SpringerBriefs in
Advanced Information and Knowledge Processing

Alexandra Okada

Knowledge Cartography for Young Thinkers

Sustainability Issues, Mapping Techniques and AI Tools

Funded by
the European Union

OPEN ACCESS

Springer

Advanced Information and Knowledge Processing

SpringerBriefs in Advanced Information and Knowledge Processing

SpringerBriefs in Advanced Information and Knowledge Processing presents concise research in this exciting field. Designed to complement Springer's *Advanced Information and Knowledge Processing* series, this Briefs series provides researchers with a forum to publish their cutting-edge research which is not yet mature enough for a book in the *Advanced Information and Knowledge Processing* series, but which has grown beyond the level of a workshop paper or journal article. Typical topics may include, but are not restricted to:

Big Data analytics
Big Knowledge
Bioinformatics
Business intelligence
Computer security
Data mining and knowledge discovery
Information quality and privacy
Internet of things
Knowledge management
Knowledge-based software engineering
Machine intelligence
Artificial Intelligence
Ontology
Semantic Web
Smart environments
Soft computing
Social networks

SpringerBriefs are published as part of Springer's eBook collection, with millions of users worldwide and are available for individual print and electronic purchase. Briefs are characterized by fast, global electronic dissemination, standard publishing contracts, easy-to-use manuscript preparation and formatting guidelines and expedited production schedules to assist researchers in distributing their research fast and efficiently.

Alexandra Okada

Knowledge Cartography for Young Thinkers

Sustainability Issues, Mapping Techniques and AI Tools

Springer

Alexandra Okada
Open University
Milton Keynes, UK

ISSN 1610-3947 ISSN 2197-8441 (electronic)
Advanced Information and Knowledge Processing
ISSN 2524-5198 ISSN 2524-5201 (electronic)
SpringerBriefs in Advanced Information and Knowledge Processing
ISBN 978-3-031-54676-1 ISBN 978-3-031-54677-8 (eBook)
https://doi.org/10.1007/978-3-031-54677-8

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Care-Know-Do

To Young Thinkers,

who brought me a lot of inspiration
even before they were born
and since they were little
have been teaching me many things
about mapping, learning, and
having fun and purpose in life.

Alexandra Okada

Committees

CONNECT—Inclusive Open Schooling with Engaging and Future-Oriented Science

CONNECT Project Scientific Committee

Dr. Alexandra Okada, Open University, UK
Dr. Eva Jaho, Exus AI Lab, UK
Dr. Georgios Kolionis, Exus AI Lab, UK
Dr. Tony Sherborne, Mastery Science, UK
Ms. Ana Beatriz Rocha, consultant, UK
Ms. Gemma Young, consultant, UK
Ms. Jude Sanders, consultant, UK
Prof. John Oates, UK
Dr. Patricia Lupion Torres, Pontificia Universidade Católica Paraná, Brazil
Dr. Raquel Glitz Kowalski, Pontificia Universidade Católica Paraná, Brazil
Dr. Silvar Ribeiro, Universidade do Estado da Bahia, Brazil
Dr. Ana Karine Rocha, Universidade do Estado da Bahia, Brazil
Dr. Sonia Maria Pinto, Universidade do Estado da Bahia, Brazil
Dr. Carmem Silva de Souza Lima, Fatec Prudente, Brazil
Ms. Rosina Malagrida, M.Sc., IRSI Living Lab, Spain
Ms. Laia Vives, M.Sc., IRSI Living Lab, Spain
Mr. Bjorn Bedsted, MA, The Danish Board of Technology, DBT, Denmark
Ms. Sigrid Vedel Neuhaus, MA, The Danish Board of Technology, DBT, Denmark
Dr. Giorgos Panselinas, Hellenic Open University, Greece
Dr. Yolanda Koulouri, Hellenic Centre for Marine Research, Greece
Mr. Alexandros Koukovinis, MA, Loba, Portugal
Ms. Candela Bravo, Loba, Portugal
Dr. Gabriel Gorghiu, Valahia University of Targovishte, Romania
Dr. Mihai Bizoi, Valahia University of Targovishte, Romania

CONNECT Project Scientific Advisors

Foreword

Once again, Alexandra Okada brings to educators a new book illustrating how various forms of knowledge representation maps can be used to enhance teaching, research, and learning, focusing this volume on sustainability education to shape the future. The book shows many examples of young students' work and provides an abundance of suggestions on how to use mapping tools to improve socioscientific thinking.

My experience with concept maps dates back to the early 1970s at Cornell University, where we faced the task of understanding how children developed science concepts in the course of audio-tutorial instruction. While modified Piagetian clinical interviews were useful and showed that children were gaining understanding of basic science concepts, such as the particulate nature of matter, energy, and energy transformations, it was difficult to explicitly demonstrate how their knowledge was changing.

Our research team, working with ideas from Ausubel et al. (1978) assimilation theory of learning and our views on the conceptual and propositional nature of knowledge, developed the idea of transforming interview transcripts into a hierarchical set of concepts and propositions. We referred to this structure as a concept map. Subsequently, others have used the term for various kinds of representations, but most of these differ in terms of the underlying theoretical foundations and/or the explicitness with which they capture the conceptual knowledge gained by individual learners and stored in their cognitive structures. Thus, it is gratifying to see many examples of knowledge maps in Okada's new book, along with suggestions for using these tools to effect meaningful learning, problem-solving, and decision-making.

