, sometimes it's just literal, they can't listen to each other” (Participant 3 – 30.16). When individuals continue speaking from within their own disciplinary frameworks, using their own methodologies, assumptions, and worldviews, “then you don't have a common language”. For example, one participant notes the lack of interest to understand the other: “it was difficult to communicate because we were, let's say, more prone to discuss about technological matters. But our colleagues working on social aspects could not fully understand what we said or they were not even interested in listening to us talking about this technical aspects and the same on the other side” (Participant 1 – 28.22). Another participant highlighted the value of holding regular discussion meetings to enable a positive atmosphere and maintain effective communication within the team “rather than just being one way traffic of information of just the technical people” (Participant 8 – 26.53). Communicating across disciplinary boundaries requires more than simply sharing information, it demands the development of shared tools and language. As one participant noted, “What is important I think is that we come up with or develop together enough tools. So to really be able to do those cross-disciplinary insights” (Participant 3 – 30.16). Yet, interviewees cautioned against an overemphasis on **interdisciplinary/generalist knowledge** at the expense of technical or theoretical specialists knowledge too. As one participant observed, “If we are all focused on generalists and knowing from each other's discipline, then you might miss important aspects of your discipline in the discussion” (Participant 6 – 25.46) and “Interdisciplinary trained people should also recognize that we still need the monodisciplinary trained people” (Participant 1 - 3.57). For successful interdisciplinary collaboration it is important that participance that are involved bring their own experience as input and inspiration for discussion. This also accounts for on the education level, were classrooms are used to bring students with different experience together: “you will see how your colleagues are discussing and you'll see that guy or that girl is really specified on this because that's where they have the curiosity” (Participant 6 – 26.19). Moreover, to establish openness and respect in working together, students should be aware that “people are different. Some people are really good at being specialist. So I think that you should harvest that in a team and not make everybody be that generalist” (Participant 6 – 24.61). Teams, in this view, function best when they integrate both generalists (who can see connections across fields) and specialists (who bring detailed knowledge and methodological rigor). This part highlights the necessity of deep disciplinary training for meaningful interdisciplinary dialogue. Rather than viewing interdisciplinarity and specialization as opposing forces, participants argued for a balanced approach that values both.

Educators also have a role to play in preserving this balance. While interdisciplinary awareness is important, one participant argued that teachers must retain deep, subject-specific expertise: “You should have a certain knowledge of interdisciplinarity, but you as a teacher... should have real specified knowledge on the topic that is your topic” (Participant 6 – 25.17). When students are expected to engage with methods, theories, or practices from other disciplines, this often requires clear and honest expectation management. This becomes especially relevant when engineering students engage with social or philosophical topics, where there is no single "right" answer. As one participant put it, when students seek definitive solutions, they should be reminded: “you're not going to learn that” (Participant 2 – 33.25). One should find a balance within the education system to have interdisciplinary work within existing disciplines, teaching fundamental knowledge and having separate education which is focused on interdisciplinary work itself. However, as the gap analysis of current training curriculum showed, interdisciplinary education programs are more and more available, though the interdisciplinary courses within engineering education is lacking. One participant named the concept of co-ownership of courses with teacher from different background increased the interdisciplinary character: “Courses that we teach, we are very explicit in that there is co-ownership... people from different departments... a topic is approached from different academic disciplines” (Participant 4 – 15.37).

Besides, one other participant addressed the important topic of **multi-level** learning. Interdisciplinary teams do not always only exist of university/theoretical level educated people. Much of the theoretically calculated work need to be done by practical educated people, learning how to work together is really important to make the CWE successful "I actually find that fascinating that I never thought about it from the university's point of view. That is a way to not only think multidisciplinary, but also to think multi-level... certainly multidisciplinary should also be done, but sometimes the crux is even more that you put different levels" (Participant 3 – 20:59). If education integrates both theoretical and practical components, it can greatly support multi-level thinking. As one participant explained, "then multi-level can help enormously to put someone with a brilliant innovative idea with both feet on the ground and [question] how would you realize all that" (Participant 3 – 21.27). Also mentioned by some participants, the importance of having **junior and seniors** mixed "... or maybe even senior and junior together" (Participant 3 – 21.27). And another participant said: "it's nice to combine this seniors and juniors all the time because you learn so much" (Participant 6 – 28.01).

Water engineering education must therefore teach both domain knowledge and collaboration and communication skills. In practice, this means giving students a strong grounding in their home discipline while develop a generalist approach and creating opportunities for them to share knowledge in an interdisciplinary space when needed.

## 4.4 Transferable skills, critical thinking and reflective practice

Applying the CWP effectively requires more than just technical know-how, it also demands a **shift in mind-set**. As discussed in the former theme, many interviewees emphasized the need for students to adopt a systems-thinking approach that considers the broader context in which technologies are implemented. This also includes broader awareness of system-level demands and underscoring the need to reduce overall water consumption, reiterated that technology should only be applied when it is genuinely **sustainable**: "Use the technology where it is actually sustainable to use it" (Participant 6 – 18.15). The same participant gave the example of "The treatment of certain waste streams such as brine resulting from reverse osmosis also requires a lot of energy. When planning for such concepts their sustainability should be investigated for example using life-cycle assessments" (Participant 6). As others emphasized, CWE should be about "not depleting the water system" (Participant 1 – 2.31), and engineering can provide "the method to measure [how to] actually achieve that" (Participant 1 – 3.03). Though, one participant emphasized that water reuse remains difficult technology, stating, "It is not easy to make it safe. It is really not easy" (Participant 11 – 3.59), particularly in the context of emerging micropollutants, for which affordable treatment technologies are still lacking. Still, there was a shared concern that current approaches can be overly technocentric: "CE is very often just about technical redesign of products" (Participant 9 – 9.29), while **demand reduction** "should also be included" (Participant 7 – 7.58). Despite widespread use of the term sustainability, participants expressed concern that many so-called sustainable technologies do not truly meet sustainability criteria. One interviewee noted that many so-called "sustainable" technologies are not truly sustainable when examined at the systems level. "A lot of people talk about sustainability... but actually developing sustainable technologies is not something that is happening a lot" (Participant 6 – 4.19). The same participant continued by pointing out the danger of over-simplistic solutions:

"They [Students] come up sometimes with solutions like growing microalgae under artificial light... And then I'm thinking—what is sustainable about that? You need to have the whole picture", knowing that artificial light cost a lot of energy and in climate with less sun-hours other solution might therefore be needed. What is sustainable and work in one context or situation might not be in another. This sustainability perspective also includes a more philosophical shift: from viewing water merely as a resource, to seeing it as a vital part of nature. As one noted, "we should not see it [water] only as a resource... water is nature" (Participant 2 – 6.41). Another participant noted that global circularity is actually decreasing—only 6.9% of material is currently cycled back into the global economy, down from 10% (https://www.circle-economy.com/ ). "The ivory implies we're getting worse at circling stuff through the economy or [we're] just consuming a rate that's faster than is able to be recycled and circled through" (Participant 7 – 6.16). Such behaviours can create rebound effects, where gains in efficiency are offset by behavioural changes. For example, one participant noted that reducing water pressure led to longer showering time (Participant 2 – 6.06). However, as another participant noted, society might initially need to increase water consumption before achieving circularity: "You need to get over a kind of bump... use more water first and only then become circular" (Participant 3 – 2.58).

This underscores how CWPs requires a shift to **longer-term perspective**: "In 40 years, I will be completely circular in terms of my water consumption, but in the meantime, I have all this duplicate installation" (Participant 3 – 31.49). On the other hand, participants frequently criticized the short-term focus of current circular water policies. "The short-term character of policies... is something that should definitely have more attention" (Participant 3 – 3.20). At the same time, the long-term consequences of for example many emerging pollutants remain unknown: "We don't know the long-term consequences for a lot of that kind of waste" (Participant 4 – 25.28). This makes the chosen timeframe for measuring impact a critical element in any sustainability assessment. When aligning CE objectives with commercial stakeholders, this becomes even more clear. One participant shared: "Some companies came up and said this is not interesting to us, because this doesn't bring what we would like to have. So at that point you had to moderate this and try to convince them: okay, this is not a short-term gain, we're doing something for the long term" (Participant 9).
Another shift in mind-set that's needed for a CWE to happen, includes the essential idea that **waste is not to be neglected** but is a product that needs to be taken up in the regenerative material cycle. One participant for example clearly explained context of this shift: "Wastewater technology and even drinking water production—it's always been focused on human health. Wastewater technology appeared because pathogens in the water created a huge public health problem. A lot of people died and still nowadays a lot of people die due to poor sanitation. So it was only seen as: let's treat it to make it safe for us. CE is different. It leaves behind the idea of waste—you don't have waste, only resources. And of course, you try to bring these resources into our production system while creating a clean and safe environment" (Participant 6 – 9.59). This shift may even challenge existing assumptions about pollution. As one interviewee put it, circular water systems may "in some cases allow a certain pollution" (Participant 4 – 40.49), if it leads to a greater systemic benefit.

However, simply viewing waste as a resource, planning on long term and considering the level sustainability is not sufficient to drive a successful transition to a CWE. Some argue that a more fundamental shift in mindset is required, in order to recognise the value of water and to fundamentally integrate this in our societies. One participant argued that we should educated students also about **purpose economy**: “The base of the purpose economy is very much based on our values. And I think we need to have other values... it's not the financial gain for stakeholders, but it is actually a value to society” (Participant 6 – 32.10). This closely aligns with what the same participant mentioned, which is the need for a **product perspective** in society: “If we really want to have a circular water system, I think that we need to address it from a product perspective” (Participant 6). This approach involves asking new types of questions—such as “What do you actually need?”—rather than focusing solely on what can be produced. The emphasis shifts from innovation for its own (market) sake to innovation that aligns closely with the actual needs of society. This requires recognizing the diversity of social activities, behaviours, and interactions, and developing solutions that are more tailored and context-specific. As an example, the same participant referred to the development of customized fertilizers. They noted that each species has unique nutritional requirements and absorbs nutrients in different ratios. Standard fertilizers often do not match the uptake capabilities of either the soil microbiome or the crops themselves. Therefore, a one-size-fits-all solution is not effective, and a more diverse and specialized one is needed.

These reflections show that **CE thinking** requires a fundamental shift in thinking how students (and professionals) understand and approach current water systems. “Technology alone will not solve circularity”; instead, a “change in mind-set” (Participant 6) is essential. This shift toward circularity entails moving beyond linear, extractive models toward systems that prioritize reuse, regeneration, and interconnectivity. As one participant noted: “Engineers... think very linearly from a problem to a solution to implementation” (Participant 4 – 26.09). And as long as the: “Scientific communities are still being seduced, mostly by engineers” (Participant 4 – 26.09), this linear mode of thinking will continue to dominate.

Promoting circular thinking within engineering disciplines is therefore especially important. This observation doesn't frame linear thinking as inherently flawed, it remains essential for addressing well-defined technical challenges. Rather, the issue arises when this mode of thinking is applied uncritically to complex, system-wide issues. Circular innovation often fails not due to technical limitations, but because of the broader operational complexity involved in scaling, adapting, and embedding new solutions: “the problem is not with the technology” (Participant 4 – 26.04). For engineering students in particular, this underscores the need to recognize that they are operating within systems that require fundamental structural and cultural change in order to become circular and sustainable. Embracing circularity means developing a new mindset, one that is context specific, sustainable, circular and sensitive to interdependencies. Participants emphasized that it is “a real different mindset”, marked by a “willingness to change business as usual” (Participant 6 – 7.55), importantly, students need to: “think differently to be able to do that” (Participant 6 – 7.55). Which also asks from the teacher position to show this change in thinking and encourage: “a broader view of what's possible already... and creating that switch in people's minds to start thinking a bit differently” (Participant 8 – 33.14). As another participant put it, this shift raises the question in both educational and professional contexts: “to what extent can learning be stimulated”, given the example of “policy processes must be shaped by learning too, instead of [being] directive right the first time” (Participant 4 – 46.54). This shift embracing principles of resilience thinking. As one participant said it: “When you start, you have an idea of how it should end, and often we try to stick to that. But circular thinking requires letting go of rigid plans... It's not about preserving the original idea at all costs, but about integrating new conditions as part of the process" (Participant 9). Thus circular thinking is about the process - the iterative process of designing and learning.

Another recurring theme across interviews was the importance of cultivating **critical thinking**. Critical thinking was described as essential transferable skill to navigating trade-offs and understanding complex systems such as CWE. We already saw with examine the sustainability level of CWPs asks for a critical mind. As one participant suggested, students should dare to: "think a bit more in depth about the different issues and how they're related, how they're not" (Participant 7 – 22.57). In addition, participant emphasized the importance of critically engaging with the policy dimension when implementing circular water technologies. And in doing so, reflect on the question: "Is there learning from a question, or is there guidance from another stakeholder?" (Participant 4). This is evident, for example, in the recognition that the transition to a CWE can be hindered by conflicting interests, as: "not every stakeholder therefore has an interest in the circular system" (Participant 4 – 34.06).

Critical thinking is closely intertwined with **reflective thinking**, which emerged as well a major theme in participant discussions. Learning itself becomes an object of inquiry—not just what to learn, but how to continue learning throughout professional practice in order to inform policy-making, decision-making, and design processes. This perspective shifts the focus toward lifelong learning as a necessary competence for engaging with complex and evolving challenges. Another participant named self-criticism indeed as important skill that is already prioritised at the master level education "Self-criticism, because I think that is one of the most important skills you ultimately have from a university graduate" (Participant 3 – 37.30). They elaborated that this skill allows individuals to acknowledge when they are on the wrong path and central to professional life: "I'm really kind of on the wrong path there. Now I'm going to try something completely different and that you do it in a professional way. That's the only way, I think, to be able to have a conversation at all about something as sometimes quite elusive as transitions" (Participant 3 - 37.49). Reflection also played a key role in group dynamics and team learning. Some programs included structured sessions where student teams periodically discussed group dynamic, communication, presentation and reviewed each other's contributions. One participant underscored the value of such peer interactions: "Transferable skills discussion to ask so at least to say let's look at each other again, how are you doing in terms of group dynamics, have you looked closely at each other's skills, but also at each other's personalities, is that a topic of conversation?" (Participant 3 – 35.43). Participants emphasized that enabling this kind of reflective thinking requires creating conditions in which students can step back, take time to process, and critically engage with what they encounter, shifting focus from simply acquiring knowledge to reproducing it, to learning how to learn.

However, that learning how to learn is often undervalued in conventional educational settings. One participant concluded clearly: "little time [is given] for reflection" (Participant 6 – 20.15). Besides, while critical thinking and self-reflection may be prominent in university learning environments, its practical application is overlooked, resulting in behaviour where: "students are so busy with ticking boxes and we need to do that, and sometimes just having the time for discussion, for the reflection, and critical thinking about what they read and really take a distance, take some time, think well about what information is given to you" (Participant 6 – 20.32). Similarly, another participant rejected the education culture of preforming just for the exams: “You take this knowledge, you write it on an exam and then you say goodbye” (Participant 11 – 27.47).

Nevertheless, the ability to reflect is not exclusive to students. One participant critically noted that while students are expected to engage in self-evaluation, educators themselves may struggle to support it effectively: “That also means that [self-evaluation] we do expect it from students, we [teachers] find it very difficult to transfer that properly” (Participant 3 – 39.54). In this evolving context, where greater emphasis is placed on critical thinking, self-reflection, and value-based learning through means of group discussions and feedback, the role of the teacher is also transforming. One participant reflected: “I think that a lot of your teachers or a lot of the teachers that are teaching nowadays are people from my generation or older… classrooms nowadays have become way more… or should become more of a discussion platform because it's easy for you to find information… You should use the classroom for that discussion and the reflection and the opinions… that should be done in the classroom” (Participant 6 – 22.57).

## 4.5 Active/Experiential learning strategies

To develop the above skills and competences, participants advocated for **project-based learning** methods. Repeatedly, they suggested to encourages students to actively explore real-world challenges through interdisciplinary teamwork. By working on a case study from the origin of the problem to its potential solution over an extended period, students develop a deeper understanding of system-level complexity while applying their expertise in context. This closely aligns with what participants named as very useful method to teach about CWE: **real-life case studies**. Example for good case studies that were mentioned were: Zero Brine, Water Minning project and Rotterdam University of Applied Science Green village (Participant 3 – 14.37). Green village is especially interested because it provides a space for students other than the University where multi-level learning can actually take place. Participants strongly emphasized the value of active, hands-on learning as a crucial component in educating students for circular water systems. They highlighted the importance of connecting learning directly to real-world practice through realistic and applied case studies: “I have already mentioned it [practice], but I would still like to emphasize it” (Participant 3 – 43.07). Another participant noted too the importance of: “practical cases where people can come along and see how this has been developed, and be there and see how this happens” (Participant 9). Working with case studies and inspire students as they can serve as valuable sources of success cases: “Students remember that success cases …of course a lot of them will not be ideal but it opens the mind to this is possible” (Participant 6 – 12.29). In addition, another participant emphasized the importance of aligning learning strategies with real-life contexts, allowing students “to have the chance to think beyond fundamental lab policies into the real world”. This perspective acknowledges that education plays a key role in shaping emerging leaders and empowering students to recognize: “I'm here to do something to add value, to create impact” (Participant 11 – 27.47). The same participant criticizes: “So it is not about I got my degree and say goodbye and then I find a nice job in the World Bank and I'm super satisfied and that's it. It is beyond that and I think we miss this a lot in our curriculum” (Participant 11 – 28.46).

Besides, **field visits** and exposure to practical examples were also frequently mentioned as effective strategies: "Field visits on real case circular approaches inspire students to learn from practitioners" (Participant 6); "learn from demonstration sites" (Participant 10). Also others emphasized that field experience—such as visits to wastewater treatment plants, industrial areas, or street sewer systems—greatly enhances the learning process: "there are a lot of skills in the head, but also in the hands of the people" (Participant 3 – 18:05). Such field visit brings theoretic learning in context and allows students to "have a look at [company's] industrial water system" and recognise the (not always pleasant) working situation: "it [industrial area's] also stink a lot, for example, but I think the experience is very important" (Participant 3 – 43.35). These experiences help students bridge the **gap between theory and real-world** complexity, as one noted, "In practice it is a bit different than it is here in the textbook" (Participant 4 – 20.14).

Some participants also advocated for students to engage in the technical implementation process, such as the "practical ability of constructing a pilot installation" (Participant 1 – 10.39). Another participant suggested to bring **test setup** to the classroom to play around "With test setups, so to speak, on a real kind of classroom level with the flowing tubes and filters" (Participant 3 – 43.35). This results in a classroom dynamic where teacher "should constantly try to find a mix between, on the one hand you sometimes have a teacher in front of the class who shares some information at the same time that you have practical information" (Participant 3 – 16.27). Besides, making use and testing "pilot set-ups [create] sort of living labs" and learn student how to implement technologies that enable circularity (Participant 6).

One participant advocated the importance of exposing students for open-ended, case-based learning formats in which students "are just thrown in at the deep" and must navigate **uncertainty**, supported by a knowledgeable facilitator (Participant 3 – 34:50). This, the participant argued, creates the most impactful and transformative learning environment. This approach not only reflects professional realities but encourages resilience during the work process. To encourage this resilience, students need to develop a sense of "ownership" (Participant 2 – 7.23). Encouraging students to take **ownership** of their learning and become self-directed was a recurring theme among participants. One participant emphasized the importance of personal responsibility, noting: "[For] master students... it is also your responsibility to make something of it" (Participant 2 – 20.16). Another highlighted the value of autonomy, suggesting that students should be given the freedom to explore their own interests within a collaborative setting: "Students being able to choose that [topic] themselves... that already helps. So someone who is really just a hard-core modeler who is not that interested in participatory process, then I'm not going to impose it to learn to read all kinds of theories about participation or something" (Participant 2 – 18.18).