There is now a general consensus that to be meaningful and useful to learners, knowledge must build on what they already know, help them remediate misconceptions, and connect their learning with real-world examples that matter for them. Learning is also recognised as a social activity and can be more meaningful when students collaborate on learning projects involving real-life issues such as the open schooling approach. Okada's CARE-KNOW-DO framework provides a practical approach for those using research to enrich education.

This book, *Knowledge Cartography for Young Thinkers: Sustainability Issues, Mapping Techniques and AI Tools*, provides valuable scaffolding for learners, offering a way to develop and enhance practical socioscientific thinking for future generations. Imagine the transformative power of this book in your hands: an essential guide for young thinkers, innovative educators, and research practitioners who are dedicated to creating impactful knowledge mapping with emerging technologies for a sustainable world.

Alexandra Okada and Joseph D. Novak
American Educator
Professor Emeritus
1932–2023

Reference

Ausubel DP, Novak JD, Hanesian H (1978) Educational psychology: a cognitive view. Holt, Rinehart + Winston, New York

Preface

My fascination with visual thinking began in childhood and continued through my teaching career; but it was only after my doctoral studies that its true value crystallised. This perception occurred during a transformative workshop at an international conference—a workshop I had the privilege to contribute to. This event redefined my understanding of knowledge mapping, incorporating playful activities and using physical games, crafting materials, and emerging technologies to facilitate learning. This hands-on approach not only built meaningful connections among participants but also sparked crucial dialogues about socioscientific issues, paving new paths for innovative educational methods.

What set these knowledge maps apart? They were dynamic, using the workshop floor as a canvas and participants from diverse backgrounds and interests who came as active agents of change. This approach transformed mapping into a visual and tactile exploration of our collective sustainability goals—covering environmental, social, and economic aspects. We engaged in data-driven discussions about pressing issues such as climate action, environmental protection, green jobs, economic resilience, social equality, health and well-being, education futures, digital equity, and information integrity.

The workshop's playful spirit nurtured our energy, evoking the freedom, imagination, and inquisitive nature often experienced in childhood. This blend of fun and interactive learning created an environment ripe for creative and critical engagement. Participants felt a sense of well-being and flexibility, which was crucial as we delved into complex discussions. We discussed comprehensive strategies focusing on renewable energy, sustainable land use, and reforestation for environmental sustainability. Social initiatives aimed at reducing income inequality and improving education and healthcare access to empower communities. Economically, we evaluated reforms in financial regulation, student loans, and job training programmes to reduce unemployment. Our approach emphasised interdisciplinary education, robust public–private partnerships, and a commitment to long-term sustainability in policymaking. The dynamic setting allowed us to use the floor as a canvas, where smart technologies facilitated the flow of ideas, enhancing our ability to visualise and map issues and solutions collaboratively. Holding hands for agreements or reviewing decisions, both literally and figuratively, we connected deeply with one another. Each touch was a sensory embodiment of our socioscientific thinking, fostering collective knowledge in action that had a significant impact on all participants.

The wide dissemination of artificial intelligence (AI) systems has facilitated the process of generating, evaluating, and refining content. Similarly, swarm intelligence (SI) offers a distinct approach to solving complex problems through collective and self-organising effort. However, neither AI nor SI can generate the genuine, sensory, lived human experiences that are fundamental to creating impactful knowledge. The power of intelligent narratives is deeply rooted in lived actions and embodied experiences. The essence of human critical and creative thought lies in our ability to experience ideas, develop contextual understanding, and engage emotionally with others. These elements are crucial for transformative outcomes that embody ethical, inclusive, and fair values and attitudes. In this context, human creativity and critical insight are more vital than ever. AI and SI can enhance knowledge mapping, problem-solving, and decision-making, but they must be firmly underpinned by ethical, socioemotional, political, and agentic human values that support a sustainable future for individuals, communities, and the global network.

This book is an extension of my dedication to visual thinking, approached in a holistic and transdisciplinary manner. It builds on the foundations laid by the 'Knowledge Cartography: Software Tools and Mapping Techniques' editions of 2008 and 2014 and other books launched in Brazil. Representing a culmination of decades of research across Europe and South America, this work pushes the boundaries of visual thinking. It uniquely integrates perspectives from multiple disciplines to enhance well-being and sustainability. Through this comprehensive approach, the book demonstrates how visual thinking can explore complex global challenges by drawing on and synthesising diverse fields of knowledge with combined techniques and AI apps. The knowledge maps we developed collaboratively in these research projects are practical tools addressed in real-world issues and are integral to open schooling initiatives supported by emerging technologies. Since 2020, the CONNECT network, which includes the Green Forum community and the Colearn Living Lab Group, has enabled open schooling activities involving sustainability issues and some AI-supported knowledge mapping.

Designed for educators, researchers, practitioners, and beginners alike, this book explores a wide array of mapping techniques and their application in today's rapidly evolving educational landscape. It charts an emancipatory path for those aspiring to use mapping not only as a tool but also as a catalyst for CARE-KNOW-DO, aiming to transform education through responsible research and innovation. This book is an invitation to empower creative, responsible, and ethically critical agents of change with emerging principles, technologies, and practices, providing actionable knowledge and fostering knowledgeable actions that we all care about.