Participants highlighted a range of didactic and pedagogical strategies aimed at deepening student engagement, enabling aforementioned system thinking, interdisciplinary group work, and aligning assessment with real-world complexity. Creating **learning communities** was such strategy. "where professionals, companies, schools, universities, colleges, also MBOs [vocational education] meet to think about: what skills do you need?", this way of learning is combined with, "Triple Level Learning and Transformative learning" (Participant 3 – 15.37) [Triple-level learning supports deeper understanding by engaging students not only in solving problems (single-loop), but also in questioning assumptions (double-loop) and reflecting on their values and ways of thinking (triple-loop). This aligns with transformative learning, which encourages learners to critically reflect on their beliefs and experiences, often leading to a fundamental shift in perspective and professional identity]. Finally, experimental set-ups such as **flipped classroom, role play and living labs** were suggested to integrate theory with practice. [The flipped classroom reverses traditional teaching by having students engage with learning materials (e.g., videos, readings) before class, allowing in-class time to focus on active, collaborative problem-solving and deeper discussion. This approach encourages self-directed learning and better application of knowledge. Role-play is an experiential learning method where students adopt specific roles to simulate real-world scenarios. It enhances empathy, communication, and systems thinking by allowing students to explore diverse perspectives and stakeholder dynamics. Living labs are real-life environments where students, researchers, and stakeholders co-create and test innovative solutions. They bridge theory and practice by embedding learning within real-world systems, enabling collaboration, experimentation, and reflection in authentic contexts] "role-playing then becomes a bit more of a tool...it's a small reflection of what happens in reality" (Participant 7 – 2.45).

Multiple participants referred to a project-based course at IHE as a strong **example of interdisciplinary, practice-oriented learning**. One participant described it as "a very intense course" covering a wide range of topics: "policies, stakeholders, pollutants, monitoring and quality, risk, toxicity assessments, ecotechnological assessments, agriculture, socioeconomic factors, and technologies" (Participant 11 – 11.26). The course includes three contradicting case studies from different countries to ensure varied contexts. The course structure involves interdisciplinary group work and flipped classroom methods. Students prepare using self-learning materials and self-tests, helping them identify their strengths and define their roles within their teams. This approach ensures early awareness of different perspectives and supports effective interdisciplinary collaboration, even when certain topics may not align with a student's background, they might resonate with other team members. Guest lectures are interactive and include in-class group exercises: "you need group work within your lecture to make it interactive" (Participant 11 – 18.18). Case studies are introduced from day one, with final presentations and reports due in the third week. Presentations occur a one day before the report deadline to allow time for feedback from peers, instructors, and case study partners. There is a strong emphasis on reflection during the presentation, as illustrated by the prompt: "What do you think? Do you think that this is a visible proposal and solution for the current case?" (Participant 11 – 24.46). Students then have 24 hours to incorporate this feedback into their final reports. To support reflective learning and continuous improvement, students also complete anonymous surveys evaluating the course process, tools, instructors, content, and its relevance to their professional careers: "anonymously surveys for the students where they assess the process, the tool use, the instructors, the topics, the connections, and the relevance of the module to their professional career" (Participant 11 – 25.25). The course places significant emphasis on both personal development and the learning process itself. Together, these insights underline a strong pedagogical shift toward experiential learning that connects theory to practice and prepares students for the challenges of implementing circular solutions in diverse, real-life contexts.

# 5 Development and Deliverables

## 5.1 Validation and Integration of Concepts

For the development of the conceptual framework, this study adopted an iterative approach in which literature findings initially informed the framework, while empirical interview data were subsequently used to refine, validate, or expand upon those insights. The validation process was structured around three categories: confirmed, conflict, and not covered. The majority of concepts derived from the literature were confirmed by the interview data, with no instances of direct conflict identified. However, one relevant concept emerged from the interviews that were not addressed in the literature. These additional empirical insights were retained and incorporated into the conceptual framework to reflect empirical perspectives not found in the academic literature. For a detailed overview of this analysis, see Appendix D.

*Confirmed findings*

The empirical findings largely confirm the key concepts identified in the literature review, with some notable elaborations from the interviews. No entirely new practices emerged from the interviews that had not been previously discussed in the literature. However, two practices—industrial symbiosis and water reuse in agriculture—were mentioned in greater detail and importance than in the existing literature. Both the literature and the interviews emphasized reducing water consumption, with this theme being consistently highlighted as a critical practice for managing water resources sustainably. Participant 6's interview and Kopnina (2022) emphasized the importance of ensuring that CWP do not merely become another technical solution that perpetuates the business-as-usual model, emphasising the importance of sustainability. The use of Life Cycle Assessment (LCA) to determine the sustainability of CWP was mentioned in both the literature and the interviews, underscoring the need for systematic evaluation of environmental impacts. The interviews and literature both explored the dual challenges of wastewater management: the technical difficulties in establishing appropriate levels of water purification and the perception challenges faced by end-users regarding wastewater as a resource. Ensuring the protection of ecosystem and human health emerged as a significant concern in both contexts. Participant 6 highlighted the need for context-specific solutions, which aligned with the perspectives offered in the literature.

System thinking emerged as a key skill in addressing CWP, with findings from the empirical data supporting the literature's advocacy for this approach (Alaerts & Kaspersma, 2022; Cappellaro, 2024; Wan Rosely & Voulvoulis, 2023; Janssens et al., 2021; Burger et al., 2019; Samberger, 2022; Lally & Forbes, 2020; Leung et al., 2024; Renfors, 2024; Mbavarira & Grimm, 2021). Both the interviews and the literature highlighted a skills gap in areas such as system thinking, suggesting that current educational programs are not adequately preparing professionals to manage circular water challenges at a systems level. Furthermore, the importance of context was emphasized, with both sources noting that political, legal, social, economic, and environmental factors play a crucial role in the effectiveness of circular water technologies. These factors align with the literature's emphasis on sectoral diversity, which plays a significant role in understanding and implementing CWP. While

both the literature and interviews discussed nexus thinking, it was not as prominent a theme. Both sources also identified the importance of adopting a systems mindset, which includes the ability to zoom in and out and understand interconnections between different elements. The methods to establish this mindset, such as systems mapping, scenario analysis, and trade-off evaluation, were consistently mentioned in both contexts.
Both the literature and interviews recognize that circular water challenges span multiple domains and require interdisciplinary approaches (Ab Hamid et al., 2024; Mokski et al., 2023; Xia & Peng, 2022; Murray et al., 2023; Podgórska & Zdonek, 2024; Renfors, 2024). Furthermore, the need for education in interdisciplinary work was discussed in both sources, with an emphasis on understanding the 'other' and developing a collaborative mindset (Alaerts & Kaspersma, 2022; Li et al., 2024; Renfors, 2024; Leung et al., 2024). This relates to the challenge of ensuring effective communication between different disciplines (Sauvé et al., 2016). Additionally, both the literature and the interviews underscored the necessity of actively involving stakeholders from outside academic institutions in educational processes, a point highlighted by various participants (Alaerts & Kaspersma, 2022; Li et al., 2024; Renfors, 2024; Hoinle et al., 2021; Burger et al., 2019; Guerreschi et al., 2023; Mbavarira & Grimm, 2021; Kehrein et al., 2020; Vinayagam et al., 2024; Frijns et al., 2024; Murray et al., 2023).
Both the interviews and literature emphasize the importance of critical thinking in CWE (Kopnina, 2022). Reflective thinking was also highlighted in both contexts (Scalabrino et al., 2022; Leung et al., 2024). Additionally, the sub-theme of self-criticism, which was discussed both in the interviews and in the literature, underscores the importance of learning from mistakes, the ability to learn how to learn, and maintaining good group dynamics that facilitate constructive feedback.

Several teaching methodologies were identified as common themes in both the literature and the interviews. Project-based learning was highlighted as a crucial pedagogical approach in both the literature and interviews. Experiential learning theory, although not explicitly mentioned in the interviews, was reflected in concepts such as 'realistic case studies' and 'hands-on demonstrations' from the interviews, which align with experiential learning principles. Both sources emphasized the importance of learning from success stories, resonating with constructivist learning principles. The concept of flipped classrooms, as mentioned in the interviews, aligns with transformative learning as discussed in the literature, because flipped classroom method invites students to acquaint themselves with the relevant information at home and use the classroom as discussion and reflection moment. Active-learning pedagogies and hands-on demonstrations were recognized in both the literature and the interviews. Both the literature and interviews emphasized the significance of learning in real-world contexts, including the use of case studies and project-based learning. Collaborative learning communities were identified as a common theme in both the literature and the interviews, reflecting interdisciplinary instructional models.

*Not covered findings*

Several important topics that were raised in the interviews were not explicitly covered in the literature. Most notably, participants emphasized the importance of a multi-level learning approach that integrates different types of learners and educational backgrounds. A key aspect of this is the connection between theoretically and practically educated students—a topic entirely absent from the reviewed literature. Although one participant (Participant 3) acknowledged this as a personal observation, and noted that such integration is neither common nor widely recognized within university education (though TuDelft has a program running where vocational, applied and theoretical educated students are matched in projects). Nevertheless, considering that the implementation of the CWP relies not only on academically trained professionals but also on practically skilled workers and broader public engagement, this omission is significant and should not be overlooked.

Another observation concerns the emphasis on preventive measures. While the literature acknowledges the importance of reducing consumption as part of the CWP, it predominantly adopts a supply-side perspective, often overlooking the need for demand-side transformations (Renfors, 2024). In contrast, the interviews placed considerably more emphasis on this aspect, including discussions around concepts such as the purpose economy and product perspective, highlighting a broader understanding of circularity that extends beyond technical solutions. While the literature discussed sectoral diversity, the concept of policy mobility, as mentioned in the interviews (participant 4), was not addressed. This concept, while commonly used in policy studies, can also be applied to CWP. The interviews introduced the idea of layered thinking, which helps to understand that solutions in one discipline may not have the same impact in another, a concept not explicitly covered in the literature. However, this concept is still very much related to political science and it therefore for this study considered to be covered by the concept of 'Diversity of solution'. Although the literature touched on the need for system thinking to address trade-offs, the interviews delved deeper into how these evaluations should be conducted, emphasizing that trade-off evaluations are not rigid processes with one correct solution, but rather reflect the priorities and constraints of different stakeholders (participant 7). Besides, literature did not discuss the trade-offs between interdisciplinary and specialist knowledge. While the literature strongly advocates for interdisciplinary education, the interviews revealed that integrating interdisciplinary projects into curricula often results in less time for specialized courses, a trade-off not explicitly discussed in the literature (participant 1, 6). While certain topics were less prominent in the interviews, they were emphasized in the literature. Notably, the importance of acknowledging end-user participation in the design of circular systems received limited attention from interviewees despite its recurring presence in academic discourse. Similarly, key concepts such as resilience thinking, decentralized practices, and water literacy were not directly addressed during the interviews. Furthermore, deeper discussions on the role of self-confidence and creativity—both identified in the literature as important for enabling innovation and adaptability in circular practices—were largely absent from the interview data. The role of educators was acknowledged in the literature, but this topic was outside the scope of the review. The ethical dimensions of water use, although mentioned in the interviews, were more extensively covered in the literature, especially in relation to posthuman ethics (Kopnina, 2022).

This chapter set out to validate literature-derived knowledge themes related to CWE education through empirical insights gathered from expert interviews. The triangulation of findings confirms the robustness of many themes while revealing important nuances and new directions for curriculum development.

## 5.2 Conceptual Framework

The conceptual framework illustrates the key concepts and relationships from research. It is the result of an iterative process combining theoretical insights from the literature with empirical findings from practitioner interviews. While the literature review provided a foundational understanding of key concepts—such as systems thinking, interdisciplinarity, ethics, and teaching methods relevant to CWE education—the interviews served to validate, enrich, and contextualize these themes further. Rather than testing a fixed theoretical model, the study allowed interview data to inform and reshape the structure of the framework, ensuring that it reflects both scholarly perspectives and real-world educational needs. The framework is therefore not only grounded in existing academic discourse but also shaped by the practical experiences, challenges, and suggestions shared by 12 educators and professionals. This dual-source approach ensures that the resulting model is both conceptually coherent and practically relevant, supporting the development of circular thinking essential for teaching CWPs. This multi-layered conceptual framework serves as both a visual and analytical tool, integrating theoretical knowledge with practice-based insights to support the creation of holistic, future-oriented learning pathways in CWE. It offers a structured overview of the key thematic knowledge areas alongside three core competence dimensions: systemic, interpersonal, and reflective. Each of these dimensions is further detailed with specific underlying concepts, as illustrated in figure 8. It illustrates how these elements contribute to the development of competences and learning objectives essential for executing CWP. The teaching and assessment methods are showed separately in figure 9.

*Structure conceptual framework*

The structure of the conceptual framework is reflects the structure of the literature review. The circular model visually represents the second research objective, which sought to identify the essential knowledge, skills, and competencies necessary for executing CWP. At the centre of the model lies the primary aim of this study: to support the cultivation of circular thinking within water engineering education by outlining the core content—the "what"—that students should engage with in a CWE course.

The circle is divided between subject-specific and generic competences. This distinction is visually represented in the framework's circular model, where the upper half of the circle corresponds to subject-specific competences and the lower half to generic competences, divided by a dotted line to indicate their conceptual differentiation.

Surrounding the core, the second ring of the circle, organized into three conceptual domains: knowledge (“what to know”), systemic and interpersonal competences (“what to do”), and reflective competence (“how to be and live”). These domains represent the foundational competencies required to develop circular thinking and enables students to execute subject-specific skills relevant to CWP. These competences encourages students to transition from linear to circular thinking, thereby equipping them to implement, upscale, maintain, and adapt CWP in diverse, dynamic and future contexts.

The outermost ring of the circle captures the integrated concepts that give more detail to the conceptual domains. These findings emerged from the process of validating and synthesizing the literature review (table 6,7 and 8) with the empirical interview findings (see Appendix C. To distinguish the origin of each concept, a color-coding system was applied: : blue indicates alignment between literature and interviews, yellow represents only found in the literature and purple highlights concepts that emerged solely from the interviews.

Importantly, these competencies are not siloed but are interlinked and mutually reinforcing. For example, systems thinking extends beyond providing methodological tools for addressing challenges at the systemic level; it also informs reflective practice by encouraging students to examine their own role and positioning within the systems they study. Showing that outcome and process are not separate: designing across different system levels (the outcome) necessitates a systems-thinking or circular mindset (the process). In this way, systems thinking is a examples that bridges the acquisition of technical knowledge with the development of personal insight, facilitating the shift from knowledge to wisdom.

*Figure 7 Conceptual framework illustrating the key knowledge concepts, and systemic, interpersonal, and reflective competences. Colour coding differentiates the origin of each theme: blue indicates alignment between literature and interviews, yellow represents only found in the literature and purple reflects themes unique to the interviews.*

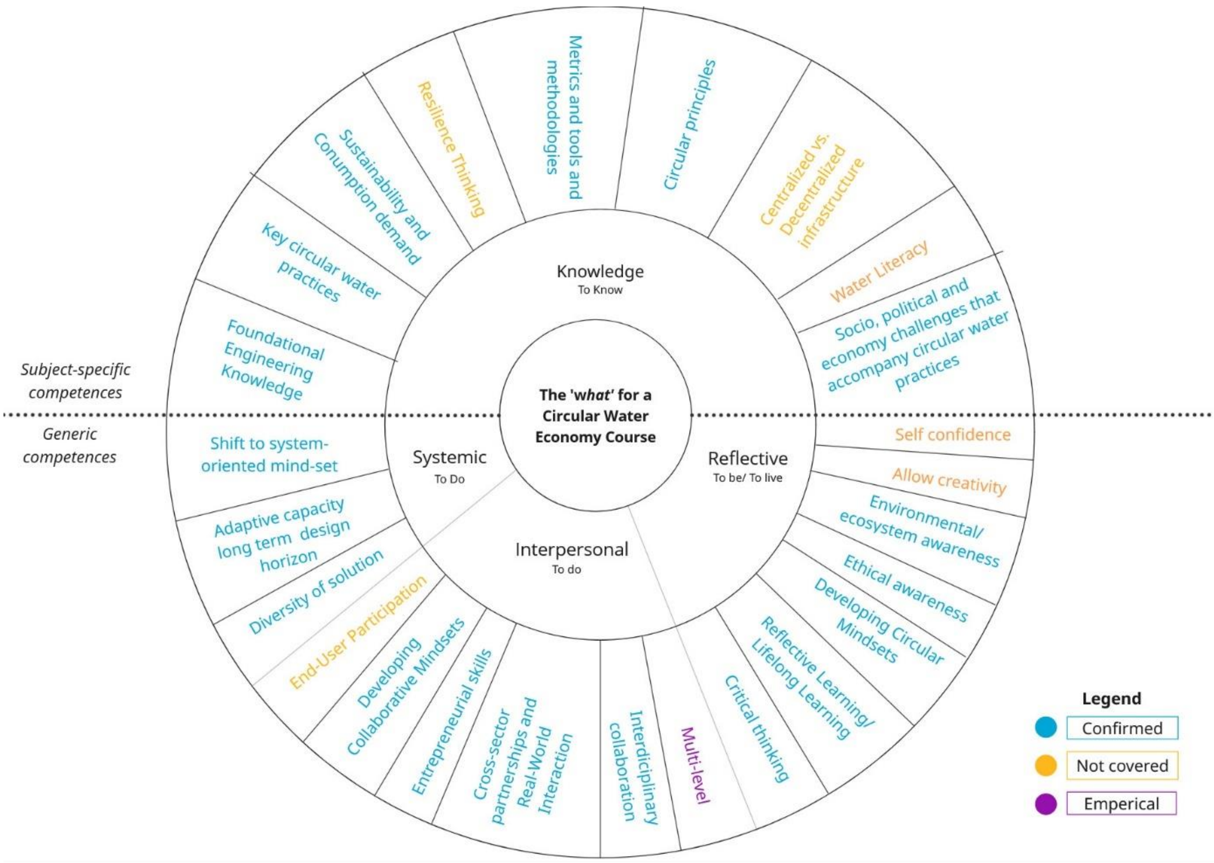
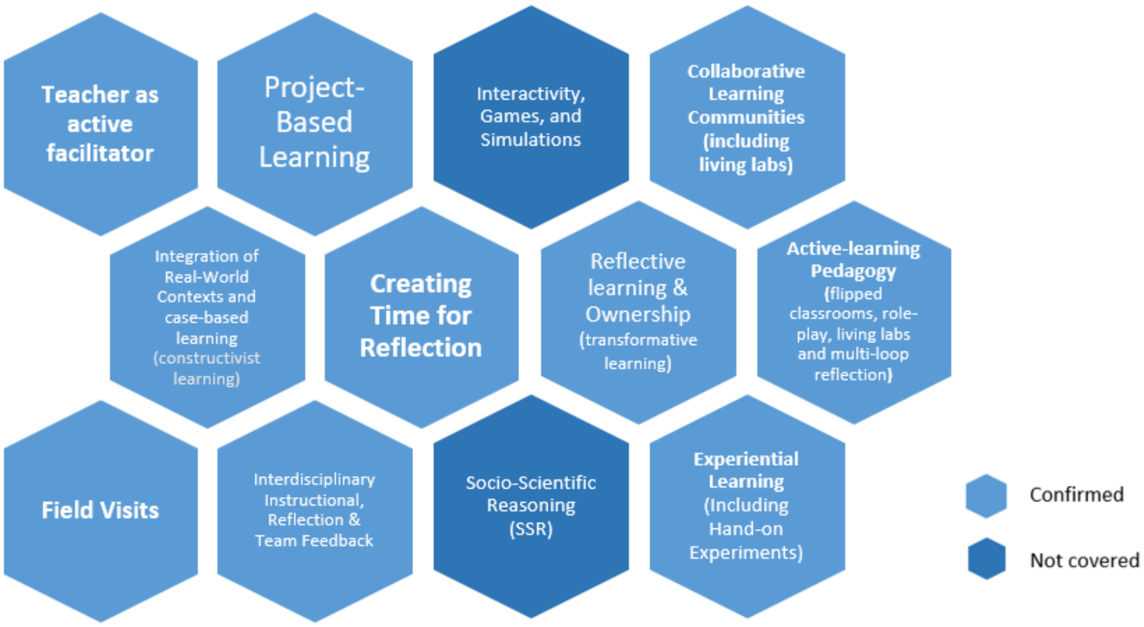


*Figure 8 Teaching and assessment methods. Colour coding differentiates the origin of each theme: light blue indicates alignment between literature and interviews, dark blue represents literature-only findings.*




## 5.3 Explanation and Recommendation

Good fundamental knowledge is crucial to understand the complexity of technology development”

- (P6).

The concepts which are included in the **knowledge** domain, emphasizes the importance of a solid foundation in engineering, process knowledge, and fundamental hydrology. Students must grasp core principles such as water reuse, nutrient recovery, and ecotechnologies, as well as the role of water in industrial symbiosis. Equally essential is an understanding of relevant tools and methodologies. Students should also explore the trade-offs between decentralized and centralized systems. Circular principles, including source protection, reuse, and waste minimization, must focus on sustainable practices, prioritizing the recovery of water, nutrients, and energy. It entails moving beyond linear, extractive models toward systems that prioritize reuse, regeneration, and interconnectivity, a recurring theme in both literature and interviews. Circular strategies should emphasize reducing resource use, such as minimizing water and energy demand, instead of relying solely on new technology for reuse. Moreover, students must adopt specific perspectives, particularly the product perspective, to question “What do we actually need?” CWPs should not only be circular but also contribute to broader systemic sustainability. Achieving these goals requires addressing the socio-political and economic challenges inherent in designing CWPs.

*Recommendation:* Integrate fundamental process engineering with CE concepts. Courses should cover traditional water treatment practices and introduce circular practices (e.g. water pinch analysis, resource recovery, nutrient recycling). Teach sustainability tools (LCA) and systems analysis tools (mapping, causal loops, and layered frameworks). And the "waste-as-resource" mindset to ground basic circular principles.

"We didn't have that systems thinking from the start... that was a big limitation"
- (P8).

**Systemic competence** emphasize the need to view circular water systems as complex, multi-dimensional, and context-dependent. Students must be equipped to understand and critically engage with the interdependencies among ecological, economic, social, and policy dimensions. Navigating these systems requires recognizing and managing trade-offs that cannot be resolved through simple cost-benefit analyses. Each disciplinary perspective contributes distinct, and sometimes conflicting, arguments—particularly when systems involve living beings, which inherently introduces diverse interests, values, and ethical considerations. While some solutions may be more robustly justified than others, system operations involving human and ecological stakeholders resist reduction to purely technical or mathematical equations, necessitating continuous ethical reflection and deliberation. A shift from isolated technological fixes to systems thinking is crucial for questioning such linear assumptions. Addressing challenges marked by uncertainty, complexity, ambiguity and rapid change requires strategic foresight, long-term planning, stakeholder engagement, effective communication. Through long-term scenario planning, system thinking helps individuals anticipate the long-term consequences of decisions. This dimension is also about how implementing CWPs adds complexity due to interconnected systems, creating challenges in areas such as system interdependencies, stakeholder conflicts, environmental variability, and economic, regulatory, and behavioural factors. Solutions must also account for sectoral and spatial diversity, and technologies should be tailored to local political, legal, and institutional contexts, acknowledging that copy-past strategies are too shallow. In this sense, systems thinking functions not only as a skill 'to do' but also as a guiding mindset that shapes how actions are conceptualized and implemented.

*Recommendation*: Incorporate cases showing regulatory or climate context differences. Work with trade-offs (e.g. reuse vs. energy demand) and long-term perspectives in projects. Introduce the concept of resilience and challenge students to design adaptive solutions. Discuss that system redesign must involve stakeholders at all layers or else the change won't "stick". Besides, highlight and show that outside academia, professional collaboration is even harder (different sectors, departments, commitments).

"There are just a whole bunch of issues where we really need all those perspectives"
- (P2)
.

**Interpersonal competence** recognises that CWP span multiple disciplines—engineering, economics, ecology, governance or social sciences—and demand collaborative work between those disciplines. This dimensions show that students should develop skills to engage in interdisciplinary teams, value diverse expertise, and understand different forms of communication, to work effectively across knowledge domains. Though, caution that pushing all students to be generalists is risky; we still need specialists. Interdisciplinary training should complement, not replace, knowledge depth. It also includes the discussion on how to connect theoretical and practical skilled students, learning how to work together is really important to make the CWE successful.

*Recommendation:* Employ interdisciplinary team projects, in some cases even joint seminars or guest lectures with other courses on economics/environmental students. Allow room to explore different communication strategies for cross-disciplinary work and present and negotiate conflicting interests. Education should not just be about representation of disciplines but about ways to bridge disciplinary knowledge and communication. Cultivating attitudes of respect and humility. Teach students that no single discipline holds the absolute truth, and recognizing the value of others' perspectives. And recognising and underline that people are different.

"Technology alone will not solve circularity…instead, a change in mind-set…is essential"
- (P6)
.

**Reflective competence** focus on developing metacognitive skills such as critical thinking and reflection. This dimension emphasizes critical thinking, ethical awareness, and personal reflection as foundational to meaningful learning and system transformation. Within the context of CWP—often embedded in dominant value systems such as capitalism—students must be encouraged to interrogate these paradigms and consider alternative, purpose-driven frameworks. Critical thinking in this setting extends beyond questioning external content (from teachers, peers, or texts) to include scrutiny of one's own assumptions and reasoning. To establish such critical thinking, ethical awareness is essential, it helps evaluating trade-offs and enabling both epistemological and ethical questioning of both the technical design as the (learning) process that brough you there. This requires a non-linear, open, holistic, and innovative mindset—one that emphasizes creative problem-solving and closely aligns with the principles embedded in systems thinking competence. As with systemic competence, resilience thinking should not be seen solely as a technical approach but as a formative process that strengthens students' self-confidence and enhances their ability to engage constructively with uncertainty and ambiguity. Rather than treating reflection as a procedural or formal requirement, this dimension frames it as a fundamental component of responsible knowledge acquisition. Technical knowledge, without the anchoring of wisdom, self-awareness, and ethical judgement, risks becoming decontextualized and misused—contributing to the erosion of truth and the rise of superficial, post-truth narratives. Wisdom emerges through ongoing, critical engagement with diverse perspectives and a mindset oriented toward lifelong learning, which allows failure and mistakes to exist.

*Recommendation*: To cultivate reflective and interpersonal competencies essential for system change and circular education, it is important to incorporate reflective assignments—such as learning journals, personal audio recordings, podcast-style conversations, or self-development tasks—alongside group debriefings that emphasize both self- and peer-evaluation. These activities should move beyond superficial, checklist-style tools (e.g., anonymous inline feedback platforms such as FeedbackFruits) and instead prioritize open, dialogic reflection. Students must be encouraged to engage in honest conversations, where feedback is exchanged face-to-face and anonymity is removed. Reflection, if it is to be a sincere learning objective, must occur in open and respectful conversations that allow for vulnerability, presence, and connection among students and educators. Students should be supported in understanding that personal expression and emotional honesty are not to be feared by, but integral to collaborative learning and professional development. In such an environment, the boundary between the formal and informal becomes a reflective tool, helping students to personally discern what to share and when, rather than a rigid set of behavioural norms applied to every individual. Creating a classroom culture grounded in inquiry, openness, and mutual respect is essential. Encouraging students to bring personal experiences into discussions helps dismantle artificial barriers between the formal and informal, allowing them to learn how and when to share meaningfully. Discussions that explore a diversity of solutions enable a circular mindset by shifting the focus from static knowledge to dynamic interpretation. Equally, assessment frameworks must reflect the centrality of critical and reflective practices. These should be valued on par with technical content, such that poor critical engagement may justifiably lead to a failing grade. However, such courses should also enable face-to-face dialog, providing students with the opportunity to articulate their reasoning, engage in constructive discussion, and potentially influence their evaluation through reflective engagement. Finally, incorporating real-world anecdotes and storytelling—as well as inviting students to contribute examples from their own daily lives—can deepen engagement, support memory retention, and build relational trust within the classroom.

“Field visits on real case circular approaches inspire students to learn from practitioners”
- (P10).

**Teaching Method and Assessment** advocates for hands-on, practice-oriented learning to connect theory with real-world application. Fieldwork, case projects, living labs, help students gain practical experiences and internalize circular thinking. Because engineering is already a discipline that asks for connection with practical application of theoretical solutions, find ways to work with stakeholders from outside the university to reflect real world settings and challenge non-academic communications skills. This part also includes recommendations on project-based learning. This way of arranging your education allows students mirror a real-life problem-solving process and seeing the problem in this whole. It allows for collaboration, have their own expertise and responsibility within the project, stimulates communication skills and allows for time for iterative design and learning processes. Connect learning to something tangible and visual, eased cognitive load and induces creativity. Use experimental tools that allowed rapid modification of components and interactions to enhanced understanding.

*Recommendation:* The following recommendations of teaching methods and assessment follow Ebbens et al. (2020) learning recipe and are ingredients to aim to enhance student engagement and learning recommendations formulated above:

**Meaningful Learning:** Connect new information to students' existing knowledge, experiences, and interests to create relevance.

- Design assignments that prompt students to draw connections between the obvious and less obvious aspects of a topic. Learn students to associate freely. Use brainstorm sessions and mind-maps sessions, where no mistakes can be made or wrong answers exist to dare students to think for themselves. Use art and aesthetics to enabling people to extend beyond the limitation of explicit, conscious knowing. Think of assignment where concept are applied 'technically' and 'personally', use for example system and resilience thinking concepts.

- Avoid assessments and practices where testing becomes a 'production' of reports, presentation or essays. Use oral test and dialogic forms of assessments, to such 'production' and so students cannot hide behind fancy academic words and learn to formulate their own arguments. Work with strict word limitations and amount of presentation slides. Thinking of alternative assessments of only writing abstracts or summaries. Split up assessment to have different rounds of feedback and have you work slowly build up throughout the course. Use games to trigger the playful and creative mind and have students motivated.

- Enable a learning environment where students feel encouraged to share personal examples and experiences. Show that learning and making mistakes can be safely and playful done. Allow the informal and formal mind to meet and learn students that personal reflection and feedback take personal commitment yet does not have to become personal.

- Align assessments with real-world tasks, such as designing a pilot system, conducting case-study analyses, participating in site visits, or engaging in hands-on experimentation, to cultivate practical skills and enhance student engagement.

- Consider alternative teaching strategies such as flipped classrooms, role-playing, or interactive games and simulations to create dynamic learning experiences. This approach repositions classroom time not merely as a space for knowledge transfer, but as an opportunity for meaningful engagement with peers and instructors—facilitating dialogue, enabling interpersonal connection, and collectively constructing meaning from individually acquired knowledge.

**Individual Accountability:** Ensure that tasks and group work are structured to promote active participation and accountability from every learner.

- In flipped classroom settings, provide students with different pieces of information and assign discussion-based activities that require them to exchange information both verbally and visually.

- For individual assignments to facilitate ownership of learning, allow students to select topics of personal interest to enhance motivation and relevance.

- Work explicitly with examples of conflict (such as trade-off, stakeholder diverse opinions, competition or other ambiguities), show students the meaning of different perspective and values, use these when conflicts arise during learning process. Don't avoid conflicts but be actively engaged with all forms of them.

**Visibility of Learning and Thinking**: Encourage students to openly express their thinking, reasoning, and problem-solving processes.

- Ask students to focus on explaining how they learned rather than just what they learned. This shifts the focus from content mastery to understanding and articulating their learning process as academic skill.

- Provide multiple opportunities for feedback and reflection, both from peers, instructors, and other senior stakeholders, to create a space for iterative learning and improvement. Avoid anonymity when doing so.

- Allow a diversity of assessment practices and give students the opportunity to choose which one fits best (e.g. oral or written test). Besides, create assessment practices that are dialogical of nature between peers of student-teachers. In this way the process of learning and level of inquiry can be made visible while also allowing feedback and reflection.

- Organise course structure by different 'levels' - a layered approach helps contextualize applied theory and practice, enabling a more comprehensive and systems-based understanding. Align the instructional design with established pedagogical frameworks, such as Merrill's (2002) First Principles of Instruction. Begin the course by presenting a comprehensive example of a Circular Water Project (CWP) challenge to provide learners with a holistic context. Subsequent lectures should build progressively on this foundation, continually referencing the initial example to reinforce continuity and relevance. Instruction should follow Merrill's four-phase approach: activating prior knowledge (e.g., "What does this remind you of?"), demonstrating new skills or concepts (e.g., "What is new or different in this information?"), enabling learners to apply what they've learned (e.g., "How would you explain what has been presented?"), and supporting integration into real-life practice (e.g., "How does this connect to a real-world example?").

## 5.4 Learning Objectives

## 5.5 Connection to Theory and Reflection

*Critiques of transformative learning*

Transformative and constructivist learning theories are frequently referenced in literature ESD and ECE, and were also mentioned in interview responses. These approaches emphasize the importance of challenging students' assumptions and worldviews, advocating for learning experiences that are grounded in real-world contexts and occur both within and beyond traditional classroom settings.

However, as discussed earlier in relation to Bateson's theory of learning, true transformation is not simply achieved through completing assignments or attaining passing grades. Bateson's four levels of learning are not hierarchical in nature; they do not represent a linear progression from basic to advanced learning. Rather, they operate simultaneously and interactively (Tosey et al., 2010). Learning at deeper levels can lead to discomfort or unexpected outcomes, including increased self-awareness that may not always be pleasant, therefore, viewing Level III learning as an ideal or "holy grail" of education reflects a goal-oriented mindset that oversimplifies the complexity of transformation (Tosey et al., 2010). Using transformative learning as a tool to deliberately "change" students' minds risks misunderstanding both the nature of learning and systems thinking. Such an approach implies a linear cause-and-effect model, where inputs (e.g., curriculum) lead predictably to outputs (e.g., transformed students). However, systems thinking and circular logic challenge this view. In complex systems, outcomes are shaped by feedback loops, tipping points, and non-linear interactions. Therefore, rather than aiming to produce transformation, transformative education should focus on building knowledge about systems thinking, enabling collaborative practices, and cultivating the reflective wisdom necessary to engage with complexity.

*Classrooms as complex systems and the role of the educator*

Rather than aiming to "achieve" third-order learning as an end goal, educators should focus on creating the conditions under which such learning might emerge. In this context, the educator's role shifts from solely knowledge deliverer to facilitator of complex, meaningful engagement. Bateson viewed the classroom as a dynamic system, composed of interacting individuals—both students and teachers—each functioning as a "holistic, self-stabilizing, self-organizing system" (Bale, 1992). No single participant controls the classroom dynamic entirely, but each one contributes to its ongoing dynamic. The classroom system is thus co-created through relationships and interactions, shaped by the presence and participation of every individual.

To facilitate deep learning within this framework, educators must create dialogical learning environments—spaces where students are invited to critically engage with paradoxes, contradictions, and underlying assumptions (Bale, 1992). This requires a high level of pedagogical expertise, as teachers must navigate and support both interpersonal and individual dynamics, while remaining sensitive to the broader contextual conditions in which learning unfolds. Such environments demand more than content delivery; they call for educators to actively construct and manage the contexts and meta-contexts that shape students' understanding of reality.

This involves establishing meaningful dialogue between the collective classroom dynamic and the personal development of each student. Teachers must be able to communicate both explicit knowledge and implicit contextual cues—such as tacit agreements (e.g., unspoken norms or shared assumptions) and context markers (e.g., tone, setting, or body language)—that influence how information is interpreted. As Bale (1992) notes, educators must be skilled in "communicating contexts in which diverse systems (personalities) can effectively exchange information". In this view, the educator is not only a transmitter of knowledge but also an integral actor within the learning system—one who contributes to and helps balance the system while being shaped by it. The teacher thus plays a dual role: enabling meaningful interactions among diverse learners and mediating between individual and collective learning processes. Effective teaching, in this sense, involves designing learning environments where diverse perspectives and personalities can interact freely, enabling learners' awareness of their own cognitive processes, assumptions, and contributions to the learning system as a whole.

*What is circular thinking really? A philosophical inquiry*

Circular thinking, as informed by Bateson's systems theory, challenges the linear, cause-effect model of understanding and replaces it with a view in which elements within a system mutually influence and co-shape one another (Tosey et al., 2010). This paradigm has significant implications for education, particularly in fields like circular water engineering, where the separation between process and outcome becomes untenable. For instance, systems thinking is not merely content to be taught ("what"), but a cognitive orientation that influences how students learn ("how"). Similarly, resilience extends beyond a technical skillset and becomes a guiding pedagogical principle—one that prepares learners not just to withstand change, but to engage actively with uncertainty, transformation, and complexity. Sterling (2013) argues that true resilience entails an integration of personal development and systemic awareness, enabling students to perceive themselves as agents within the systems they study.

Aligned with this, a circular mindset recognizes that systems evolve through ongoing feedback loops, and that establishing CWPs is an iterative, never-final process of designing, adapting, and learning. Circular thinking, therefore, thrives on reflective and critical inquiry—where learning itself becomes both the object of investigation and the method through which transformation occurs. However, in academic settings, reflective dimensions are often underdeveloped in practice. While critical thinking is encouraged in theory, it is rarely given the time or space needed to truly develop, leading students to reproduce existing knowledge rather than question it or contribute to its evolution.

The design of effective CWE curricula must therefore move beyond the superficial inclusion of relevant topics or learning methods. A genuinely CWE course does not simply "tick the boxes" of circularity topics; rather, it models circular thinking in both its content and approach. Teaching should reflect the very principles it seeks to inspire, where the learning outcome 'what' (knowledge content) and the learning process 'how' (method of acquisition) are mutually reinforcing. Circular thinking must be executed, not just described. Education, in this context, is not just about transferring knowledge but about cultivating mindsets that are open, reflective, and capable of engaging with complexity. By creating space for critical inquiry and relational learning, educators can support students in developing the skills and attitudes needed to navigate and contribute to a circular and sustainable future.

Thus, to enable the competencies necessary for executing CWP, teaching approaches must embody the very circular principles they aim to cultivate. This means acknowledging that the mindset, intention, and presence we bring to teaching shape both the learning process and its outcomes. When driven by openness, humility, and integrity, education becomes a generative space where both knowledge and character evolve. Conversely, if processes are rushed or ego-driven, they produce outcomes that reflect those limitations. In this view, the process is not merely a means to an end—it holds intrinsic value and must be aligned with the desired outcome.

To establish circular thinking in education, it calls for teaching designs that honours complexity, diversity, and relationality, cultivating both technical understanding and human development as intertwined aims.

# 6 Discussion and Conclusion

## 6.1 Methodological Limitations & Reflexivity

## 6.2 Additional Discussion

## 6.3 Future Research

*Transition Science*

Transition science was not treated as an independent area of focus within this research on CWE education. Although it was occasionally mentioned in the literature, it was not a central theme in the selected papers and was excluded from the initial search terms of the literature review. As this study prioritized identifying skills and competencies more directly related to Education for CWE, transition science was not seen as a primary focus. However, its omission highlights a valuable avenue for future research. Given the frequent references to systemic change and transitions from one state to another in both the literature and interviews, integrating transition science into CWE education is important.

Future research should explore how transition science can contribute to understanding the nature of systemic shifts within water systems and broader sustainability transformations. This includes questioning whether the CWE is a final goal or a guiding principle. Transition science offers theoretical tools to unpack such complexities and can enrich CWE curricula by highlighting the dynamics of change, resistance, tipping points, and feedback loops. Further investigation is needed to explore how education itself can reflect circular principles in both content and pedagogy—ensuring that teaching practices align with the systems they aim to transform. In short, future studies should address how to educate for a circular system through circular ways of teaching and thinking.

*Critical and reflective thinking among educators*

The central role of educators in transformative learning calls for future research into the development of their own critical and reflective capacities. While student transformation is often emphasized in ECE, educators must also engage in ongoing reflection on their teaching philosophies, interdisciplinary challenges, and assumptions. As Guerreschi et al. (2023) point out, while interdisciplinary collaboration is widely promoted, it is often experienced as a barrier by educators, partly due to vague implementation strategies and insufficient support. This reflects a broader issue: although interdisciplinary competencies are crucial for driving sustainable transitions, their practical meaning and classroom application often remain vague. ECE in general and for a course on CWE specifically, this must move beyond the superficial use of these buzzwords. Their value lies in meaningful implementation, which requires time, openness, and genuine commitment—qualities that cannot be enforced through simple curricula change alone. For example, effective interdisciplinary collaboration involves more than assembling individuals from different fields; it demands shared purpose, sustained dialogue, and mutual trust. How this is established has no straight answer. Though, once again, this underscores the inseparability of outcome (interdisciplinary collaboration) and process (genuine openness engagement). A CWE program that genuinely aims to enable transformation must be led by educators who are themselves engaged in reflective, transformative practice. Thus, educators should demonstrate the behaviours and mindsets they wish to cultivate in students. A course on circular water engineering should therefore be led by teachers who embody the reflective, systems-oriented thinking they aim to promote.

Future research should investigate how educators can be supported in developing interdisciplinary competencies, not only through formal training but also through collaborative learning environments and peer-led processes. Additionally, studies could examine effective models of interdisciplinary teaching in CWE, focusing on how educators themselves embody the mindset and behaviours they aim to cultivate in students. This includes exploring teacher readiness, openness to change, and institutional support structures that enable long-term pedagogical transformation.