Milton Keynes, UK Alexandra Okada

Acknowledgements

The open research presented in this book is part of the CONNECT project, funded by the European Union's Horizon 2020 Research and Innovation Programme (grant no. 872814) and the METEOR project (grant no. 101178320). Earlier phases were conducted during the ENGAGE project (grant no. 612269) and the WeSPOT project (grant no. 318499) under Open Licence CC 4.0, adhering to the Declaration of Helsinki, and approved by the Ethics Committees in the UK, various European countries, and Brazil. I extend my heartfelt gratitude to all the colleagues involved in these extensive consortia, particularly to the CONNECT Scientific Committee and Advisors.

Over the past decade, these projects—anchored in sustainability, the CARE-KNOW-DO framework, and mapping techniques developed with and for young learners—have significantly influenced sustainability initiatives, research methodologies, and our professional journeys. The mentorship provided by experienced educators and the creative contributions of young minds have been instrumental in aligning our endeavours with the principles of responsible research and innovation. It is truly an honour to both support and be supported by such a dedicated community.

Our journey of learning transforms our understanding of human relationships and subjects, especially supported by research, education mentorship, and reflective practices with emerging technologies towards the 2030 and 2050 goals for healthy lives and planet. I am deeply grateful to all my students and educators in Brazil, the United Kingdom, and Europe; and to my mentors, Simon Buckingham Shum and Tony Sherborne, for their invaluable support during the series of books *Knowledge Cartography* (2008, 2014) and for opening doors to various projects such as OpenLearn and Science UpD8.

I am immensely grateful for Paulo Freire's pioneering ideas on critical pedagogy and transformative education, which have profoundly influenced my approach to education. As a member of his research group at PUC-SP Brazil, I had the privilege of engaging with his revolutionary concepts, applying them first-hand in knowledge mapping for transformative practice (Freire 1967). Heartfelt thanks to his work and all the professors at the PUC-SP Education Curriculum Faculty for this enriching journey. I also extend profound gratitude to Joseph Novak for his brilliant and enduring contributions to education. His work, like Freire's, continues to enrich the way learners feel, think, and act—a true gift to generations (Novak 2011). His insights and dedication have impacted the field of knowledge and will continue to transform educational practices. We stand on the shoulders of giants like them, and it is with a deep sense of honour and responsibility that we carry forward their torch, illuminating the path of learning and discovery for every young mapper. Their legacies will forever be a beacon guiding our efforts to nurture the curious minds of our future.

Join our knowledge mapping network

This work was funded by the European Commission No. 318499, No. 612269 and No. 872814

SUSTAINABLE DEVELOPMENT GOALS

Dr. Alexandra Okada supports the Sustainable Development Goals

Alexandra Okada and Young Thinkers,
Knowledge Cartographers

References

Freire P (1967) Education as a practice of freedom. Peace and Earth, Rio de Janeiro

Novak J D (2011) Education theory: meaningful learning underlies the constructive integration of thinking, feeling, and acting, leading to empowerment for commitment and responsibility. Meaningful Learn Rev 1(2):1–14

Okada A, Buckingham Shum S, Sherborne T (eds) (2008/2014) Knowledge cartography. Software tools and mapping techniques. Springer, London

About This Book

This book presents meaningful mapping techniques, including examples across different levels of education, particularly in science, using AI tools with the purpose of sustainability. It also offers pedagogical activities based on CARE-KNOW-DO teaching principles, aimed at engaging diverse age groups, genders, and locations with actionable knowledge. This pioneering work integrates various mapping methods—mind maps, concept maps, argument maps, dialogue maps, web maps, and other diagrams.

Audience

This book guides readers from exploration to actionable outcomes for engaging children and adolescents with pressing issues (CARE), for deepening their understanding (KNOW), and for encouraging them to take effective action towards sustainability (DO). It is particularly useful for:

- **Teachers** seek to engage students with current issues and promote deep learning and sustainability actions.
- **Teacher trainers** aim to expand visual teaching strategies, including the use of knowledge maps.
- **Non-formal educators** look to enhance learners' visual thinking skills.
- **Researchers and advisors** are interested in engaging the public through visual communication methods.
- **Professionals** use knowledge maps for decision-making and sense-making.
- **Independent learners** explore new ways of enhancing their thinking skills through knowledge mapping.

Case Studies

The book features three case studies that demonstrate how students can use AI to enhance their knowledge mapping guided by the CARE-KNOW-DO framework. These studies show how students refine drafts, verify information with expert feedback, distil key findings, and customise communication for different audiences. This method promotes continuous collaboration and encourages a cycle of critical exploration and meaningful learning.

Methodology

The research methodology for this book involved six key procedures:

1. **Literature Review**: The use of maps drawn from scientific articles in peer-reviewed journals was analysed.
2. **Case Studies towards Agenda 2030**: Examined various types of maps organised by young people with expert support, considering the UN Sustainable Development Goals.
3. **Pedagogical Approaches**: Provided examples of various projects and teacher training programmes from several countries, emphasising meaningful learning through knowledge maps.
4. **Ethics and Licencing**: All research complied with ethical standards and Creative Commons licences.
5. **Knowledge Mapping Supported by the RRI**: We addressed six RRI components in the research: inclusion, gender equity, ethics, public engagement, science education, and governance.
6. **Comprehensive Peer Review**: This review involved a diverse group of stakeholders, including science educators, external evaluators, curriculum designers, students, professional development coaches, and project managers, who reviewed the content produced in English and Portuguese.