*Individual and Collective Learning*

While learning can be a deeply personal experience, it can also be a team experience. “Theories of learning are too often focus on the individual”, Bateson’s theory is one of the view that attempt to address this issue (Engeström, 2001 cited in Tosey at al., 2010). Bateson’s ideas suggest that learning is not just an individual process, but a social one, where the influence and interaction between people play a crucial role in the learning process (Tosey et al., 2019). Learning occurs not only within individuals but also through their engagement with others. Though conflict and competition are natural features of organic systems, reframing the classroom as a shared learning system can open new possibilities. When students are encouraged to approach learning as a collective responsibility—rather than as a competition—different dynamics of engagement, accountability, and belonging can emerge. In individualistic cultures, this shift requires a rethinking of teaching methods and educational goals, moving toward models that value cooperation, mutual support, and interdependence.

Future research should investigate how the individual and collective foundations of teaching influence students' learning outcomes and educational experiences. Research could also focus on how to best establish such communal responsibility and shared purpose, and whether such approaches increase student agency or undermine them.

*Including society into teaching methods*

Finally, future research should consider broadening the scope of CWE education through outreach to the public and intergenerational learning. Water literacy literature emphasizes that misconceptions about water systems often begin early and persist into adulthood (Lally & Forbes, 2020). Future studies could investigate the effects of involving university students in teaching younger audiences—whether through workshops, educational games, or other outreach strategies. Such practices may not only reinforce foundational knowledge for the students but also raise community-wide awareness and understanding of circular water systems. This line of research could explore the mutual benefits of such teaching activities, particularly in how simplifying complex concepts for others can deepen the students’ own understanding.

## 6.4 IE Connection

## 6.5 Conclusion

This thesis set out to investigate how higher education institutions within the European Union can effectively integrate circular thinking into water engineering curricula, thereby equipping future professionals to meet the demands of a CWE. Through a combination of a systematic literature review and expert interviews, the study identified significant gaps, requisite competencies, and teaching approaches essential for aligning academic training with the realities of circular water systems.

*Sub question 1: Are current water engineering educational programs in the EU equipping graduates with the skills and competences required for implementing CWE practices in the water sector?*

An analysis of 47 Master's-level water engineering programs across the EU answers the first sub research question and revealed a disconnect between existing curricula and the needs of the emerging CWE. Although many programs incorporate general themes of sustainability, interdisciplinarity and resource efficiency, few provide dedicated instruction on CWPs. Even fewer promote the systems-based, and reflexive capacities necessary for addressing complex, real-world water challenges. Current educational structures largely remain anchored in traditional, discipline-specific paradigms, insufficiently preparing graduates for the systemic and integrated nature of circular water solutions.

*Sub question 2: What are the critical CWPs to educate future water professionals for a CWE in the EU?*

To bridge this gap, the thesis identified core areas of CWP critical for future water professionals, including: foundational circular principles; advanced technologies for resource recovery; water reuse and nutrient recycling systems; nature-based and decentralized solutions; the Water Resource Recovery Facility (WRRF) paradigm; water literacy; and an understanding of the socio-political and economic dimensions of circularity. These areas collectively reflect a paradigmatic shift from linear to regenerative models of water management that integrate technological innovation with environmental stewardship and social responsibility.

*Sub question 3: What skills and competences should young professionals have to execute these new CWPs?*

*The successful adoption of these practices requires the cultivation of a distinct set of graduate competencies. Besides a strong technical foundation, these include systems thinking for addressing complex interdependencies, interdisciplinary collaboration that transcends disciplinary silos, and critical-reflective skills for iterative learning and adapt strategies in real-world contexts. These competences show how professionals must also be adaptable and capable of working across institutional and cultural boundaries, particularly as circular solutions need be tailored to local conditions.*

*Sub question 4: How is circular thinking established through interdisciplinary, systems-thinking, and reflective learning approaches used to support education on CWPs?*

Cultivating a circular mindset entails more than the inclusion of relevant content on CWP; circular thinking is best cultivated when interdisciplinary collaboration, systems-oriented analysis, and reflective practice are intentionally combined in the learning process. Circular thinking challenges linear, cause-effect models by emphasizing feedback loops, iterative reasoning, and relational understanding—core principles of systems resilient thinking. In education, this means embedding reflective and critical inquiry into both the content and the process of learning and professional self-development. To enable a genuinely circular mindset, education must evolve from a focus on technical knowledge acquisition to the cultivation of adaptive, open, and critically engaged learners. This involves decoupling from a purely outcome-driven model and embracing a process-oriented teaching that values uncertainty, dialogue, and collaboration. It invites students to develop the epistemic flexibility needed to navigate and influence complex socio-ecological systems. Such a mindset is not merely a conceptual shift from linear to circular logic, but an epistemological expansion that values relational understanding, feedback loops, and socio-ecological complexity. Not to throw overboard linear thinking as old thinking, it recognizes that linear thinking remains valuable for certain technical problems, and that circularity involves complementing—not replacing—existing analytical approaches with integrative, adaptive reasoning. Such an approach recognizes that learners inhabit dual roles: they are both agents shaping systems and subjects shaped by those same socio-technical and institutional system structures. This reflexive positioning is crucial for cultivating the capacity to engage meaningfully with uncertain, complex, ambiguous, and transformative futures. Yet, in academic environments, these reflective and systemic dimensions often remain underdeveloped in practice. While critical thinking is frequently advocated in theory, educational structures rarely allocate the temporal or conceptual space necessary for its deep integration. As a result, students may reproduce dominant paradigms rather than interrogate or reimagine them. The character of teaching methods and assessment practices are as relevant to establish such circular thinking.

*Sub question 5: How are teaching methods and assessment practices designed for prompt circular thinking within water-related education programs?*

To establish a circular mindset, it calls for educational practices that are experiential, student-centred, and grounded in real-world challenges. Methods such as project-based learning, living labs, role-plays, and case studies provide opportunities for students to engage with the complexities of circular water systems. Though, traditional assessment tools are often inadequate for evaluating such learning; instead, performance-based assessments—including reflective journals, peer evaluations, and collaborative portfolios—are better suited to measure students' investigative, critical, and adaptive capabilities. When students are immersed in learning environments that simulate professional practice—where they share responsibility, navigate real-world constraints, and take ownership—they are more likely to develop the intrinsic motivation, engagement, and greater self-confidence required to become agents of change.

*Main research question: What subject-specific and generic competences, along with teaching approaches, are necessary for higher education in the EU to effectively embed circular thinking into water engineering curricula and prepare future water professionals for a CWE?*

Subject-specific competences include mastery of CWPs (e.g., water reuse, nutrient/energy/material recovery in WRRFs, treatment of emerging contaminants, nature-based and decentralized solutions), plus the ability to apply metrics and tools (LCA, systems mapping), reasoning about resilience and trade-offs, and navigate policy, regulatory, and economic contexts. Generic competences centre on systems thinking and complexity handling, interdisciplinary collaboration and communication, and reflective/critical practice. Teaching should combine active/experiential and project-based learning with real-world case studies and collaborations (industry/campus), games/simulations, flipped-classroom elements, and dialogic, reflective assessment—so that learning outcomes (*the what)* and the learning process (*the how*) mutually reinforce each other and allows circular thinking to grow.

Ultimately, this thesis underscores the necessity of transformative education. Preparing students for the CWE involves more than delivering new content; it requires enabling openness to diverse perspectives, encouraging reflexivity, and promoting cognitive flexibility. Rather than imposing a rigid dualism between linear and circular thinking, educators must support students in navigating this spectrum with understanding.. As one expert noted, "…circular thinking requires letting go of rigid plans… It's not about preserving the original idea at all costs, but about integrating new conditions as part of the process". The wisdom lies in recognizing that circularity is not the antithesis of what has come before, but its evolution—an invitation to rethink, reimagine, and redesign water systems in ways that are both technically sound and socially just.

In conclusion, equipping future water professionals for a circular future demands a holistic reorientation of EU higher education. Learning objectives, competencies, and teaching strategies must converge around interdisciplinarity, systems thinking, and reflective practice. Where students are encouraged to see the relationship between what they learn and how they learn it. Only through such transformative educational models can graduates be prepared to innovate responsibly, act adaptively, and lead the systemic transitions necessary for sustainable and resilient water futures.

# Bibliography

*Introduction*


Ab Hamid, N., Kamaruzaman, F. M., & Rasul, M. S. (2024). Exploring Dominant Approach for Teaching Circular Economy. *International Journal of Academic Research in Progressive Education and Development*, *13*(1).

Akhtar, N., Syakir Ishak, M. I., Bhawani, S. A., & Umar, K. (2021). Various natural and anthropogenic factors responsible for water quality degradation: A review. *Water*, *13*(19), 2660.

Akpor, O. B., & Muchie, B. (2011). Environmental and public health implications of wastewater quality. *African Journal of Biotechnology*, *10*(13), 2379-2387.

Alaerts, G. J. (2022). Water, physically connected yet institutionally fragmented—Investing in its strategies, asset classes, and organizations. In *Financing investment in water security* (pp. 17-55). Elsevier.

Barab, S., & Squire, K. (2004). Design-based research: Putting a stake in the ground. Journal of the Learning Sciences, 13(1), 1–14. https:// doi. org/ 10. 1207/ s1532 7809j ls1301_1

Beiderbeck, D., Frevel, N., von der Gracht, H. A., Schmidt, S. L., & Schweitzer, V. M. (2021). Preparing, conducting, and analyzing Delphi surveys: Cross-disciplinary practices, new directions, and advancements. MethodsX, 8, 101401.

Bigg, G. R., Jickells, T. D., Liss, P. S., & Osborn, T. J. (2003). The role of the oceans in climate. *International Journal of Climatology: A journal of the Royal Meteorological Society*, *23*(10),

Boon, H. J. (2024). A Comprehensive Approach to Water Literacy in the Context of Climate Change. *Education Sciences*, *14*(6), 564.

Borowski-Maaser, I., Graversgaard, M., Foster, N., Prutzer, M., Roest, A. H., & Boogaard, F. (2021). WaterCoG: evidence on how the use of tools, knowledge, and process design can improve water co-governance. *Water*, *13*(9), 1206.

Brears, R. C. (2020). *Developing the CWE*. Cham, Switzerland: Springer International Publishing.

Bronstert, A. (2003). Floods and climate change: interactions and impacts. *Risk Analysis: An International Journal*, *23*(3), 545-557.

Brown, R. R., Keath, N., & Wong, T. H. (2009). Urban water management in cities: historical, current and future regimes. *Water science and technology*, *59*(5), 847-855.

Bugallo-Rodríguez, A., & Vega-Marcote, P. (2020). Circular economy, sustainability and teacher training in a higher education institution. International Journal of Sustainability in Higher Education, 21(7), 1351-1366.


Bugallo-Rodríguez, A., & Vega-Marcote, P. (2020). Circular economy, sustainability and teacher training in a higher education institution. *International Journal of Sustainability in Higher Education*, *21*(7), 1351-1366.


Caissie, D. (2006). The thermal regime of rivers: a review. *Freshwater biology*, *51*(8), 1389-1406.

Ceccaroni, L., Woods, S. M., Butkevičienė, E., Parkinson, S., Sprinks, J., Costa, P., ... & Piera, J. (2023). The role of citizen science in promoting ocean and water literacy in school communities: The ProBleu Methodology. *Sustainability*, *15*(14), 11410.

Conole, G., & Fill, K. (2005). A learning design toolkit to create pedagogically effective learning activities. *Journal of Interactive Media in Education*, (1).

Cosgrove, W. J., & Loucks, D. P. (2015). Water management: Current and future challenges and research directions. *Water Resources Research*, *51*(6), 4823-4839.


Cosgrove, W. J., & Loucks, D. P. (2015). Water management: Current and future challenges and research directions. *Water Resources Research*, *51*(6), 4823-4839.


Coyne, R. (2005). Wicked problems revisited. *Design studies*, *26*(1), 5-17.

Craswell, E. (2021). Fertilizers and nitrate pollution of surface and ground water: an increasingly pervasive global problem. *SN Applied Sciences*, *3*(4), 518.

Daniell, K. A., & Barreteau, O. (2014). Water governance across competing scales: Coupling land and water management. *Journal of hydrology*, *519*, 2367-2380.

Delgado, A., Rodriguez, D. J., Amadei, C. A., & Makino, M. (2024). Water in circular economy and resilience (WICER) framework. *Utilities Policy*, *87*, 101604.

Dolan, F., Lamontagne, J., Link, R., Hejazi, M., Reed, P., & Edmonds, J. (2021). Evaluating the economic impact of water scarcity in a changing world. *Nature communications*, *12*(1), 1-10.

Douville, H., Raghavan, K., Renwick, J., Allan, R. P., Arias, P. A., Barlow, M., ... & Zolina, O. (2021). Water cycle changes.

du Plessis, A. (2022). Persistent degradation: Global water quality challenges and required actions. *One Earth*, *5*(2), 129-131.

Dwivedi, A. K. (2017). Researches in water pollution: A review. *International Research Journal of Natural and Applied Sciences*, *4*(1), 118-142.

Earle, A., Jägerskog, A., & Öjendal, J. (Eds.). (2013). *Transboundary water management: Principles and practice*. Routledge.

Eickhout, B., Bouwman, A. V., & Van Zeijts, H. (2006). The role of nitrogen in world food production and environmental sustainability. Agriculture, ecosystems & environment, 116(1-2), 4-14.

Elsner, G. (2023). Will Europe's next crisis be a water crisis?. *European View*, *22*(2), 255-262.

Ersoy, A., & Lagendijk, A. (2024). 'Mattering'the circular economy: tackling the Achilles' heel of sustainable places via adopting a critical-relational perspective. Cambridge Journal of Regions, Economy and Society, 17(3), 565-576.

Falkenmark, M., & Rockström, J. (2004). *Balancing water for humans and nature: the new approach in ecohydrology*. Earthscan.

Farrelly, M., & Brown, R. (2011). Rethinking urban water management: experimentation as a way forward?. *Global environmental change*, *21*(2), 721-732.

Fathollahi-Fard, A. M., Ahmadi, A., & Al-e-Hashem, S. M. (2020). Sustainable closed-loop supply chain network for an integrated water supply and wastewater collection system under uncertainty. *Journal of Environmental Management*, *275*, 111277.

Ferraz, D., & Pyka, A. (2023). Circular economy, bioeconomy, and sustainable development goals: a systematic literature review. Environmental Science and Pollution Research, 1-22.

Ferriman A. BMJ readers choose the "sanitary revolution" as greatest medical advance since 1840. BMJ2007;334: 111.2.doi:10.1136/bmj.39097.611806.DB pmid:17235067.

Fletcher, C., Ripple, W. J., Newsome, T., Barnard, P., Beamer, K., Behl, A., ... & Wilson, M. (2024). Earth at risk: An urgent call to end the age of destruction and forge a just and sustainable future. *PNAS nexus*, *3*(4), pgae106.

Flörke, M., Schneider, C., & McDonald, R. I. (2018). Water competition between cities and agriculture driven by climate change and urban growth. *Nature Sustainability*, *1*(1), 51-58.

Geissdoerfer, M., Savaget, P., Bocken, N. M., & Hultink, E. J. (2017). The Circular Economy–A new sustainability paradigm?. *Journal of cleaner production*, *143*, 757-768.

Geissen, V., Mol, H., Klumpp, E., Umlauf, G., Nadal, M., van der Ploeg, M., ... & Ritsema, C. J. (2015). Emerging pollutants in the environment: a challenge for water resource management. *International soil and water conservation research*, *3*(1), 57-65.

Ghafourian et al. (2021) conducts an economic assessment of nature-based solutions that support circularity in water systems.

Ghafourian, M., Stanchev, P., Mousavi, A., & Katsou, E. (2021). Economic assessment of nature-based solutions as enablers of circularity in water systems. *Science of The Total Environment*, *792*, 148267.

Giannoccaro, I., Ceccarelli, G., & Fraccascia, L. (2021). Features of the higher education for the circular economy: the case of Italy. Sustainability, 13(20), 11338.

Giuliani, M., Lamontagne, J. R., Reed, P. M., & Castelletti, A. (2021). A state-of-the-art review of optimal reservoir control for managing conflicting demands in a changing world. *Water Resources Research*, *57*(12), e2021WR029927.

Goel, P. K. (2006). *Water pollution: causes, effects and control*. New age international.

Guerra-Rodríguez, S., Oulego, P., Rodríguez, E., Singh, D. N., & Rodríguez-Chueca, J. (2020). Towards the implementation of circular economy in the wastewater sector: Challenges and opportunities. *Water*, *12*(5), 1431.

Gravemeijer, K., & Cobb, P. (2006). Design research from a learning design perspective. In *Educational design research* (pp. 29-63). Routledge.

Green, R. A. (2014). The Delphi technique in educational research. *Sage Open*, *4*(2), 2158244014529773.

Gupta, E., & Prabhakar, V. N. (2024). A Bronze Age Inland Water Network and Its Role in the Maritime Trade Network of the Harappan (Indus) Civilization. Journal of Maritime Archaeology, 19(2), 327-350.

Han, X., Boota, M. W., Soomro, S. E. H., Ali, S., Soomro, S. G. H., Soomro, N. E. H., ... & Tayyab, M. (2024). Water strategies and management: current paths to sustainable water use. *Applied Water Science*, *14*(7), 154.

He, C., Liu, Z., Wu, J., Pan, X., Fang, Z., Li, J., & Bryan, B. A. (2021). Future global urban water scarcity and potential solutions. *Nature Communications*, *12*(1), 4667.

Hein, C. (2020). *Adaptive strategies for water heritage: Past, present and future* (p. 435). Springer Nature.

Herrington, J., & Oliver, R. (2000). An instructional design framework for authentic learning environments. *Educational technology research and development*, *48*(3), 23-48.

Imaduddin, M., & Eilks, I. (2024). A scoping review and bibliometric analysis of educational research on water literacy and water education. SUSTAINABLE CHEMISTRY AND PHARMACY, 42. https://doi.org/10.1016/j.scp.2024.101833

Ingrao, C., Strippoli, R., Lagioia, G., & Huisingh, D. (2023). Water scarcity in agriculture: An overview of causes, impacts and approaches for reducing the risks. *Heliyon*.

IPCC, 2021: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*[Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, In press, doi:10.1017/9781009157896.

IPCC. (2022). *Climate change 2022: Impacts, adaptation, and vulnerability* (Chapter 4). Retrieved from https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_Chapter04.pd

Iwmi. (2024, 28 augustus). *Wicked water problems: Facing challenges, finding solutions*. International Water Management Institute (IWMI). https://www.iwmi.cgiar.org/news/wicked-water-problems-facing-challenges-finding-solutions/

Janssens, L., Kuppens, T., & Van Schoubroeck, S. (2021). Competences of the professional of the future in the circular economy: Evidence from the case of Limburg, Belgium. Journal of Cleaner Production, 281, 125365.

Jepson, W., Budds, J., Eichelberger, L., Harris, L., Norman, E., O'Reilly, K., ... & Young, S. (2017). Advancing human capabilities for water security: A relational approach. *Water Security*, *1*, 46-52.

Johansson, N. (2021). Does the EU's action plan for a circular economy challenge the linear economy?. *Environmental Science & Technology*, *55*(22), 15001-15003.

Julio, N., Figueroa, R., & Ponce Oliva, R. D. (2021). Water resources and governance approaches: Insights for achieving water security. *Water*, *13*(21), 3063.

Julio, N., Figueroa, R., & Ponce Oliva, R. D. (2022). Advancing toward water security: addressing governance failures through a metagovernance of modes approach. *Sustainability Science*, *17*(5), 1911-1920

Kakwani, N. S., & Kalbar, P. P. (2020). Review of Circular Economy in urban water sector: Challenges and opportunities in India. *Journal of Environmental Management*, *271*, 111010.

Kaunda, C. S., Kimambo, C. Z., & Nielsen, T. K. (2012). Hydropower in the context of sustainable energy supply: a review of technologies and challenges. *International Scholarly Research Notices*, *2012*(1), 730631.

Khorrami, M., & Malekmohammadi, B. (2021). Effects of excessive water extraction on groundwater ecosystem services: Vulnerability assessments using biophysical approaches. *Science of the Total Environment*, *799*, 149304.

Kirchherr, J., & Piscicelli, L. (2019). Towards an education for the circular economy (ECE): five teaching principles and a case study. Resources, Conservation and Recycling, 150, 104406.

Kopnina, H. (2020). Education for the future? Critical evaluation of education for sustainable development goals. The Journal of Environmental Education, 51(4), 280-291.

Lane, J. M., & Pretes, M. (2020). Maritime dependency and economic prosperity: Why access to oceanic trade matters. *Marine Policy*, *121*, 104180.