How AI was Used to Support Book Production

In this book, a variety of AI mapping tools were utilised to enhance the development of teaching, learning, and research materials, particularly focusing on refining content, layouts, and map descriptions. These tools enabled educators and learners to re-evaluate sustainability issues, generate new prompts, reflect on initial responses, critically review content, and collaboratively revise outcomes based on their sense-making processes. To avoid potential uncertainties regarding image copyrights generated with AI support, the final maps presented in this book are illustrations not generated by AI. Additionally, all images are licensed under Creative Commons, ensuring that they can be legally reused under proper citation. The AJE Curie AI tool, recommended by the publisher, was also employed by the author to improve the readability, clarity, and conciseness of the text.

This book is structured as follows:

Chapter 1 introduces the book's purpose.
Chapter 2 explores the historical roots of cartography and knowledge mapping.
Chapter 3 delves into the development of visual thinking in childhood.
Chapter 4 outlines pedagogical principles and strategies for knowledge mapping activities.
Chapter 5 presents nineteen mapping techniques, showcasing examples from both young people and scientists.
Chapter 6 explores three case studies of knowledge mapping applications within open schooling.
Chapter 7 offers recommendations and concluding remarks.

Each chapter features an abstract detailing the learning objectives and concludes with reflective remarks highlighting key points, including questions for reflective discussions that link to subsequent chapters.

About the Author

Dr. Alexandra Okada is an associate professor and senior researcher with a distinguished background in Computer Science, Science Communication, and Emancipatory Education. With more than thirty years of professional experience, she has made significant contributions to educational organisations, industry, and policy. Her career has included positions at IBM, Johnson & Johnson, public and private schools, higher education, and government institutions before joining the Open University-UK, where she has been for the past 18 years.

Dr. Okada specialises in knowledge mapping for sustainability and is at the forefront of "open schooling," an innovative approach introduced by the European Union and aligned with the United Nations' Agenda 2030. Her novel learning model, CARE-KNOW-DO, integrates ethical considerations, collective knowledge building, and action-oriented problem-solving, demonstrating originality and innovation. This holistic framework guides students, families, and communities in making responsible, collaborative decisions with effective science-based actions through open schooling.

She advocates for transformative education through the CARE-KNOW-DO framework and emerging technologies, in line with responsible research and innovation principles. Dr. Okada's work emphasises the importance of human-centric AI in delivering a sustainable economy and society by placing sustainability goals at the centre while respecting users' protection and privacy.

As a green and blue activist, Dr. Okada's passion for social justice and environmental preservation is evident, as is her enthusiasm for diving and knowledge mapping. She is the principal investigator of several internationally funded projects and an expert consultant for the European Union and UNESCO. Dr. Okada is a prolific author of more than 20 books and 150 peer-reviewed articles, including the children's literature book *Green Library: Care, Know, Do*, which reflects her commitment to engaging and meaningful education.

Dr. Okada, the leader of the CONNECT network, the Green Forum, and the COLEARN Living Lab, has contributed to the design of various platforms promoting socioscientific thinking through emotional, intellectual, and social engagement.

These open research network of students, scientists, teachers, entrepreneurs, policymakers, and families aim to enhance connections to science, scientific capital, and scientific literacy through fun, engaging, and critical-creative learning experiences designed to shape sustainable futures.

Dr. Alexandra Okada
UN SDG 2023 Summit
Senior Researcher and Expert Advisor
https://research.open.ac.uk/people/alpo3
e-mail: ale.okada@open.ac.uk
The Open University UK
Rumpus Research Group

Contents

List of Figures

Chapter 1
Knowledge Cartography

Abstract This first chapter outlines three key learning objectives:

1. Understand the concept of knowledge cartography.
2. Recognise the importance of knowledge mapping in historical and contemporary educational contexts.
3. Identify key methods and tools for mapping knowledge in education including AI apps used.

Keywords Thinking skills · Sensemaking · Decision-making · Mapping techniques · AI apps

Knowledge cartography refers to the practice of creating visual representations of expertise domains. It involves the art and technique of graphically charting knowledge concepts, connections, and pathways to enhance understanding and communication. These visual representations, often referred to as knowledge maps, can take various forms, including mind maps for brainstorming, concept maps for exploring meanings, argument maps for developing reasoning, and diagram maps for outlining processes or workflows, among others.

The purpose of knowledge cartography is to:

- **Organise Information**: structure and categorise hypermedia and multimodal content systematically.
- **Reveal Relationships**: uncover how pieces of information relate to each other by visually connecting concepts.
- **Facilitate Learning**: promote a deeper comprehension of complex information with visual understanding.
- **Enhance Action Plans**: connect meaningful knowledge and practices to elaborate a consolidated workplan.
- **Expand Creative Thinking**: amplify new ideas and connections individually and collectively.
- **Aid Decision-Making**: support more informed decisions by clearly laying out options and pathways.

A. Okada, *Knowledge Cartography for Young Thinkers*, SpringerBriefs in Advanced Information and Knowledge Processing, https://doi.org/10.1007/978-3-031-54677-8_1

In essence, knowledge cartography is a field that intersects with education, cognitive psychology, and information science, among others, and is used widely in academic research, learning, business strategy, and data analysis to make sense of complex topics and large amounts of information.

Knowledge mapping is an increasingly popular strategy across scientific disciplines. A growing number of software tools, methods, and techniques have assisted researchers in embracing visual thinking, enabling them to envision, analyse, and generate new knowledge that is vital for decision-making processes (Harley and Woodward 1987; Liang et al. 2022). Knowledge maps have also found practical applications in education as pedagogical tools that help students grasp information visually through meaningful representations, fostering a deeper understanding (Okada et al. 2008; 2014).