Larsen, T. A., Hoffmann, S., Lüthi, C., Truffer, B., & Maurer, M. (2016). Emerging solutions to the water challenges of an urbanizing world. Science, 352(6288), 928-933.

Larson, K. L., White, D. D., Gober, P., & Wutich, A. (2015). Decision-making under uncertainty for water sustainability and urban climate change adaptation. *Sustainability*, *7*(11), 14761-14784.

Levy, A. R., & Moore Mensah, F. (2020). Learning through the experience of water in elementary school science. *Water*, *13*(1), 43.

Liu, J., Dietz, T., Carpenter, S. R., Folke, C., Alberti, M., Redman, C. L., ... & Provencher, W. (2007). Coupled human and natural systems. *AMBIO: a journal of the human environment*, *36*(8), 639-649.

Masi, F., Rizzo, A., & Regelsberger, M. (2018). The role of constructed wetlands in a new circular economy, resource oriented, and ecosystem services paradigm. *Journal of environmental management*, *216*, 275-284.

Mbavarira, T. M., & Grimm, C. (2021). A systemic view on circular economy in the water industry: learnings from a Belgian and Dutch case. Sustainability, 13(6), 3313.

McCarroll, M., & Hamann, H. (2020). What we know about water: A water literacy review. *Water*, *12*(10), 2803.

McGrane, S. J. (2016). Impacts of urbanisation on hydrological and water quality dynamics, and urban water management: a review. *Hydrological Sciences Journal*, *61*(13), 2295-2311.

McKenney, S., Nieveen, N., van den Akker, J., Gravemeijer, K., McKenney, S., & Nieveen, N. (2006). An introduction to educational Design Research. *Teoksessa van den Akker, J., Gravemeijer, K., McKenney, S. & Nieveen, N.(toim.), Educational Design Research. London: Routledge*, 110-144.

Mesa, J. A., & Esparragoza, I. (2021, October). Towards the implementation of Circular Economy in Engineering Education: A systematic review. In 2021 IEEE Frontiers in Education Conference (FIE) (pp. 1-8). IEEE.

Mishra, A., Mukherjee, S., Merz, B., Singh, V. P., Wright, D. B., Villarini, G., ... & Stedinger, J. R. (2022). An overview of flood concepts, challenges, and future directions. *Journal of hydrologic engineering*, *27*(6), 03122001.

Mishra, A., Mukherjee, S., Merz, B., Singh, V. P., Wright, D. B., Villarini, G., ... & Stedinger, J. R. (2022). An overview of flood concepts, challenges, and future directions. *Journal of hydrologic engineering*, *27*(6), 03122001.

Mishra, R. K. (2023). Fresh water availability and its global challenge. *British Journal of Multidisciplinary and Advanced Studies*, *4*(3), 1-78.

Moench, M. (1994). Approaches to ground water management: to control or enable?. *Economic and Political Weekly*, A135-A146.

Molle, F. (2006). *Planning and managing water resources at the river-basin level: Emergence and evolution of a concept* (Vol. 16). IWMI.

Moreno-Guerrero, A. J., Romero-Rodríguez, J. M., López-Belmonte, J., & Alonso-García, S. (2020). Flipped learning approach as educational innovation in water literacy. *Water*, *12*(2), 574.

Morseletto, P., Mooren, C. E., & Munaretto, S. (2022). Circular economy of water: definition, strategies and challenges. *Circular economy and sustainability*, *2*(4), 1463-1477.

Morseletto, P., Mooren, C. E., & Munaretto, S. (2022). Circular economy of water: definition, strategies and challenges. *Circular economy and sustainability*, *2*(4), 1463-1477.

Moss, T. (2003). Solving problems of 'fit'at the expense of problems of 'interplay'? The spatial reorganisation of water management following the EU Water Framework Directive. In *How institutions change:*

*perspectives on social learning in global and local environmental contexts* (pp. 85-121). Wiesbaden: VS Verlag für Sozialwissenschaften.

Moss, T., & Newig, J. (2010). Multilevel water governance and problems of scale: Setting the stage for a broader debate. *Environmental management*, *46*, 1-6.

Mostacedo-Marasovic, S. J., Mott, B. C., White, H., & Forbes, C. T. (2022). Towards water literacy: an interdisciplinary analysis of standards for teaching and learning about humans and Water. Disciplinary and Interdisciplinary Science Education Research, 4(1), 25.

Nasr-Azadani. (2020, 27 januari). Sustainability Competencies – Ellie Nasr-Azadani. Geraadpleegd op 19 februari 2025, van https://sites.psu.edu/ellienasr/2020/01/27/sustainability-competencies/

Neves, S. A., & Marques, A. C. (2022). Drivers and barriers in the transition from a linear economy to a circular economy. *Journal of Cleaner Production*, *341*, 130865.

Nunes, B. T., Pollard, S. J., Burgess, P. J., Ellis, G., De los Rios, I. C., & Charnley, F. (2018). University contributions to the circular economy: Professing the hidden curriculum. Sustainability, 10(8), 2719.

Nwokediegwu, Z. Q. S., Adefemi, A., Ayorinde, O. B., Ilojianya, V. I., & Etukudoh, E. A. (2024). Review of water policy and management: Comparing the USA and Africa. *Engineering Science & Technology Journal*, *5*(2), 402-411.

O'Shea G, Luoto S, Bor S, Hakala H, Nielsen IB (2021) The CWE and the seven Cs. In Jakobsen S, et al. (ed) Research Handbook of Innovation for a Circular Economy. Edward Elgar Publishing.

Olsson, G. (2015). *Water and energy: threats and opportunities*. IWA publishing.

Oughton C, Anda M, Kurup B, Ho G (2021) Water circular economy at the Kwinana Industrial Area, Western Australia—the dimensions and value of industrial symbiosis. Circ Econ Sustain 1(3):995–1018.

Owens, D. C., Petitt, D. N., Lally, D., & Forbes, C. T. (2020). Cultivating water literacy in STEM education: Undergraduates' socio-scientific reasoning about socio-hydrologic issues. *Water*, *12*(10), 2857.

P.M. Reed, J.R. Kasprzyk Water resources management: the myth, the wicked, and the future Journal of Water Resources Planning and Management, 135 (2009), pp. 411-413

Pahl-Wostl, C. (2007). Transitions towards adaptive management of water facing climate and global change. *Water resources management*, *21*, 49-62.

Pansera, M., Genovese, A., & Ripa, M. (2021). Politicising Circular Economy: what can we learn from Responsible Innovation?. *Journal of Responsible Innovation*, *8*(3), 471-477.

Papamichael, I., Voukkali, I., Stylianou, M., Naddeo, V., Ksibi, M., Zarra, T., & Zorpas, A. A. (2024). Sustainable production and consumption. *Euro-Mediterranean Journal for Environmental Integration*, 1-6

Petrie, B., Barden, R., & Kasprzyk-Hordern, B. (2015). A review on emerging contaminants in wastewaters and the environment: current knowledge, understudied areas and recommendations for future monitoring. *Water research*, *72*, 3-27.

Peydayesh, M., & Mezzenga, R. (2024). The circular economy of water across the six continents. *Chemical Society Reviews*.

Plomp, T. (2013). Educational design research: An introduction. *Educational design research*, 11-50.

Poff, N. L., Brown, C. M., Grantham, T. E., Matthews, J. H., Palmer, M. A., Spence, C. M., ... & Baeza, A. (2016). Sustainable water management under future uncertainty with eco-engineering decision scaling. *Nature Climate Change*, *6*(1), 25-34.

Pot, W. (2019). Anticipating the future in urban water management: An assessment of municipal investment decisions. *Water Resources Management*, *33*(4), 1297-1313.

Qu, D., Shevchenko, T., & Yan, X. (2020). University curriculum education activities towards circular economy implementation. International Journal of Scientific and Technology Research, 9(5), 200-206.

Ramm, K., & Smol, M. (2024). The potential for water recovery from urban waste water-The perspective of urban waste water treatment plant operators in Poland. *Journal of Environmental Management*, *358*, 120890.

Rammel, C., Stagl, S., & Wilfing, H. (2007). Managing complex adaptive systems—a co-evolutionary perspective on natural resource management. *Ecological economics*, *63*(1), 9-21.

Reid, A. J., Carlson, A. K., Creed, I. F., Eliason, E. J., Gell, P. A., Johnson, P. T., ... & Cooke, S. J. (2019). Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biological reviews*, *94*(3), 849-873.

Reid, P. C., Fischer, A. C., Lewis-Brown, E., Meredith, M. P., Sparrow, M., Andersson, A. J., ... & Washington, R. (2009). Impacts of the oceans on climate change. *Advances in marine biology*, *56*, 1-150.

Renfors, S. M. (2024). Education for the circular economy in higher education: an overview of the current state. International Journal of Sustainability in Higher Education, 25(9), 111-127.

Richey, A. S., Thomas, B. F., Lo, M. H., Reager, J. T., Famiglietti, J. S., Voss, K., ... & Rodell, M. (2015). Quantifying renewable groundwater stress with GRACE. *Water resources research*, *51*(7), 5217-5238.

Ritzema, H. P., & Van Loon-Steensma, J. M. (2018). Coping with climate change in a densely populated delta: A paradigm shift in flood and water management in the Netherlands. *Irrigation and Drainage*, *67*, 52-65.

Sadoff, C., & Muller, M. (2009). *Water management, water security and climate change adaptation: early impacts and essential responses*. Stockholm: Global Water Partnership.

Sánchez-García, E., Martínez-Falcó, J., Marco-Lajara, B., & Manresa-Marhuenda, E. (2024). Revolutionizing the circular economy through new technologies: A new era of sustainable progress. *Environmental Technology & Innovation*, *33*, 103509.

Sauvé, S., Lamontagne, S., Dupras, J., & Stahel, W. (2021). Circular economy of water: Tackling quantity, quality and footprint of water. *Environmental Development*, *39*, 100651.

Scalabrino, C., Navarrete Salvador, A., & Oliva Martínez, J. M. (2022). A theoretical framework to address education for sustainability for an earlier transition to a just, low carbon and circular economy. *Environmental Education Research*, *28*(5), 735-766.

Scanlon, B. R., Fakhreddine, S., Rateb, A., de Graaf, I., Famiglietti, J., Gleeson, T., ... & Zheng, C. (2023). Global water resources and the role of groundwater in a resilient water future. *Nature Reviews Earth & Environment*, *4*(2), 87-101.

Schindler, S., O'Neill, F. H., Biró, M., Damm, C., Gasso, V., Kanka, R., ... & Wrbka, T. (2016). Multifunctional floodplain management and biodiversity effects: a knowledge synthesis for six European countries. *Biodiversity and conservation*, *25*, 1349-1382

Serrano-Bedia, A. M., & Perez-Perez, M. (2022). Transition towards a circular economy: A review of the role of higher education as a key supporting stakeholder in Web of Science. Sustainable Production and Consumption, 31, 82-96.

Silva, J. A. (2023). Wastewater treatment and reuse for sustainable water resources management: a systematic literature review. *Sustainability*, *15*(14), 10940.

Sipahutar, R., Bernas, S. M., & Imanuddin, M. S. (2013). Renewable energy and hydropower utilization tendency worldwide. *Renewable and Sustainable Energy Reviews*, *17*, 213-215.

Smith, M. D., Sikka, A., Dirwai, T. L., & Mabhaudhi, T. (2023). Research and innovation in agricultural water management for a water-secure world. *Irrigation and Drainage*, *72*(5), 1245-1259.

Smol, M., Adam, C., & Preisner, M. (2020). Circular economy model framework in the European water and wastewater sector. *Journal of Material Cycles and Waste Management*, *22*, 682-697.

Stahel, W. R. (2019). *The circular economy: A user's guide*. Routledge.

Straub, L., Hartley, K., Dyakonov, I., Gupta, H., van Vuuren, D., & Kirchherr, J. (2023). Employee skills for circular business model implementation: A taxonomy. Journal of Cleaner Production, 410, 137027.

Suárez-Eiroa, B., Fernández, E., Méndez-Martínez, G., & Soto-Oñate, D. (2019). Operational principles of circular economy for sustainable development: Linking theory and practice. *Journal of cleaner production*, *214*, 952-961.

Tahir S, Steichen T and Shouler M (2018). Water and circular economy: a white paper. Ellen Mac=Arthur Foundation, Arup, Antea Group.

Thissen, W., Kwakkel, J., Mens, M., van der Sluijs, J., Stemberger, S., Wardekker, A., & Wildschut, D. (2017). Dealing with Uncertainties in Fresh Water Supply: Experiences in the Netherlands. *Water Resources Management*, *31*(2), 703–725. https://doi.org/10.1007/s11269-015-1198-1

Tiippana-Usvasalo, M., Pajunen, N., & Maria, H. (2023). The role of education in promoting circular economy. *International Journal of Sustainable Engineering*, *16*(1), 92-103.
Tleuken, A., Tokazhanov, G., Jemal, K. M., Shaimakhanov, R., Sovetbek, M., & Karaca, F. (2022). Legislative, institutional, industrial and governmental involvement in circular economy in central Asia: a systematic review. *Sustainability*, *14*(13), 8064.
Tonni, I. and Oliver, R. 2013. A Delphi approach to define learning outcomes and assessment. European Journal of Dental Education 17(1), pp. e173-e180.
Tzanakakis, V. A., Paranychianakis, N. V., & Angelakis, A. N. (2020). Water supply and water scarcity. *Water*, *12*(9), 2347.
Vidal, R., Marques, P. C., de Britto Vidal Filho, W., & Afzal, A. (2024). The role of higher education institutions in training engineers for the era of circular economy: the Portuguese case. Studies in Education Sciences, 5(3), e6221-e6221.
Vinayagam, V., Sikarwar, D., Das, S., & Pugazhendhi, A. (2024). Envisioning the innovative approaches to achieve circular economy in the water and wastewater sector. *Environmental Research*, *241*, 117663.
Vlachos, E., & Braga, B. (2001, May). The challenge of urban water management. In *Frontiers in urban water management: Deadlock or hope* (pp. 1-36). Cornwall: IWA Publishing.
Vörösmarty, C. J. et al. Global threats to human water security and river biodiversity. Nature 467, 555-561 (2010).
Weissbrodt, D. G., Winkler, M. K., & Wells, G. F. (2020). Responsible science, engineering and education for water resource recovery and circularity. *Environmental Science: Water Research & Technology*, *6*(8), 1952-1966.
Wesselink, A., Warner, J., Syed, M. A., Chan, F., Tran, D. D., Huq, H., ... & Zegwaard, A. (2015). Trends in flood risk management in deltas around the world: Are we going'soft'?. *International Journal of Water Governance*, *3*(4), 25-46.
Wesselink, A., Warner, J., Syed, M. A., Chan, F., Tran, D. D., Huq, H., ... & Zegwaard, A. (2015). Trends in flood risk management in deltas around the world: Are we going'soft'?. *International Journal of Water Governance*, *3*(4), 25-46.
Wiek, A., Withycombe, L., & Redman, C. L. (2011a). Key competencies in sustainability: A reference framework for academic program development. Sustainability Science, 6(2), 203–218. https://doi.org/10.1007/s11625-011-0132-6
Williams, I., Roberts, K., Shaw, P., & Cleasby, B. (2018). Applying circular economy thinking to industry by integrating education and research activities. *Detritus*, *1*, 134-143.
World Bank, World Development Report 2009: Reshaping Economic Geography. World Development Reports (World Bank, Washington, DC, 2009).
Xu, C. Y., Widén, E., & Halldin, S. (2005). Modelling hydrological consequences of climate change—progress and challenges. *Advances in Atmospheric Sciences*, *22*, 789-797.
Yalew, S., Prasad, P., Mul, M., & van der Zaag, P. (2024). Integrating equity and justice principles in water resources modeling and management. *Environmental Research Letters*, *19*(11), 111001.
Zikos, D., & Hagedorn, K. (2017). Competition for water resources from the European perspective. In *Competition for water resources* (pp. 19-35). Elsevier.
Serrano-Bedia, A. M., & Perez-Perez, M. (2022). Transition towards a circular economy: A review of the role of higher education as a key supporting stakeholder in Web of Science. *Sustainable Production and Consumption*, *31*, 82-96.
Sotelo, T. J., Sioen, G. B., & Satoh, H. (2021). Circling the drain: a systems analysis of opportunities for enhanced sewer self-purification technologies in wastewater management. Journal of Environmental Management, 288, 112451.

### *Educational theory/ connection with theory*


Bale, L. S. (1992). Gregory Bateson's theory of mind: Practical applications to pedagogy. *URL: http://www. narberthpa. com/Bale/lsbale_dop/learn. htm [2.2009]*.

Bateson, G. (2000). *Steps to an ecology of mind: Collected essays in anthropology, psychiatry, evolution, and epistemology*. University of Chicago press.

Dolye (2006) To appear in G. Scarlett (Ed.), Classroom management: An A-Z guide. New York: Sage, 2014

Ebbens, S., S. Ettekoven, M. Van Ast, O. de Loor en L. Spijkerboer (2020). *Effectief leren. De docent als regisseur.* Groningen: Noordhoff.

Handley, K., Sturdy, A., Fincham, R., & Clark, T. (2006). Within and beyond communities of practice: Making sense of learning through participation, identity and practice. *Journal of management studies*, *43*(3), 641-653.

Merrill, M.D. (2002). First Principles of Instruction. Educational Technology Research and Development, 50 (3), 43-59

Mezirow, J. (2018). Transformative learning theory. In *Contemporary theories of learning* (pp. 114-128). Routledge.

Tosey, P., Visser, M., & Saunders, M. N. (2012). The origins and conceptualizations of 'triple-loop' learning: A critical review. *Management learning*, *43*(3), 291-307.).

Sterling, S. (2013). Learning for resilience, or the resilient learner? Towards a necessary reconciliation in a paradigm of sustainable education. In *Resilience in social-ecological systems* (pp. 45-62). Routledge.

Wenger, E. (1998). Communities of practice: Learning as a social system. *Systems thinker*, *9*(5), 2-3.


### *Method*


Beiderbeck, D., Frevel, N., von der Gracht, H. A., Schmidt, S. L., & Schweitzer, V. M. (2021). Preparing, conducting, and analyzing Delphi surveys: Cross-disciplinary practices, new directions, and advancements. *MethodsX*, *8*, 101401.

Clarke, V., & Braun, V. (2014). Thematic analysis. In Encyclopedia of critical psychology (pp. 1947-1952). Springer, New York, NY.

Conole, G., & Fill, K. (2005). A learning design toolkit to create pedagogically effective learning activities. *Journal of Interactive Media in Education*, (1).

Green, R. A. (2014). The Delphi technique in educational research. *Sage Open*, *4*(2), 2158244014529773.

McKenney, S., & Reeves, T. (2018). *Conducting educational design research*. Routledge.

Gravemeijer, K., & Cobb, P. (2006). Design research from a learning design perspective. In *Educational design research* (pp. 29-63). Routledge.

Jacobsen, M., & McKenney, S. (2024). Educational design research: grappling with methodological fit. *Educational technology research and development*, *72*(5), 2743-2762.

Krathwohl, D. R. (2002). A revision of Bloom's taxonomy: An overview. *Theory into practice*, *41*(4), 212-218.

McKenney, S., Nieveen, N., van den Akker, J., Gravemeijer, K., McKenney, S., & Nieveen, N. (2006). An introduction to educational Design Research. *Teoksessa van den Akker, J., Gravemeijer, K., McKenney, S. & Nieveen, N.(toim.), Educational Design Research. London: Routledge*, 110-144.

Page MJ, et al. BMJ 2021;372:n71. doi: 10.1136/bmj.n71.

Plomp, T. (2013). Educational design research: An introduction. *Educational design research*, 11-50.

Siddaway, A. P., Wood, A. M., & Hedges, L. V. (2019). How to do a systematic review: a best practice guide for conducting and reporting narrative reviews, meta-analyses, and meta-syntheses. *Annual review of psychology*, *70*(1), 747-770. Harden, R. M. (2002). Learning outcomes and instructional objectives: is there a difference?. Medical teacher, 24(2), 151-155.

### *Introduction Literature Review*


Bianchi, G., Pisiotis, U. and Cabrera Giraldez, M., GreenComp The European sustainability competence framework, Punie, Y. and Bacigalupo, M. editor(s), EUR 30955 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-46485-3, doi:10.2760/13286, JRC128040.

Calenda, M., & Tammaro, R. (2015). The assessment of learning: from competence to new evaluation. Procedia-Social and Behavioral Sciences, 174, 3885-3892.