Undoubtedly, knowledge mapping that is supported by technology has proven to be helpful for scientists and professionals in solving real-world problems and exploring uncertainties (MacEachren et al. 2005) while improving the educational experience in teaching, research, and learning (Cañas et al. 2022, Cañas and Novak 2014). However, there is limited research about the value of mapping as an integrated knowledge framework to scaffold learning across all levels of education. To explore this gap, this book delves into the benefits of knowledge maps, discusses their real-world implementation in schools including local and global challenges and emerging technologies, engaging learners educators, and experts in authentic problem-solving scenarios. Such research is essential for promoting meaningful learning among children and young people, as well as facilitating scientific communication from scientists.

Addressing sustainability challenges, now more than ever, requires crucial partnerships across various sectors. We are confronted with complex global issues, including climate change, rapid technological advancement, economic competition, social inequalities, educational gaps, and misinformation. The Independent Group of Scientists appointed by the UNESCO Secretary-General (2023) highlights this era as a pivotal moment in advancing towards the United Nations' sustainable development goals. Effective local action on these global issues necessitates collaboration among students, educators, scientists, professionals, business leaders, citizens, and policymakers, supported by emancipatory artefacts. As proposed by Okada and Gray (2023), approaches such as eco-governance, eco-entrepreneurship, and eco-leadership demand the use of emerging technologies, participatory methodologies, and the intellectual contributions of both young visionaries and experienced experts. This book explores these combined efforts, supported by a form of collective and individual knowledge mapping, which are essential in navigating and addressing the complex digital landscape. Knowledge mapping in education aims to equip learners with visual scientific reasoning and collaborative problem-solving approaches, connecting STEAM disciplines with education and science communication to address real societal challenges such as climate action, technological advancements, and social issues. By integrating mapping techniques and tools in educational settings, this book aims to enrich learning processes for communities of learners, educators and experts who seek to advance the United Nations' sustainable development goals.

1.1 Transdisciplinary Value

Mapping knowledge supports individuals in visually articulating their thoughts, transcending traditional textual methods. Historical precedents, such as geographical maps, underscore the innate human capacity to visually represent and categorise information—a practice that predates written and numerical systems (Wolodtschenko and Forner 2007). Contemporary applications of knowledge maps offer multidisciplinary strategies for organising ideas and conducting investigative inquiries, reinforcing their relevance across educational spectra.

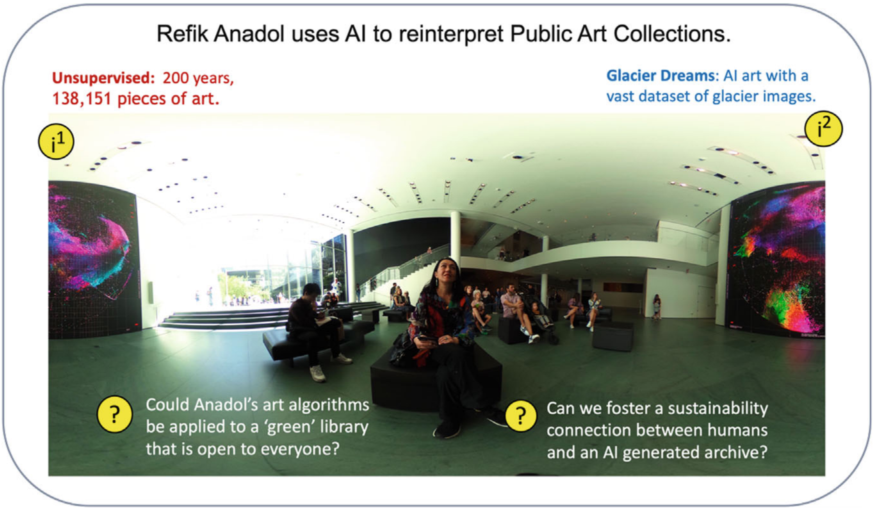
Historically, there have been renowned scientists who utilised visual art as a means of communicating scientific ideas, by simplifying info to communicate clearly. The physicist Stephen Hawking (2009), for instance, became famous for his works on theoretical physics, such as "A Brief History of Time." His books frequently incorporated diagrams and illustrations to elucidate intricate scientific concepts for a general audience.

Conversely, in the realm of art, artists harness science to express their imaginative and inventive minds. While primarily celebrated as an artist, Leonardo da Vinci was also a scientist and inventor. He produced numerous diagrammatic maps and sketches that seamlessly combined his artistic prowess with scientific observations. These included detailed anatomical drawings and elaborate depictions of machinery and inventions.

In the field of mathematics, Escher (2000), although primarily renowned as an artist, often integrated intricate mathematical and optical concepts into his works. His tessellations and impossible objects stand as examples of how he intertwined mathematical and scientific ideas within his art. Within the realm of STEM, Fuller (1980), an architect, engineer, and designer, is known for his geodesic domes. He extensively employed geometric diagrams and models to illustrate his design principles.

In AI-based media art, such as 'Unsupervised' and 'Glacier Dreams', the artist Refik Anadol utilises artificial intelligence to map and reinterpret extensive art databases. Anadol (2020)'s AI digital creations consistently produce new and surreal forms, immersing viewers in a dynamic, large-scale installation, displayed in public spaces. His work not only prompts contemplation of AI's role in creativity but also invites millions to participate in cocreating within his dynamic artistic realm (Map 1.1).