European Commission. (2015, December 2). *Closing the loop – An EU action plan for the Circular Economy* (COM(2015) 614 final). Publications Office of the European Union

Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. Journal of Cleaner production, 114, 11-32

Harden, R. M. (2002). Learning outcomes and instructional objectives: is there a difference?. Medical teacher, 24(2), 151-155.

Kennedy, D., Hyland, Á., & Ryan, N. (2009). Learning outcomes and competences.

Kirchherr, J., Reike, D. & Hekkert, M. 2017, "Conceptualizing the circular economy: an analysis of 114 definitions". Resources, Conservation and Recycling, Vol. 127 No., pp. 221-232.

Klieme, E., Hartig, J., & Rauch, D. (2008). The concept of competence in educational contexts. Assessment of competencies in educational contexts, 3, 22.

Murray, A., Skene, K., & Haynes, K. (2017). The circular economy: an interdisciplinary exploration of the concept and application in a global context. Journal of business ethics, 140, 369-380

Rotherham, A. J., & Willingham, D. T. (2010). 21st-century" skills. American educator, 17(1), 17-20.

Reike, D., Vermeulen, W. J., & Witjes, S. (2022). Conceptualization of circular economy 3.0: Synthesizing the 10R hierarchy of value retention options. *Towards a Circular Economy: Transdisciplinary Approach for Business*, 47-69.

UNESCO. (2020). Education for sustainable development: A roadmap. In *United Nations Educational, Scientific And Cultural Organization* (ISBN 978-92-3-100394-3). the United Nations Educational, Scientific and Cultural Organization. https://doi.org/10.54675/YFRE1448

Wagenaar, R. (2014). Competences and learning outcomes: a panacea for understanding the (new) role of Higher Education?. Tuning journal for higher education, 1(2), 273-302.

*Waters Center for Systems Thinking*. (z.d.). Geraadpleegd op 30 juli 2025, van https://waterscenterst.org/


### *Literature review*


Ab Hamid, N., Kamaruzaman, F. M., & Rasul, M. S. (n.d.). Exploring Dominant Approach for Teaching Circular Economy. Retrieved 4 April 2025, from https://pdfs.semanticscholar.org/4eba/7de387572a89005965fda28410b7a49ba99f.pdf

Abidli, A., Huang, Y., Rejeb, Z. B., Zaoui, A., & Park, C. B. (2022). Sustainable and efficient technologies for removal and recovery of toxic and valuable metals from wastewater: Recent progress, challenges, and future perspectives. Chemosphere, 292, 133102.

Afghani, N., Hamhaber, J., & Frijns, J. (2022). An Integrated Assessment Framework for Transition to Water Circularity. SUSTAINABILITY, 14(14). https://doi.org/10.3390/su14148533

Alaerts, G. J., & Kaspersma, J. M. (2022). Facing global transitions in water management: Advances in knowledge and capacity development and towards adaptive approaches. WATER POLICY, 24(5), 685–707. https://doi.org/10.2166/wp.2022.301

Al-Azzawi, M. S. M., Gondhalekar, D., & Drewes, J. E. (2022). Neighborhood-Scale Urban Water Reclamation with Integrated Resource Recovery for Establishing Nexus City in Munich, Germany: Pipe Dream or Reality? Resources, 11(7), Article 7. https://doi.org/10.3390/resources11070064

Arora, M., Yeow, L. W., Cheah, L., & Derrible, S. (2022). Assessing water circularity in cities: Methodological framework with a case study. RESOURCES CONSERVATION AND RECYCLING, 178. https://doi.org/10.1016/j.resconrec.2021.106042

Bellver-Domingo, A., & Hernández-Sancho, F. (2022). Circular economy and payment for ecosystem services: A framework proposal based on water reuse. JOURNAL OF ENVIRONMENTAL MANAGEMENT, 305. https://doi.org/10.1016/j.jenvman.2021.114416

Berbel, J., Mesa-Perez, E., & Simon, P. (2023). Challenges for Circular Economy under the EU 2020/741 Wastewater Reuse Regulation. GLOBAL CHALLENGES, 7(7). https://doi.org/10.1002/gch2.202200232

Bermúdez, L. A., Díaz, J. C. L., Pascual, J. M., Martínez, M. D. M., & Capilla, J. M. P. (2022). Study of the Potential for Agricultural Reuse of Urban Wastewater with Membrane Bioreactor Technology in the Circular Economy Framework. AGRONOMY-BASEL, 12(8). https://doi.org/10.3390/agronomy12081877

Bhatt, P., Bhandari, G., Bhatt, K., & Simsek, H. (2022). Microalgae-based removal of pollutants from wastewaters: Occurrence, toxicity and circular economy. CHEMOSPHERE, 306. https://doi.org/10.1016/j.chemosphere.2022.135576

Boon, H. J. (2024). A Comprehensive Approach to Water Literacy in the Context of Climate Change. EDUCATION SCIENCES, 14(6). https://doi.org/10.3390/educsci14060564

Borah, S. J., Ram, R., Kumar, V., & Dubey, K. K. (2023). Leakage of surfactants in greywater: Environmental impact, mitigation, and their circular economy. Journal of Environmental Chemical Engineering, 11(5), 110715.

Bouziotas, D., Stofberg, S., Frijns, J., Nikolopoulos, D., & Makropoulos, C. (2023). Assessing the resilience of circularity in water management: A modeling framework to redesign and stress-test regional systems under uncertainty. URBAN WATER JOURNAL, 20(5), 532–549. https://doi.org/10.1080/1573062X.2023.2190030

Burger, M., Stavropoulos, S., Ramkumar, S., Dufourmont, J., & van Oort, F. (2019). The heterogeneous skill-base of circular economy employment. Research Policy, 48(1), 248–261. https://doi.org/10.1016/j.respol.2018.08.015

Capodaglio, A. G. (2023). Biorefinery of Sewage Sludge: Overview of Possible Value-Added Products and Applicable Process Technologies. WATER, 15(6). https://doi.org/10.3390/w15061195

Cappellaro, E. (n.d.). Developing complex thinking through a systemic framework for water education: A case study on the domestic water cycle in French curricula. International Research in Geographical and Environmental Education, 0(0), 1–20. https://doi.org/10.1080/10382046.2024.2391661

Castellet-Viciano, L., Hernández-Chover, V., & Hernández-Sancho, F. (2022). The benefits of circular economy strategies in urban water facilities. SCIENCE OF THE TOTAL ENVIRONMENT, 844. https://doi.org/10.1016/j.scitotenv.2022.157172

Chhandama, M., Rai, P. K., & Lalawmpuii. (2023). Coupling bioremediation and biorefinery prospects of microalgae for circular economy. BIORESOURCE TECHNOLOGY REPORTS, 22. https://doi.org/10.1016/j.biteb.2023.101479

Cipolletta, G., Ozbayram, E. G., Eusebi, A. L., Akyol, Ç., Malamis, S., Mino, E., & Fatone, F. (2021). Policy and legislative barriers to close water-related loops in innovative small water and wastewater systems in Europe: A critical analysis. JOURNAL OF CLEANER PRODUCTION, 288. https://doi.org/10.1016/j.jclepro.2020.125604

Das, S., Singh, C. K., Sodhi, K. K., & Singh, V. K. (2023). Circular economy approaches for water reuse and emerging contaminant mitigation: Innovations in water treatment. ENVIRONMENT DEVELOPMENT AND SUSTAINABILITY. https://doi.org/10.1007/s10668-023-04183-z

David, L. O., Aigbavboa, C., Adepoju, O., & Nnamdi, N. (2025). Applying circular economy strategies in mitigating the perfect storm: The built environment context. SUSTAINABLE FUTURES, 9. https://doi.org/10.1016/j.sftr.2025.100444

de la Torre, R., Onggo, B. S., Corlu, C. G., Nogal, M., & Juan, A. N. A. (2021). The Role of Simulation and Serious Games in Teaching Concepts on Circular Economy and Sustainable Energy. ENERGIES, 14(4). https://doi.org/10.3390/en14041138

Deda, D., Barros, M. V., Rigueiro, C., & Teixeira, M. R. (2022). From Linear to Circular Ideas: An Educational Contest. SUSTAINABILITY, 14(18). https://doi.org/10.3390/su141811207

Delgado, A., Rodriguez, D. J., Amadei, C. A., & Makino, M. (2024). Water in circular economy and resilience (WICER) framework. Utilities Policy, 87, 101604.

Dhanker, R., Khatana, K., Verma, K., Singh, A., Heena, Kumar, R., & Mohamed, H. I. (2023). An integrated approach of algae-bacteria mediated treatment of industries generated wastewater: Optimal recycling of water and safe way of resource recovery. BIOCATALYSIS AND AGRICULTURAL BIOTECHNOLOGY, 54. https://doi.org/10.1016/j.bcab.2023.102936

Dias, D. F. C., Abily, M., Ribeiro, J. M., Jouhara, H., & Katsou, E. (2024). Screening Rainwater Harvesting Potentialities in the EU Industrial Sector: A Framework for Site-Specific Assessment. WATER, 16(12). https://doi.org/10.3390/w16121758

Drogkoula, M., Kokkinos, K., & Samaras, N. (2023). A Comprehensive Survey of Machine Learning Methodologies with Emphasis in Water Resources Management. APPLIED SCIENCES-BASEL, 13(22). https://doi.org/10.3390/app132212147

Evans, B., Khoury, M., Vamvakeridou-Lyroudia, L., Chen, O., Mustafee, N., Chen, A. S., Djordjevic, S., & Savic, D. (2023). A modelling testbed to demonstrate the circular economy of water. JOURNAL OF CLEANER PRODUCTION, 405. https://doi.org/10.1016/j.jclepro.2023.137018

Fernandes, E., & Marques, R. C. (2023). Review of Water Reuse from a Circular Economy Perspective. WATER, 15(5). https://doi.org/10.3390/w15050848

Fidélis, T., Cardoso, A. S., Riazi, F., Miranda, A. C., Abrantes, J., Teles, F., & Roebeling, P. C. (2021). Policy narratives of circular economy in the EU–Assessing the embeddedness of water and land in national action plans. Journal of Cleaner Production, 288, 125685.

Frijns, J., Smith, H. M., & Makropoulos, C. (2024). Enabling the uptake of circular water solutions. WATER POLICY, 26(1), 94–110. https://doi.org/10.2166/wp.2024.167

Garito, M. A., Caforio, A., Falegnami, A., Tomassi, A., & Romano, E. (2023). Shape the EU future citizen. Environmental education on the European Green Deal. ENERGY REPORTS, 9, 340–354. https://doi.org/10.1016/j.egyr.2023.06.001

Ghafourian, M., Nika, C. E., Mousavi, A., Mino, E., Al-Salehi, M., & Katsou, E. (2022). Economic impact assessment indicators of circular economy in a decentralised circular water system—Case of eco-touristic facility. SCIENCE OF THE TOTAL ENVIRONMENT, 822. https://doi.org/10.1016/j.scitotenv.2022.153602

Ghafourian, M., Stanchev, P., Mousavi, A., & Katsou, E. (2021). Economic assessment of nature-based solutions as enablers of circularity in water systems. SCIENCE OF THE TOTAL ENVIRONMENT, 792. https://doi.org/10.1016/j.scitotenv.2021.148267

Giannoccaro, I., Ceccarelli, G., & Fraccascia, L. (2021). Features of the Higher Education for the Circular Economy: The Case of Italy. SUSTAINABILITY, 13(20). https://doi.org/10.3390/su132011338

Gude, V. G. (2021). One water—Evolving roles of our precious resource and critical challenges. AQUA-WATER INFRASTRUCTURE ECOSYSTEMS AND SOCIETY, 70(4), 467–482. https://doi.org/10.2166/aqua.2021.154

Guerra-Rodríguez, S., Oulego, P., Rodríguez, E., Singh, D. N., & Rodríguez-Chueca, J. (2020). Towards the Implementation of Circular Economy in the Wastewater Sector: Challenges and Opportunities. Water, 12(5), Article 5. https://doi.org/10.3390/w12051431

Guerreschi, A., Piras, L., & Heck, F. (2023). Barriers to Efficient Knowledge Transfer for a Holistic Circular Economy: Insights towards Green Job Developments and Training for Young Professionals. YOUTH, 3(2), 553–578. https://doi.org/10.3390/youth3020038

Haizan, W. L., Roselya, W., & Voulvoulis, N. (2023). Systems thinking for the sustainability transformation of urban water systems. In CRITICAL REVIEWS IN ENVIRONMENTAL SCIENCE AND TECHNOLOGY (Vol. 53, Issue 11, pp. 1127–1147). TAYLOR & FRANCIS INC. https://doi.org/10.1080/10643389.2022.2131338

Harris, S., Tsalidis, G., Corbera, J. B., Gallart, J. J. E., & Tegstedt, F. (2021). Application of LCA and LCC in the early stages of wastewater treatment design: A multiple case study of brine effluents. In JOURNAL OF CLEANER PRODUCTION (No. 127298; Vol. 307). ELSEVIER SCI LTD. https://doi.org/10.1016/j.jclepro.2021.127298

Hernández-Chover, V., Castellet-Viciano, L., Bellver-Domingo, A., & Hernández-Sancho, F. (2022). The Potential of Digitalization to Promote a Circular Economy in the Water Sector. WATER, 14(22). https://doi.org/10.3390/w14223722

Hernández-Chover, V., Castellet-Viciano, L., Fuentes, R., & Hernández-Sancho, F. (2023). Circular economy and efficiency to ensure the sustainability in the wastewater treatment plants. JOURNAL OF CLEANER PRODUCTION, 384. https://doi.org/10.1016/j.jclepro.2022.135563

Hernández-Chover, V., Castellet-Viciano, L., & Hernández-Sancho, F. (2022). A Tariff Model for Reclaimed Water in Industrial Sectors: An Opportunity from the Circular Economy. WATER, 14(23). https://doi.org/10.3390/w14233912

Hoffman, J., Pelzer, P., Albert, L., Béneker, T., Hajer, M., & Mangnus, A. (2021). A futuring approach to teaching wicked problems. JOURNAL OF GEOGRAPHY IN HIGHER EDUCATION, 45(4), 576–593. https://doi.org/10.1080/03098265.2020.1869923

Hoinle, B., Roose, I., & Shekhar, H. (2021). Creating Transdisciplinary Teaching Spaces. Cooperation of Universities and Non-University Partners to Design Higher Education for Regional Sustainable Transition. SUSTAINABILITY, 13(7). https://doi.org/10.3390/su13073680

Ilmasari, D., Kamyab, H., Yuzir, A., Riyadi, F. A., Khademi, T., Al-Qaim, F. F., Kirpichnikova, I., & Krishnan, S. (2022). A review of the biological treatment of leachate: Available technologies and future requirements for the circular economy implementation. BIOCHEMICAL ENGINEERING JOURNAL, 187. https://doi.org/10.1016/j.bej.2022.108605

Imaduddin, M., & Eilks, I. (2024). A scoping review and bibliometric analysis of educational research on water literacy and water education. SUSTAINABLE CHEMISTRY AND PHARMACY, 42. https://doi.org/10.1016/j.scp.2024.101833

Issaoui, M., Jellali, S., Zorpas, A. A., & Dutournie, P. (2022). Membrane technology for sustainable water resources management: Challenges and future projections. SUSTAINABLE CHEMISTRY AND PHARMACY, 25. https://doi.org/10.1016/j.scp.2021.100590

Jakubus, M. (2024). Current Trends in Sustainable Sewage Sludge Management-A Case Study for Poznań County, Poland. SUSTAINABILITY, 16(12). https://doi.org/10.3390/su16125056

Janssens, L., Kuppens, T., & Van Schoubroeck, S. (2021). Competences of the professional of the future in the circular economy: Evidence from the case of Limburg, Belgium. JOURNAL OF CLEANER PRODUCTION, 281. https://doi.org/10.1016/j.jclepro.2020.125365

Kakwani, N. S., & Kalbar, P. P. (2024). Prioritization of strategies for urban water circular economy using water circularity indicator. WATER POLICY, 26(5), 480–505. https://doi.org/10.2166/wp.2024.233

Kehrein, P., van Loosdrecht, M., Osseweijer, P., Garfí, M., Dewulf, J., & Posada, J. (2020). A critical review of resource recovery from municipal wastewater treatment plants – market supply potentials, technologies and bottlenecks. Environmental Science: Water Research & Technology, 6(4), 877–910. https://doi.org/10.1039/c9ew00905a

Khajvand, M., Mostafazadeh, A. K., Drogui, P., Tyagi, R. D., & Brien, E. (2022). Greywater characteristics, impacts, treatment, and reclamation using adsorption processes towards the circular economy. ENVIRONMENTAL SCIENCE AND POLLUTION RESEARCH, 29(8), 10966–11003. https://doi.org/10.1007/s11356-021-16480-z

Khoury, M., Evans, B., Chen, O. T., Chen, A. S., Vamvakeridou-Lyroudia, L., Savic, D. A., Djordjevic, S., Bouziotas, D., Makropoulos, C., & Mustafee, N. (2023). NEXTGEN: A serious game showcasing circular economy in the urban water cycle. JOURNAL OF CLEANER PRODUCTION, 391. https://doi.org/10.1016/j.jclepro.2023.136000

Kioupi, V., Vakhitova, T. V., & Whalen, K. A. (2022). Active learning as enabler of sustainability learning outcomes: Capturing the perceptions of learners during a materials education workshop. MRS ENERGY & SUSTAINABILITY, 9(1), 64–78. https://doi.org/10.1557/s43581-021-00019-3

Kirchherr, J., & Piscicelli, L. (2019). Towards an Education for the Circular Economy (ECE): Five Teaching Principles and a Case Study. Resources Conservation and Recycling, 150, 104406. https://doi.org/10.1016/j.resconrec.2019.104406

Kopnina, H. (2022). Exploring posthuman ethics: Opening new spaces for postqualitative inquiry within pedagogies of the circular economy. AUSTRALIAN JOURNAL OF ENVIRONMENTAL EDUCATION, 38(3–4), 361–374. https://doi.org/10.1017/aee.2021.16

Koseoglu-Imer, D. Y., Oral, H. V., Calheiros, C. S. C., Krzeminski, P., Güçlü, S., Pereira, S. A., Surmacz-Górska, J., Plaza, E., Samaras, P., Binder, P. M., van Hullebusch, E. D., & Devolli, A. (2023). Current challenges and future perspectives for the full circular economy of water in European countries. JOURNAL OF ENVIRONMENTAL MANAGEMENT, 345. https://doi.org/10.1016/j.jenvman.2023.118627

Kundu, D., Dutta, D., Samanta, P., Dey, S., Sherpa, K. C., Kumar, S., & Dubey, B. K. (2022). Valorization of wastewater: A paradigm shift towards circular bioeconomy and sustainability. SCIENCE OF THE TOTAL ENVIRONMENT, 848. https://doi.org/10.1016/j.scitotenv.2022.157709

LaDue, N. D., Ackerman, J. R., Blaum, D., & Shipley, T. F. (2021). Assessing Water Literacy: Undergraduate Student Conceptions of Groundwater and Surface Water Flow. WATER, 13(5). https://doi.org/10.3390/w13050622

Lally, D., & Forbes, C. (2020). Sociohydrologic Systems Thinking: An Analysis of Undergraduate Students' Operationalization and Modeling of Coupled Human-Water Systems. Water (Basel), 12(4), 1040-. https://doi.org/10.3390/w12041040

Lange, K. P. H., Korevaar, G., Oskam, I. F., & Herder, P. M. (2022). Re-organise: Game-Based Learning of Circular Business Model Innovation. FRONTIERS IN SUSTAINABILITY, 3. https://doi.org/10.3389/frsus.2022.809700

Lechtenberg, F., Somoza-Tornos, A., Espuña, A., & Graells, M. (2021). Targeting economic and environmental benefits associated with the integration of regeneration units in water systems. JOURNAL OF CLEANER PRODUCTION, 323. https://doi.org/10.1016/j.jclepro.2021.129022

Lee, Y. C., Leite, F., & Lieberknecht, K. (2023). Prioritizing selection criteria of distributed circular water systems: A fuzzy based multi-criteria decision-making approach. JOURNAL OF CLEANER PRODUCTION, 417. https://doi.org/10.1016/j.jclepro.2023.138073

Leung, J. K. L., Ng, D. T. K., & Tsui, C. Y. (2024). A Primer for Design and Systems Thinkers: A First-Year Engineering Course for Mindset Development. EDUCATION SCIENCES, 14(1). https://doi.org/10.3390/educsci14010086

Li, J. Q., Wang, X. D., Liang, X. H., Song, X. L., Pan, L., & Lu, L. H. (2024). Water as a Key Focus Point for Developing Education for Sustainable Development: Content Analysis Based on Curriculum Standards. SUSTAINABILITY, 16(24). https://doi.org/10.3390/su162411229

Liu, Q. L., Yang, L. J., & Yang, M. Y. (2021). Digitalisation for Water Sustainability: Barriers to Implementing Circular Economy in Smart Water Management. SUSTAINABILITY, 13(21). https://doi.org/10.3390/su132111868

Manisha, M., Verma, K., Ramesh, N., Anirudha, T. P., Santrupt, R. M., Das, R., Kumar, M. S. M., Chanakya, H. N., & Rao, L. (2023). Socio-economic impact assessment of large-scale recycling of treated municipal wastewater for indirect groundwater recharge. SCIENCE OF THE TOTAL ENVIRONMENT, 859. https://doi.org/10.1016/j.scitotenv.2022.160207

Mannina, G., Badalucco, L., Barbara, L., Cosenza, A., Di Trapani, D., Gallo, G., Laudicina, V. A., Marino, G., Muscarella, S. M., Presti, D., & Helness, H. (2021). Enhancing a Transition to a Circular Economy in the Water Sector: The EU Project WIDER UPTAKE. WATER, 13(7). https://doi.org/10.3390/w13070946

Mannina, G., Badalucco, L., Barbara, L., Cosenza, A., Di Trapani, D., Laudicina, V. A., Muscarella, S. M., & Presti, D. (2022). Roadmapping the Transition to Water Resource Recovery Facilities: The Two Demonstration Case Studies of Corleone and Marineo (Italy). WATER, 14(2). https://doi.org/10.3390/w14020156

Mannina, G., Gulhan, H., & Ni, B. J. (2022). Water reuse from wastewater treatment: The transition towards circular economy in the water sector. BIORESOURCE TECHNOLOGY, 363. https://doi.org/10.1016/j.biortech.2022.127951

Marques, R. C., Pinto, F. S., & Miranda, J. (2023). Inclusivity, resilience, and circular economy of water services: Embracing a sustainable water future. UTILITIES POLICY, 85. https://doi.org/10.1016/j.jup.2023.101685

Mbavarira, T. M., & Grimm, C. (2021). A Systemic View on Circular Economy in the Water Industry: Learnings from a Belgian and Dutch Case. SUSTAINABILITY, 13(6). https://doi.org/10.3390/su13063313

McCarroll, M., & Hamann, H. (2020). What We Know about Water: A Water Literacy Review. WATER, 12(10). https://doi.org/10.3390/w12102803

Mendoza, J. M. F., Gallego-Schmid, A., & Azapagic, A. (2019). A methodological framework for the implementation of circular economy thinking in higher education institutions: Towards sustainable campus management. Journal of Cleaner Production, 226, 831–844. https://doi.org/10.1016/j.jclepro.2019.04.060

Mokski, E., Leal, W., Sehnem, S., & Guerra, J. (2023). Education for sustainable development in higher education institutions: An approach for effective interdisciplinarity. INTERNATIONAL JOURNAL OF SUSTAINABILITY IN HIGHER EDUCATION, 24(1), 96–117. https://doi.org/10.1108/IJSHE-07-2021-0306

Murray, R. T., Marbach-Ad, G., McKee, K., Lansing, S., Winner, M. E., & Sapkota, A. R. (2023). A curricular model to train doctoral students in interdisciplinary research at the food-energy-water nexus. FRONTIERS IN EDUCATION, 8. https://doi.org/10.3389/feduc.2023.1114529

Neri, A., Rizzuni, A., Garrone, P., & Cagno, E. (2024). Barriers and drivers to the development of an effective water reuse chain: Insights from an Italian water utility. CLEAN TECHNOLOGIES AND ENVIRONMENTAL POLICY. https://doi.org/10.1007/s10098-024-02899-8

Nguyen, M. D., Thomas, M., Surapaneni, A., Moon, E. M., & Milne, N. A. (2022). Beneficial reuse of water treatment sludge in the context of circular economy. ENVIRONMENTAL TECHNOLOGY & INNOVATION, 28. https://doi.org/10.1016/j.eti.2022.102651

Nika, C. E., Gusmaroli, L., Ghafourian, M., Atanasova, N., Buttiglieri, G., & Katsou, E. (2020). Nature-based solutions as enablers of circularity in water systems: A review on assessment methodologies, tools and indicators. Water Research, 183, 115988. https://doi.org/10.1016/j.watres.2020.115988

Nika, C. E., Vasilaki, V., Expósito, A., & Katsou, E. (2020). Water Cycle and Circular Economy: Developing a Circularity Assessment Framework for Complex Water Systems. Water Research, 187, 116423. https://doi.org/10.1016/j.watres.2020.116423

Novaes, C., & Marques, R. (2023). Are Rainwater and Stormwater Part of the Urban CE Efficiency? SUSTAINABILITY, 15(14). https://doi.org/10.3390/su151411168

Olabi, A. G., Shehata, N., Sayed, E. T., Rodriguez, C., Anyanwu, R. C., Russell, C., & Abdelkareem, M. A. (2023). Role of microalgae in achieving sustainable development goals and circular economy. SCIENCE OF THE TOTAL ENVIRONMENT, 854. https://doi.org/10.1016/j.scitotenv.2022.158689

Owens, D. C., Petitt, D. N., Lally, D., & Forbes, C. T. (2020). Cultivating Water Literacy in STEM Education: Undergraduates' Socio-Scientific Reasoning about Socio-Hydrologic Issues. WATER, 12(10). https://doi.org/10.3390/w12102857

Oyewo, O. A., Ramaila, S., & Mavuru, L. (2022). Harnessing Project-Based Learning to Enhance STEM Students' Critical Thinking Skills Using Water Treatment Activity. EDUCATION SCIENCES, 12(11). https://doi.org/10.3390/educsci12110780

Padhye, L. P., Bandala, E. R., Wijesiri, B., Goonetilleke, A., & Bolan, N. (2022). Hydrochar: A Promising Step Towards Achieving a Circular Economy and Sustainable Development Goals. FRONTIERS IN CHEMICAL ENGINEERING, 4. https://doi.org/10.3389/fceng.2022.867228

Parada, M. P., Kehrein, P., Xevgenos, D., Asveld, L., & Osseweijer, P. (2022). Societal values, tensions and uncertainties in resource recovery from wastewaters. JOURNAL OF ENVIRONMENTAL MANAGEMENT, 319. https://doi.org/10.1016/j.jenvman.2022.115759

Peydayesh, M., & Mezzenga, R. (2024). The circular economy of water across the six continents. CHEMICAL SOCIETY REVIEWS, 53(9), 4333–4348. https://doi.org/10.1039/d3cs00812f

Plevri, A., Monokrousou, K., Makropoulos, C., Lioumis, C., Tazes, N., Lytras, E., Samios, S., Katsouras, G., & Tsalas, N. (2021). Sewer Mining as a Distributed Intervention for Water-Energy-Materials in the Circular Economy Suitable for Dense Urban Environments: A Real World Demonstration in the City of Athens. WATER, 13(19). https://doi.org/10.3390/w13192764

Podgórska, M., & Zdonek, I. (2024). Interdisciplinary collaboration in higher education towards sustainable development. SUSTAINABLE DEVELOPMENT, 32(3), 2085–2103. https://doi.org/10.1002/sd.2765

Ramírez-Agudelo, N. A., de Pablo, J., & Roca, E. (2021). Exploring alternative practices in urban water management through the lens of circular economy-A case study in the Barcelona metropolitan area. JOURNAL OF CLEANER PRODUCTION, 329. https://doi.org/10.1016/j.jclepro.2021.129565

Ramm, K., & Smol, M. (2024). The potential for water recovery from urban waste water—The perspective of urban waste water treatment plant operators in Poland. JOURNAL OF ENVIRONMENTAL MANAGEMENT, 358. https://doi.org/10.1016/j.jenvman.2024.120890

Renfors, S. M. (2024). Education for the circular economy in higher education: An overview of the current state. INTERNATIONAL JOURNAL OF SUSTAINABILITY IN HIGHER EDUCATION, 25(9), 111–127. https://doi.org/10.1108/IJSHE-07-2023-0270

Renfrew, D., Vasilaki, V., McLeod, A., Lake, A., Danishvar, S., & Katsou, E. (2022). Where is the greatest potential for resource recovery in wastewater treatment plants? WATER RESEARCH, 220. https://doi.org/10.1016/j.watres.2022.118673

Renfrew, D., Vasilaki, V., Nika, E., Tsalidis, G., Marin, E., & Katsou, E. (2024). Systematic assessment of wastewater resource circularity and sustainable value creation. WATER RESEARCH, 251. https://doi.org/10.1016/j.watres.2024.121141

Royse, E. A., Manzanares, A. D., Wang, H. Q., Haudek, K. C., Azzarello, C. B., Horne, L. R., Druckenbrod, D. L., Shiroda, M., Adams, S. R., Fairchild, E., Vincent, S., Anderson, S. W., & Romulo, C. (2024). FEW questions, many answers: Using machine learning to assess how students connect food-energy-water (FEW) concepts. HUMANITIES & SOCIAL SCIENCES COMMUNICATIONS, 11(1). https://doi.org/10.1057/s41599-024-03499-z

Samberger, C. (2022). The role of water circularity in the food-water-energy nexus and climate change mitigation. ENERGY NEXUS, 6. https://doi.org/10.1016/j.nexus.2022.100061

Samberger, C., Imen, S., Messologitis, K., Umble, A., & Jacangelo, J. G. (2024). Assessing circularity of wastewater treatment systems: A critical review of indicators. JOURNAL OF INDUSTRIAL ECOLOGY, 28(2), 262–276. https://doi.org/10.1111/jiec.13457

Santos, A. S. P., Lima, M. A. D., Paixao, M. M., Jordao, E. P., & Vieira, J. M. P. (2024). A perspective for the acceptance of water reuse: History of the valorization of wastewater throughout the development of society. WATER POLICY, 26(4), 336–358. https://doi.org/10.2166/wp.2024.196

Sauvé, S., Bernard, S., & Sloan, P. (2016). Environmental sciences, sustainable development and circular economy: Alternative concepts for trans-disciplinary research. Environmental Development, 17, 48–56. https://doi.org/10.1016/j.envdev.2015.09.002

Sauvé, S., Lamontagne, S., Dupras, J., & Stahel, W. (2021). Circular economy of water: Tackling quantity, quality and footprint of water. ENVIRONMENTAL DEVELOPMENT, 39. https://doi.org/10.1016/j.envdev.2021.100651

Scalabrino, C., Salvador, A. N., & Martínez, J. M. O. (2022). A theoretical framework to address education for sustainability for an earlier transition to a just, low carbon and circular economy. ENVIRONMENTAL EDUCATION RESEARCH, 28(5), 735–766. https://doi.org/10.1080/13504622.2022.2031899

Serrano-Bedia, A. M., & Perez-Perez, M. (2022). Transition towards a circular economy: A review of the role of higher education as a key supporting stakeholder in Web of Science. SUSTAINABLE PRODUCTION AND CONSUMPTION, 31, 82–96. https://doi.org/10.1016/j.spc.2022.02.001

Sibley, D. F., Anderson, C. W., Merle Heidemann, Heidemann, M., John Merrill, Merrill, J., Joyce Parker, Parker, J., David W. Szymanski, & Szymanski, D. W. (2007). Box diagrams to assess students systems thinking about the rock, water and carbon cycles. Journal of Geoscience Education, 55(2), 138–146. https://doi.org/10.5408/1089-9995-55.2.138

Silva, J. A. (2022). Implementation and Integration of Sustainability in the Water Industry: A Systematic Literature Review. SUSTAINABILITY, 14(23). https://doi.org/10.3390/su142315919

Smol, M. (2023). Circular Economy in Wastewater Treatment Plant-Water, Energy and Raw Materials Recovery. ENERGIES, 16(9). https://doi.org/10.3390/en16093911

Smol, M., & Koneczna, R. (2021). Economic Indicators in Water and Wastewater Sector Contributing to a Circular Economy (CE). RESOURCES-BASEL, 10(12). https://doi.org/10.3390/resources10120129

Smol, M., Mejia, A., Gastaldi, M., & D'Adamo, I. (2025). Environmental Indicators for Assessment of Circular Economy (CE) Implementation in the Water and Wastewater Sector. BUSINESS STRATEGY AND THE ENVIRONMENT, 34(2), 1993–2011. https://doi.org/10.1002/bse.4090

Smol, M., Szoldrowska, D., & Duda, J. (2025). Identification of Barriers and Driving Forces for Circular Economy (CE) Implementation in Water and Wastewater Companies. BUSINESS STRATEGY AND THE ENVIRONMENT, 34(2), 2167–2189. https://doi.org/10.1002/bse.4097

Tiippana-Usvasalo, M., Pajunen, N., & Maria, H. (2023). The role of education in promoting circular economy. INTERNATIONAL JOURNAL OF SUSTAINABLE ENGINEERING, 16(1), 92–103. https://doi.org/10.1080/19397038.2023.2210592

Valenti, F., & Toscano, A. (2021). A GIS-Based Model to Assess the Potential of Wastewater Treatment Plants for Enhancing Bioenergy Production within the Context of the Water-Energy Nexus. ENERGIES, 14(10). https://doi.org/10.3390/en14102838

Van Borek, S., & Abrams, A. L. (2023). Respecting local knowledge keepers through cellphilms featuring local water bodies: Towards decolonizing water management. AQUA-WATER INFRASTRUCTURE ECOSYSTEMS AND SOCIETY, 72(5), 663–672. https://doi.org/10.2166/aqua.2023.169

Vinayagam, V., Sikarwar, D., Das, S., & Pugazhendhi, A. (2024). Envisioning the innovative approaches to achieve circular economy in the water and wastewater sector. ENVIRONMENTAL RESEARCH, 241. https://doi.org/10.1016/j.envres.2023.117663

Voulvoulis, N. (2018). Water reuse from a circular economy perspective and potential risks from an unregulated approach. Current Opinion in Environmental Science & Health, 2, 32–45. https://doi.org/10.1016/j.coesh.2018.01.005

Wan Rosely, W. I. H., & Voulvoulis, N. (2023). Systems thinking for the sustainability transformation of urban water systems. Critical Reviews in Environmental Science and Technology, 53(11), 1127–1147. https://doi.org/10.1080/10643389.2022.2131338

Whalen, K., Berlin, C., Johanna Ekberg, Ekberg, J., Ilaria Giovanna Barletta, Barletta, I. G., Peter Hammersberg, & Hammersberg, P. (2017). 'All they do is win': Lessons learned from use of a serious game for Circular Economy education. Resources Conservation and Recycling, 135, 335–345. https://doi.org/10.1016/j.resconrec.2017.06.021

Whitehill, S., Hayles, C. S., Jenkins, S., & Taylour, J. (2022). Engagement with Higher Education Surface Pattern Design Students as a Catalyst for Circular Economy Action. SUSTAINABILITY, 14(3). https://doi.org/10.3390/su14031146

Xia, L., & Peng, G. H. (2022). Interdisciplinarity in Graduate Education for Groundwater Science and Technology. SUSTAINABILITY, 14(9). https://doi.org/10.3390/su14095645

Yadav, G., Mishra, A., Ghosh, P., Sindhu, R., Vinayak, V., & Pugazhendhi, A. (2021). Technical, economic and environmental feasibility of resource recovery technologies from wastewater. In SCIENCE OF THE TOTAL ENVIRONMENT (No. 149022; Vol. 796). ELSEVIER. https://doi.org/10.1016/j.scitotenv.2021.149022

Zhan, Z. H., Yao, X., & Li, T. T. (2023). Effects of association interventions on students' creative thinking, aptitude, empathy, and design scheme in a STEAM course: Considering remote and close association. INTERNATIONAL JOURNAL OF TECHNOLOGY AND DESIGN EDUCATION, 33(5), 1773–1795. https://doi.org/10.1007/s10798-022-09801-x

Zhang, X. Y., & Liu, Y. (2022). Circular economy is game-changing municipal wastewater treatment technology towards energy and carbon neutrality. CHEMICAL ENGINEERING JOURNAL, 429. https://doi.org/10.1016/j.cej.2021.132114

Zimmermann, K. (2024). End-user participation in drinking water management through Awareness, Education, and Resources: Tools for Water Partnerships. WATER POLICY, 26(12), 1222–1233. https://doi.org/10.2166/wp.2024.045

# Appendix A: Questionnaire educators

## Circular Water Economy - key learning objectives from Academics - Questionnaire

**Section 1: Research area relevance to the circular water economy & Its impact on curriculum design**

1. What is your current research area/field? And what are the main research questions in your research area?
2. How does your current research area intersect with the CE and sustainable water management?
3. Are there emerging topics in your research that you believe will become essential for future circular (water) professionals?
4. What aspects/subjects/topics/concepts of your research area do you think are currently integral to ensuring sustainable/circular water management?
5. What aspects in your research area do you think could enhance students' understanding of the complexities involved in (circular) water management?

**Section 2: Research area contributions to learning outcomes and skills development**

1. Are there any particular tools, methodologies, or approaches from your research that you think future water professionals must learn to effectively engage in circular water management?
2. Can you identify key innovations, findings or areas from your research that would provide practical case studies relevant to circular (water) economy?
3. In your opinion, what are the top three challenges in your research area that could serve as learning objectives for future circular (water) professionals?
4. Are there trade-offs in your field that could serve as valuable discussion topics in circular water economy education?
5. What specific skills or competencies are essential for current (water) professionals to support the transition to a circular (water) economy?

**Section 3: Assessment techniques aligned with research area**

1. Based on your research expertise, what types of assessments would be most effective for evaluating students' understanding?
2. Could any of the research methodologies you use in your research area be adapted for student assessments?
3. How can students apply findings from your research area to real-world problems as part of their assessments?

**Section 5: Feedback**

Do you have any additional suggestions for how your research can inform the structure or content of the proposed master's program?

# Appendix B: Questionnaire Case study holders

## Circular Water Economy - key learning objectives from Case Study Holders - Questionnaire

**Section 1: personal background and project context**

1. Can you briefly describe your role in the project(s) WATER-MINNING/ ULTIMATE?
2. What types of technologies or practices were developed, and what role did you or your team play in their development or application?

**Section 2: Specifics on CE Practices and Principles (best practices)**

1. What motivated your organization or team to work on circular water solutions?
2. Were any trade-offs or tensions encountered when applying CE pprinciples in your water management project context? How were these navigated?

**Section 3: Skills and Competencies for Circular Water Technology Development**

1. From your experience, what skills/competencies were most essential for developing and integrating the circular technologies mentioned earlier? And what skills/competencies do you think are needed to upscale, maintaining, and adapt those technologies?
2. Which of these skills/competencies were already present in the team, and which needed to be developed along the way and what did you learn from that?
3. Were there any unexpected skills/competencies or forms of knowledge that proved to be crucial during the process?
4. In your view, what should be emphasized in education programs to better prepare future professionals for working with circular water economy systems?

**Section 5: Specifics on Interdisciplinarity, Complexity, Systems Thinking, and Collaboration**

1. Did systems thinking play a role in how your team approached the project? If so, how was it applied in practice?
2. How did you and your team manage the complexity and uncertainty inherent in circular water systems? Can you name examples where complexity and uncertainty showed in your project?
3. Did interdisciplinarity play a role in how your team approached the project? If so, how was it applied in practice?
4. What communication and collaboration strategies helped bridge differences in perspective, language, or values within or outside the team?

**Section 6: Reflections and Open Questions**

1. Are there any skills or mindsets you believe will become increasingly important in future circular water projects that we have not discussed?
2. What would you recommend educational institutions focus on to better align curricula with real-world CWPs?
3. Is there anything we didn’t ask that you think is important for others to learn from your experience?