Generative AI boasts capabilities such as creative content generation, automation, and continuous interactions for sensemaking and personalisation but also poses challenges, including bias, transparency, quality control, integrity, and ethics. The critical use of generative AI is essential for maximising its positive aspects and mitigating potential risks (Holmes and Porayska-Pomsta 2023; Miao 2022; Miao and Holmes 2021; Miao et al. 2021; Luckin and Holmes 2016). With this in mind,



Map 1.1 Workshop map about Anadol's AI art, ThingLink. Okada (2024)

acquiring mapping skills is not just essential for a future dominated by science and technology; it is a collaborative and continuous process crucial for making informed decisions, especially when addressing challenges and adversities. In education, AI mapping applications promise to improve productivity by providing varied content for teaching, research, and learning, provided that learners can develop skills to analyse truthfulness and trustworthiness. These apps simplify content evaluation and ensure ease of use, facilitating practical interactions. However, there is a notable scarcity of empirical research about AI within school education. Authoritative sources, such as UNESCO and various national governments, recognise the potential of AI to contribute to achieving Agenda 2030s goals, including promoting the quality of education. However, there is an urgent need for more rigorous scientific studies in this field (UN 2021).

Rapidly Evolving Technology and Societal Needs

Understanding technological advancements, social concerns, the evolving role of science, and the importance of education helps us use knowledge mapping strategically. With this objective, Map 1.2 outlines the evolution of the internet and related technologies, educational paradigms, and societal goals from 1990' through 2020', aligned with the transitions from Web 1.0 to Web 3.0 indicating progressively increasing user interactivity and data processing capabilities. This comprehension enables educators to support young thinkers in building and mapping knowledge in context, preparing them with the skills they need for the future.

The technologies used progressed from static HTML pages to dynamic content creation tools such as blogs and wikis and then to advanced data frameworks and applications involving the Internet of Things, blockchain, AI, and mixed reality.

	1990-2005 Web 1.0: READ only	2005-2015 Web 2.0: READ-WRITE	2015-2030 Web3.0: READ-WRITE-EXECUTE
Science role	Science in society	Science with society	Science with, for and by society
Social Concerns	Poverty	Inequalities	Social Injustices
Societal Goals	Inclusive societies	Diversity, Equity, Inclusion for all	A fair sustainable world
Sustainability Act	Earth Summit 1992, Rio	Green Deal 2015, Paris	SDG Acceleration UN 2030, New York
Attitude	Be Aware	Be Committed	Be Effective
Environment	Global Warming	Climate Change	Climate Urgency
Biodiversity	Deforestation	Air and Water Pollution	Ecosystem degradation
Trends	Globalisation	Digitalisation	Green Digital Innovation
Economy	Information economy	Platform economy	Token economy
Health concerns	HIV/AIDS crisis	SARS, H1N1, Ebola	ZIKA, COVID, Biotech weapons
Internet	WEB 1.0, Read-Only	WEB 2.0, Wildly Read-Write	WEB 3.0, Read-Write-Own
Technologies	Browsers	Cloud-based, social media	Mobile Apps & AI tools
Communication	Unimodal (text based)	Bimodal (images/videos)	Multimodal and immersive interaction
Content	Institutional Providers	User-generated content	Semantic Web Users, AI generated Apps
Example	Britannica Online	Wikipedia	Wikidata, ChatGPT, etc.
Copyrights	Reserved, institutional	Open licences (e.g. CC)	Legal and Ethical uncertainties
Digital concerns	Undefined digital laws	Privacy, security, reliability issues	Misinformation in mass, AI insecurity
Access	Reading	Team editing, curation, authoring	Coauthoring, Collaborative Sensemaking
Map features	Static maps	Interactive maps	Cloud-based and AI assisted maps
Mapping-spaces	Encyclopaedia online	Wiki Digital Library	Community based showcase
Education	Transmissive	Collaborative, Open, Personal	Hyperpersonalised, Emancipatory
Curriculum	Predefined, outdated	Flexible, open, updated	Responsive, future-oriented, just-in-time
Contexts	Abstract, hypothetical	Personal and collaborative	Real-life Issues, Global-Challenges
Research	Summaries/synthesis	Participatory research	Responsible Research and Innovation
Learning	e-learning	Colearning	Coinquiring, Open Schooling, Living Lab
Resources	Abstracted, theoretical	Fragmented, multidisciplinary	Authentic, real-world skill-based
Activities	Printed, textbook,	Cocreation	Problem-solving, Decision Making
Assessment	Knowledge Memorisation	Knowledge/skill performance	Competences based outcomes
Educator	Knowledge Transmitter	Open Learning facilitator	Open Schooling multi actors
Learner	Receiver, reproducer	Coauthor, colearner	Knowledge map change-agent

Map 1.2 Chronological map of sustainability issues, word. Okada (2024)

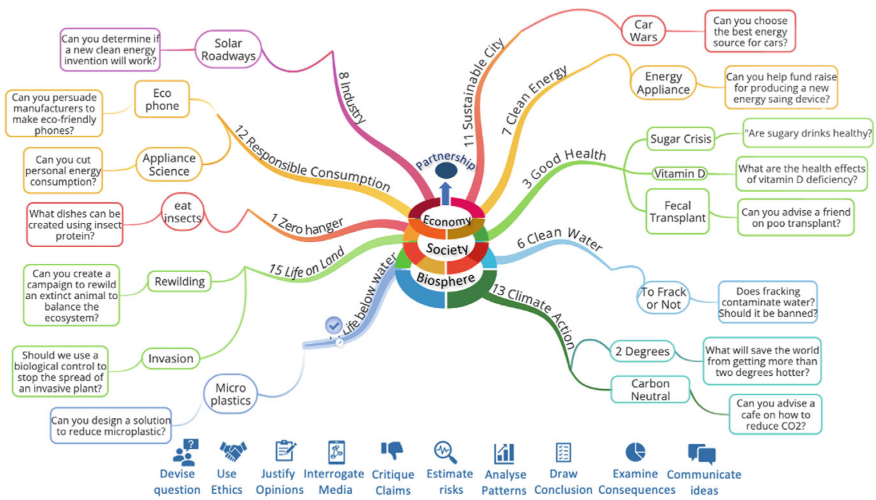
The focus of content shifted from company-driven to community-centric and then to personalised content powered by AI and individual networks towards a human-centred approach to AI (United Nations 2021).

The role of science in society transitioned from being in society, with society, to being with and for society, reflecting a deeper engagement with and impact on societal needs. Societal goals also shifted from striving for societies to emphasising diversity, equity and inclusion (OECD n.d.), ultimately aiming for wellbeing, equity, and sustainability. This table encapsulates the broad trends in how the internet and digital technology can influence shifts in societal values, education, and science.

Contemporary educational approaches have been criticising traditional transmissive education focused on teaching through reading, listening, and copying content. Learning should be a participatory, collaborative process where students build knowledge through more personalised and purpose-driven experiences. These shifts are key for revolutionising pedagogical approaches, curricula, and assessment methods, moving towards a model that is collaborative, flexible, and responsive to real-world issues. Educators should act as facilitators of open schooling, encouraging learners to be co-authors actively participating in their education through practices such as the CARE-KNOW-DO approach. The integration of AI tools in knowledge cartography has the potential to enhance sustainability education. Knowledge maps can serve as visual guides to help students and educators navigate complex issues, foster a deeper understanding, and enable informed decision-making. The evolution highlighted in the table underscores a paradigm shift towards an educational framework where learning should be a shared, community-driven process and where knowledge should not only be acquired but also constructed collaboratively to foster a sustainable future. This is one of the goals of open schooling, which brings together schools, universities, and local communities to use formal and non-formal knowledge to discuss and solve sustainability issues, as presented in the following section.

1.2 Sustainability Issues

Sixteen educational scenarios are grouped by three layers of the SDGs—Biosphere, Society, and Economy—supported by partnership models. Map 1.3 introduce these resources related to sustainability issues for teachers to guide students in decision-making and RRI-responsible research and innovation skills. In the context of open schooling, partnership is a key approach for authentic education. Open schooling emerged in 2015 to describe the cooperation among schools, universities, and societies for students to solve real-life problems supported by formal, non-formal and informal learning. This approach was also implemented in the ENGAGE and CONNECT projects. This map serves as an educational resource that links various hypermedia resources developed by Mastery Science with the international ENGAGE and CONNECT project consortia, including researchers, teachers, curriculum developers, and students.



Map 1.3 Map of sustainability issues and socioscientific resources, Ayoa. Okada (2024)

Map 1.4 Map of sustainability issues for open schooling, Ayoa. Okada (2024)

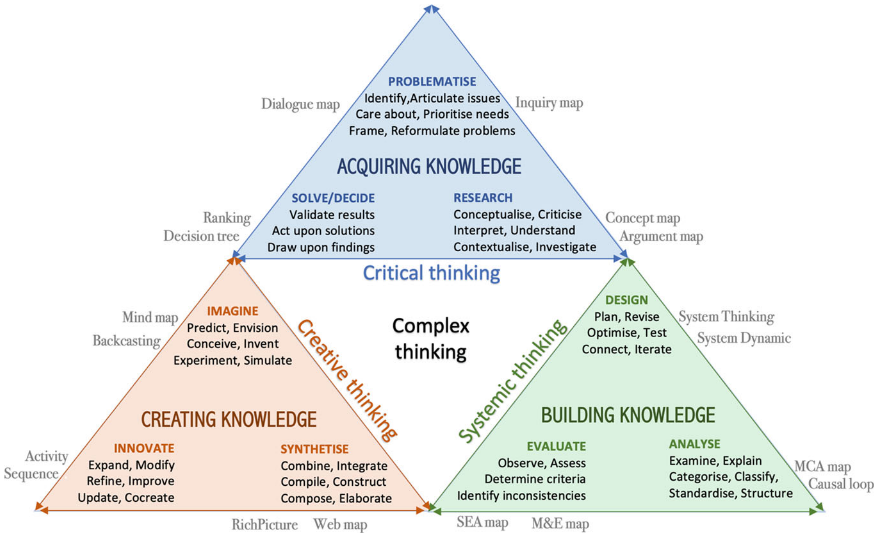
Fourteen open scenarios are linked to nine thinking processes relevant for students to develop knowledge, skills, attitudes, and values. Map 1.4 introduces these resources related to sustainability issues raised by students to practise RRI skills.

1.3 Thinking Skills and Knowledge Mapping Competencies

Map 1.5 presents a model for enhancing complex thinking by integrating three groups: building knowledge through critical thinking, systematising knowledge via systemic thinking, and creating knowledge through creative thinking supported by insights from Paul (1992), Jonassen et al. (1998), Jonassen (2000) and Okada (2006, 2010). This model was used to design activities and analyse the case studies (see Chaps. 6 and 7).