# Appendix C: Overview of sub-themes

*Figure 9 Overview of sub-themes with their description and example quotes from interviews*

| **Major Theme** | ***Sub-Theme*** | **Description** | **Representative Quote** |
|---|---|---|---|
| Technical Knowledge & Circular-Economy Thinking | *Foundational Engineering Knowledge* | Strong grounding in core engineering disciplines is essential for students. | "Good fundamental knowledge is crucial in (water) technology…basic process engineering tools…" (P6). |
| | *Key CWE practices content* | Essential technical topics include (direct) water reuse, contaminant removal, nutrient recovery, advanced separation processes. | – (Paraphrase of consensus; no single quote) |
| Systems Thinking & Complexity | *Complicated Implementation Challenges* | Many circular projects fail at scale due to lack of systems skills, policy misalignment, or non-technical barriers. | "Many current circular projects…stay in pilots…and break down in scaling up, because the policy doesn't allow it." (P4). |
| | *Shift to system-oriented mind-set* | Emphasizing a shift from siloed technology fixes to systems thinking, questioning linear assumptions. | "It's not about focusing on technology alone…You [must] see the whole system." (P7). |
| | *Context & Policy Adaptation* | Understanding that technologies must be adapted to local political, legal and institutional contexts (policy mobility principle). | "The technology was developed in a certain context, and the policy around it too…. You can't copy one to the other purely because of the context" (P4). |

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| | *New complexities* | Implementing CWPs adds multiple layers of complexity. Designing for a circular system—which is more interconnected—creates new challenges across various dimensions, including system interdependencies, stakeholder conflicts, environmental and geographic variability, as well as economic, regulatory, and behavioural factors. | "Management capability and problem-solving skills become much more relevant, because the failure of one unit can disrupt the entire system" (P1) |
| | *Integrality* | CWPs, their technologies, industries, and resources are interconnected within circular systems. Like Industrial Symbiosis. | "The realization is that by implementing different circular practices you have impact on other systems" (P7).<br>"Water is…an ideal way to make connections between processes…restore elements used in another process." (P6). |
| | *Stakeholder Engagement Across Layers* | Emphasizing that system redesign must involve stakeholders at all layers or else the change won't "stick." Besides, highlight that outside academia, professional collaboration is even harder (different sectors, departments, commitments). | "technical redesign does not mean at all that you will actually change behaviour or that you will actually create a different economy… you have to speak to stakeholders at all those different layers" (P3).<br>"It's very difficult... different companies and different sectors, different industries. You have other commitments....the effort is underestimated." (P7). "what happens over there is not my problem" (P7) |

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| | *Multi-layer and Interdependencies Thinking* | Teaching students to recognize multiple system layers (physical, design, market, behavioural, regulatory) and design accordingly. Highlighting how a change in water system(e.g. reuse) affects energy, agriculture, etc. – "nexus" thinking But also being able to Zooming In and Out and see the bigger picture. | "There's a physical layer, a design layer, then a market layer, behavioural layers, regulation layers... So you realize you can design on different layers" (P3).<br>""If you implement circular practices in the water sector—like recovering and reusing wastewater—what does that imply for energy demand, for example?" (P7).<br>"You need to see the trade-offs…don't stay in your little box…think a bit bigger" (P7). |
| | *Systems Mapping & Analysis Tools* | Advocating teaching tools like systems maps, scenario analysis, causal loops, and trade-off evaluation to build systems models. | "…support students in developing mental and visual models of circular systems, recognize dependencies across domains…" (P3). |
| | *Managing Trade-offs* | Recognizing specific trade-offs (e.g. water quality vs. reuse, sustainability vs. cost) and teaching compromises rather than one-size-fits-all solutions. | "Optimizing all trade-offs doesn't exist…we find a compromise that may not be optimal for everyone but still works." (P7). |
| | *System Boundary Awareness* | Teaching the distinction between closed vs. open systems (water cycles are highly open systems) and its impact on complexity. | "To what extent is this a closed system or an open system? Around water and nutrients, these systems are very open. Completely different influences go in and out. If you're talking about plastic bottles, that might be a fairly closed system" (P4). |
| Interdisciplinary Collaboration & Communication | *Multiple Disciplinary Perspectives* | Stressing that water challenges span over engineering, ecology, economics, sociology, policy, etc., so all must be integrated. | "There are just a whole bunch of issues where we really need all those perspectives" (P2). |

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| | *Economic Drivers & Market Realities* | Emphasizing that economic viability often determines success – students must understand market forces and finance. | "the economic side of things, the market economic side of things I believe is very critical to be part of those [CE] projects, because if there's no market for it, well, you can produce as much as you want. You're not going to sell it" (P8). |
| | *Environmental & Ecosystem Awareness* | Including environmental systems health and ecosystem services; encourages long-term and system-wide thinking beyond economics. | "We all should realise our ecosystem services are very important and we are very dependent on ecosystems for our services, but not a lot of people are concerned about ecosystems health" (P6). |
| | *Socio-Political Equity & Power* | Recognizing that CE transitions has winners and losers, affect equity and power relations; teaches students to question "win-win" claims. | "there is a group that benefits from it and a group that benefits less, there are winners and losers… So when people talk about win-win situations, you have to be suspicious in itself, because they are trying to sell something"" (P4). |
| | *Respect & Openness to Other Ways of Knowing* | Cultivating attitudes of respect and humility. Teach students that no single discipline holds the absolute truth, and recognizing the value of others' perspectives. | "Recognize that the other person's contribution is valuable" (P1). "keep in mind that you on your own can't give that last answer" (P3) |
| | *Challenge of Interdisciplinary Practice* | Caution that pushing all students to be generalists is risky; we still need specialists. Interdisciplinary training should complement, not replace, knowledge depth. | "If we are all focused on generalists and knowing from each other's discipline, then you might miss important aspects of your discipline in the discussion (P6). |

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| | *Communication* | Communicating across disciplinary boundaries requires more than simply sharing information, it demands the development of shared tools and language. | "people don't want to listen to each other, sometimes it's just literal, they can't listen to each other" (P3) |
| | *Multi-level* | Much of the theoretically calculated work need to be done by practical educated people, learning how to work together is really important to make the CWE successful | "then multi-level can help enormously to put someone with a brilliant innovative idea with both feet on the ground and [question] how would you realize all that" (P3). |
| Transferable Skills, Critical Thinking & Reflective Practice | *Values & Purpose Economy* | Highlighting the role of values and a purpose-driven economy (purpose over profit) in driving circular innovation. | "The base of the purpose economy is very much based on our values. And I think we need to have other values… it's not the financial gain for stakeholders, but it is actually a value to society" (P6). |
| | *Sustainability & Consumption Management* | Emphasizing reducing resource use (e.g. less water/energy demand) rather than relying solely on new technology for reuse. But also teaching students to take specific perspective, in case of a product perspective, ask "What do we actually need?" instead of always designing what is possible. | Don't pump so much water in the system in the first place, demand reduction "should also be included"" (P7). "The ivory implies we're getting worse at circling stuff through the economy or [we're] just consuming a rate that's faster than is able to be recycled and circled through" (P7). "If we really want to have a circular water system, I think that we need to address it from a product perspective" (P6). |

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| | *Long-Term Perspective & Design Horizon* | Noting that circular solutions often require long time-frames (beyond short political cycles) to prove that they are sustainable. | "Some companies came up and said this is not interesting to us, because this doesn't bring what we would like to have. So at that point you had to moderate this and try to convince them: okay, this is not a short-term gain, we're doing something for the long term" (P9). |
| | *CE thinking* | Move beyond linear, extractive models toward systems that prioritize reuse, regeneration, and interconnectivity. Teach students to change business as usual and that the transition to circular models is not a linear process. It is not a final outcome, but a way of working - an ongoing, iterative approach. But also to have a Waste-as-Resource Perspective | "Engineers… think very linearly from a problem to a solution to implementation" (P4)."Technology alone will not solve circularity"; instead, a "change in mind-set" is essential (P6).<br>"Allowing pollution in one area can be acceptable if…we achieve net environmental benefit." (P4). |
| | *Allow diversity of solution* | Teach students to go beyond purely mechanical linear thinking and adopt a more organic, systems-level mindset, one that still values analytical skills but also embraces complexity and diversity of solutions. | "It's never gonna be like petroleum… one solution for all" (P6). |
| | *Critical Thinking* | Teaching students to analyse depth, question assumptions, recognize trade-offs, and think in systemic layers. | "Students should… think in layers and dare to think a bit more in depth about the different issues and how they're related." (P7). "not every stakeholder therefore has an interest in the circular system" (P4). |

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| | *Personal Reflection & Adaptability / Lifelong Learning* | Instilling habits of reflection (learning about one's own learning) and adaptability so professionals keep learning and evolving. Encouraging self-critique so students can change when they are on the wrong path and learn from mistakes | "policy processes…must be shaped by learning too, instead of [being] directive right the first time" (P4).<br>"I'm really kind of on the wrong path there. Now I'm going to try something completely different and that you do it in a professional way. That's the only way, I think, to be able to have a conversation at all about something as sometimes quite elusive as transitions" (P3) |
| Active/Experiential Learning Strategies | *Project-Based Learning* | Immersing students in real or realistic problem scenarios rather than lectures; using case studies and realistic projects. | (Paraphrased from many participants) |
| | *Realistic Case Studies/ Learning from Success Stories* | Using existing circular water projects (e.g. Zero Brine, Water Mining, Green Village) as case studies to link theory with practice and bring learning into context. Showcasing partially successful circular projects to inspire students and "open the mind" to what is possible. | "Field visits on real case circular approaches inspire students to learn from practitioners." (P6).<br>"Success cases…not ideal, but it opens the mind to this is possible" (P6). |
| | *Creating Time for Reflection* | critical thinking and self-reflection practical application how to incorporate it into education is overlooked and highlighting the need for discussion and reflection in class. | "little time [is given] for reflection" (P6) |
| | *Teacher as active Facilitator* | Shifting the teacher's role to discussion leader and guide (rather than lecturer), using classroom time for dialogue and sense-making. | "Classrooms… should become more of a discussion platform…you should use the classroom for discussion, reflection, opinions." (P6). |

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| | *Peer Reflection & Team Feedback* | Structuring regular team check-ins for students to discuss group dynamics, communication, and each other's strengths/weaknesses. | "Transferable skills discussion to ask so at least to say let's look at each other again, how are you doing in terms of group dynamics, have you looked closely at each other's skills, but also at each other's personalities, is that a topic of conversation?" (P3). |
| | *Hands-On Demonstrations* | Bringing working test setups or living labs into the classroom so students can experiment (e.g. flowing tubes, pilot reactors). | "Bring test setups to the classroom…with flowing tubes and filters…mix of teacher info and practical info." (P3). |
| | *(Industrial) Field Visits* | Touring industrial facilities (even "it stinks a lot") so students witness complexity first-hand and bridge theory-practice gap. | "Have a look at [company's] industrial water system…it stinks a lot, but the experience is very important" (P3). |
| | *Embracing Uncertainty & Ownership* | Using open-ended, "deep-end" case problems to build resilience; encouraging student ownership by chosen their own topic of interest and create autonomy over their learning topics. | "Students are just thrown in at the deep end…supported by a facilitator. This creates the most impactful and transformative learning" (P3)."For master's students… it is your responsibility to make something of it" (P2). |
| | *Collaborative Learning Communities* | Engaging students in multi-level communities (professionals, universities, vocational schools) to discuss needed skills. | ""professionals, companies, schools, universities, colleges, also MBOs [vocational education] meet to think about: what skills do you need?" (P3). |
| | *Active Classroom Methods* | Using flipped classrooms, role-play, living labs and "multi-loop" reflection to integrate theory with practice. | "role-playing then becomes…a small reflection of what happens in reality" (P7). |

# Appendix D: Integrated Concepts

*Table 10 Integration of the concepts from interviews and literature review used for the conceptual framwork. Concepts in grey means that the concept was mentioned though the section did not align*

| Section | Interviews concepts | Literature concepts | Framework |
|---|---|---|---|
| **Knowledge themes** | Foundational Engineering Knowledge | Water domain specificity; Technical barriers and Operational Complexity; Technical challenges | **Foundational Engineering Knowledge** (including Water domain specificity, Technical barriers and Operational Complexity) |
| | CWPs | Water reuse; WWTPs; Emerging contaminants; Transformative technologies | **Key CWE practices content** (including water reuse, reuse of products, WWTPs operation, emerging contaminants and other transformative technologies) |
| | Waste-as-Resource Perspective; sustainability | Circular principles (including source protection, reuse, and waste minimization. *Close the loop:* Recovery of water, nutrients, and energy must include repurposing. Circular strategies must prioritize sustainable uses.) | **Circular principles** (including source protection, reuse, and waste minimization. *Close the loop:* Recovery of water, nutrients, and energy must include repurposing. Circular strategies must prioritize sustainable uses.) |
| | Systems Mapping & Analysis Tools | Metrics and tools and methodologies | **Metrics and tools and methodologies** (such as Life-Cycle assessment, Systems Mapping & Analysis Tools) |
| | Sustainability & Consumption Management | Water/pollutant refusal (prevention) | **Sustainability & Consumption Management** ( such as |

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|---|---|---|---|
| | | | Water/pollutant refusal and product perspective) |
| | | | |
| | - | Resilience thinking | **Resilience thinking** |
| | - | Centralized vs. Decentralization infrastructure | **Decentralization vs. centralisation practices** |
| | - | Water literacy | **Water literacy:** fundamental knowledge of hydrological water cycles |
| | Socio-Political Equity & Power | Socio, political and economy challenges | Socio, political and economy challenges that accompany CWPs |
| **Systemic** | Shift to System-oriented Mind-set; Integrality (like industrial symbiose); Multi-layer and Interdependencies thinking; Evaluating Trade-offs; System Boundary Awareness | System thinking | **Shift to system-oriented mind-set** (including recognising integrality, complexities, interdependencies and system boundaries) |
| | Long-Term Perspective & Design Horizon | Adaptive Planning Long term Thinking | **Adaptive planning long term design horizon** |
| | Allow diversity of solution | Sectoral diversity; Spatial diversity | **Diversity of solution** (including Sectoral and Spatial diversity) |
| **Interpersonal** | Multiple Disciplinary Perspectives | Interdisciplinary Collaboration | **Interdisciplinary collaboration** |
| | Respect & Openness to Other Ways of Knowing | Developing Collaborative Mindsets | **Developing Collaborative Mindsets** (including Respect & Openness to Other Ways of Knowing ) |
| | Economic Drivers & Market Realities | Entrepreneurial Skills | **Entrepreneurial skills** (including awareness of Economic Drivers & Market Realities) |

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|---|---|---|---|
| | Interdisciplinary Real-World Complexity | Stakeholder Engagement/ Cross-sector partnerships and Real-World Interaction | **Stakeholder Engagement/ Cross-sector partnerships and Real-World Interaction** |
| | Multi-level | - | **Multi-level** (collaboration between vocational, applied and theoretical education) |
| | - | End-User Participation in Water Management | **End-User Participation for CWPs design** |
| **Reflective** | CE thinking; Sustainability; Values & | Developing Circular Mindsets; A shared understanding, willingness to understand differing perspectives. challenge and transform systems The concept of "embracing empathy" and understanding others is crucial | **Developing Circular Mindsets** (including learning about purpose economy and resilient thinking). |
| | - | Allow Creativity | **Allow creativity** |
| | Critical Thinking | Critical Thinking | **Critical thinking** |
| | Personal Reflection & Adaptability / Lifelong Learning | Reflections; Transformative learning | **Reflective Learning/ Lifelong Learning** |
| | Environmental & Ecosystem Awareness | Economic and Environmental Benefits | **Environmental & Ecosystem Awareness** |
| | "Water is nature" | Ethical Awareness; Posthuman Ethics | **Ethical awareness** ( involves understanding the value of water as well as recognizing one's own values and their implications in decision-making) |
| | - | Self Confidence | **Self confidence** |
| | | | |
| **Teaching method** | Project-Based Learning | Project-Based Learning | **Project-Based Learning** |

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|---|---|---|---|
| | Realistic Case Studies | Integration of Real-World Contexts and case-based learning; Constructivist learning; | **Integration of Real-World Contexts and case-based learning** |
| | (Industrial) Field Visits | Field trips | **Field Visits** |
| | Hands-On Demonstrations | Experiential Learning Theory (ELT); Visualization and interactive tools | **Experiential Learning** (Including Hand-on Experiments) |
| | Peer Reflection & Team Feedback | Interdisciplinary Instructional Models | **Interdisciplinary Instructional, Reflection & Team Feedback** |
| | Embracing Uncertainty & Ownership | Transformative Learning | **Reflective learning, Embracing Uncertainty & Ownership** |
| | Collaborative Learning Communities | - | **Collaborative Learning Communities** (including living labs) |
| | Creating Time for Reflection | - | **Creating Time for Reflection** |
| | Teacher as Active Facilitator | *(was left out on purpose)* | **Teacher as active facilitator** |
| | - | Socio-Scientific Reasoning (SSR) | **Socio-Scientific Reasoning (SSR)** |
| | - | Interactivity, Games, and Simulations | **Interactivity, Games, and Simulations** |
| | Active Classroom Methods | Active-learning Pedagogies | **Active-learning Pedagogy (**flipped classrooms, role-play, living labs and "multi-loop" reflection**)** |

# Appendix E: Code Book

| All Codes | Merged codes | Sub-themes |
|---|---|---|
| actors analyses | behavioural change | Case studies |
| assessing | case studies | Circular thinking - mindset change |
| case studies | CE components | Clarifying complexity |
| choices | circularity | Cummunication |
| circular thinking | clarify complexity | Different perspectives |
| Circularity vs. sustainability | co-creation | Feedback |
| clarify complexity | common language | Fieldwork |
| classroom dynamic | complex | Fundamental knowledge |
| co-creation | critical thinking | Gap theory and real-world |
| common language | develop together enough tools | Horizon |
| communication | didactics | Integrality |
| complex | economic perspective | lack of system thinking |
| compromise | education | Learning communities |
| Conceptual map | expirience in the field | Learning proces |
| consortium | feedback | Methods of teaching |
| context | feeling of ownership | mixedlevel  knwoledge |
| co-ownership | flips, classrooms | Ownership |
| critical thinking | future generation | policy constrains/ policy mobility |
| CWE technologies | group work | problem or project based learning |
| decentralized solution | hands-on | problem-solving |
| degree of circularity | Horizon | Product perspective |
| develop together enough tools | incomplete perspective on exsisting knowledge level | Reflective thinking |
| directed education | industrial symbiosis | Self-criticism/reflection |
| economic perspective | integrality | Shift in perspective |
| ecotechnology | interdiciplinarity | Specialist/generalist |
| engineers thinking | layering of the system layers | Stakeholders |
| enviromental perspective | LCA | Sustainable |
| example emerging topic | learning communities | Teacher |
| expirience in the field | method for students intrests | Trade-off |
| feedback | method of assesment | Transition |
| feeling of ownership | multi level | Use of new concepts |
| flips, classrooms | not depleting the water system | |
| fundamental knowledge | practice | |

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|---|---|---|
| future generation | perspectives | |
| group dynamic | problem solving | |
| group work | problems of the CE | |
| hands-on | public support | |
| hard skills | rebound effect | |
| history | reduce water use | |
| Horizon | reflection | |
| Huff framework | right to nature | |
| Implementation Science | role philosophy | |
| Including social sciences | responsibility | |
| industrial symbiosis | single and double loop learning | |
| indutry perspective | skills | |
| integrality | stakeholders | |
| integrated resources managemen | symbiosis | |
| interdiciplinarity | system design | |
| layering of the system layers | teacher | |
| LCA | trade-offs | |
| learning be stimulated | transferable skills | |
| learning communities | Transformative learning | |
| linear thinking | transition | |
| living labs | transport medium | |
| method for students intrests | Triple Level Learning | |
| mindset | water | |
| multi level | | |
| nature-based/green chemistry | | |
| nexus thinking | | |
| Other CE concepts | | |
| perspectives | | |
| policy coherence analysis | | |
| policy mobility | | |
| Policy Promoting or Restrictive | | |
| pollutants | | |
| practical knowledge | | |
| problem solving | | |
| problem-oriented learning | | |
| problems of the CE | | |
| process analysis | | |
| product perspective | | |
| project start | | |
| Purpose economy. | | |
| rebound effect | | |
| reduce water use | | |
| reflection | | |

| | | |
|---|---|---|
| relate theory to practice | | |
| Reproduce | | |
| resilient | | |
| responsible | | |
| right to nature | | |
| risk assessments | | |
| role-playing | | |
| scenario discovery | | |
| simplify | | |
| single and double loop learning | | |
| socio/political perspective | | |
| specialist or generalist | | |
| stakeholders | | |
| story | | |
| sustainable technologies | | |
| System boundaries | | |
| system design | | |
| system dynamics modelling | | |
| system thinking | | |
| teacher | | |
| technical perspective | | |
| technical problem | | |
| technical water competences | | |
| trade-offs | | |
| transfer knowledge | | |
| transferable skills | | |
| Transformative learning | | |
| transition | | |
| transport medium | | |
| Triple Level Learning | | |
| try and error | | |
| uncertainty and complexity | | |
| water | | |
| water pinch | | |
| water pricing | | |