- **Critical thinking**: problematise, conducting research, making decisions, and developing solutions. It involves acquiring knowledge through conceptualising, contextualising, and validating results and drawing upon findings.
- **Creative thinking**: generating new ideas and perspectives. It includes processes such as imagining, innovating, and creating knowledge, as indicated by activities such as predicting, envisioning, experimenting, expanding, modifying, and updating.
- **Systemic thinking**: designing, analysing, and evaluating knowledge systematically. It comprises planning and connecting information, examining processes, explaining results, observing systems, and evaluating their dynamics. Systemic thinking is about the big picture and the ripple effects within large systems. Systemic thinking emphasises a methodical, organised approach to building knowledge for problem-solving by understanding interactions, feedback loops, and dynamics within systems.

The techniques and tools associated with each cognitive process are described in Chap. 5 with examples in Chap. 6. For instance, mind maps are used for creative



Map 1.5 Knowledge mapping: competencies, Thinglink. Okada (2024)

knowledge generation, while inquiry methods and concept maps are employed for knowledge acquisition. Additionally, causal loops and system thinking maps are instrumental in building knowledge for problem-solving or decision-making. Map 1.5 serves as a resource for designing educational activities that foster comprehensive thinking skills using various mapping techniques to enhance competencies, as described next.

1.4 Mapping Techniques

Map 1.6 presents a structured list of various mapping and diagramming techniques categorised by type of thinking: critical, creative, and systems thinking. Each category includes six techniques, underpinned by principles described in Chap. 4. The map provides a summary of each technique, including its definition, function, and brief historical context. This timeline map serves as a reference for understanding the evolution and application of these techniques in knowledge management and decision-making to build, systematise, and create knowledge.

The first mapping techniques, particularly related to systems thinking, were initiated in the 1950s. Creative thinking with mind mapping emerged in the 1970s. Critical thinking (Paul 1992) involving concept and argument mapping became more popular in the 1980s.

See references in Chap. 5.

	Maps	Techniques Description
Critical thinking	Dialogue map	Dialogue map is a graphical representation of a conversation with a set of questions or problems, answers or solutions, pros and cons, notes, references and conclusions. The conversation is configured through the visualisation of the map itself . This technique was introduced by Conklin in 2000's.
	Inquiry map	Inquiry map indicates critical lines of inquiry about a particular topic, which helps learners navigate into their research, make connections between question, concepts, data, interpretation and findings to develop a deeper understanding of the topic. This technique was developed by Okada in 2000's.
	Argument map	Argument map represents a reasoning structure with a set of assumptions, reasons and objections that constitute arguments aimed at clarifying a given subject. This technique was presented by Van Gelder in 2000s and inspired by Toulmin argument model.
	Concept map	Concept map is a visual representation of concepts and their relationships through hierarchical links described by words that determine valid sentences or propositions thus establishing a meaning within a certain domain of knowledge. This technique was created by Novak in the 1970s.
	Decision tree map	Decision tree map is useful for evaluating situations where there are multiple choices with uncertain outcomes; applied to various fields. This technique was developed by various researchers including Ross Quinlan, but the exact origins are not fully clear.
	Ranking map	Ranking map is used in decision-making to determine the relative importance or acceptability of different items by placing them in order of preference, structure or matrix. This technique was developed by unknown individual or team and an exact date is not provided.
Creative thinking	Activity map	Active diagram map is used to model the workflow or business process within a system, showing the sequence of activities and the flow of control from previous to the next. This technique emerged linked to UML developed by Grady Booch, Ivar Jacobson, and James Rumbaugh in the 1990s.
	Sequence map	Sequence diagram map illustrates how objects or parts of a system interact with each other and in what sequence those interactions occur. This technique was inspired by Grady Booch in the mid-1990s.
	Rich Picture map	Rich pictures, or Rich maps are visual illustrations to represent complex situations and express ideas and realtionships that cannot easily be conveyed with words or numbers. This technique was developed by Peter Checkland in the 1980s.
	Web map	Web Map is a hypermedia representation to present information networks of multimodal content of the internet as shown by Dodge & Kitchin; Chen and Zeiliger. This technique emerged in the 1980s.
	Mind map	Mind map is a representation of ideas that emerge through keywords and their associations involving text, image, colours, spatial connections, symbols in order to visualise, classify and generate ideas. This technique created by Buzan in the 1970s.
	Backcasting map	Backcasting map is a graphical visual plan that starts with defining a desirable future and then works backwards to identify policies and programs that will connect that specified future to the present. This technique was notably developed by John Robinson in the 1970s.
Systemic thinking	MCA map	Multicriteria analysis map (MCA) is useful for decision-making by comparing options based on a defined set of objectives, which must be identified by the decision-makers. It outlines a number of options for decision-making. This technique was created by Kepner and Tregoe in the 1980s.
	MCD map	A Multiple Cause Diagram map (MCD) is a visual representations to analyse complex connections or relationships and better understand the factors influencing outcomes, particularly in the context of causation and prevention. This technique was inspired by the work of Meadows et al. in the 1970s.
	Causal loop map	Causal loop map is a visual representation used to explain complex systems, particularly in system dynamics modelling. This technique was introduced by Meadows et al. in the 1970s.
	SEA map	Strategic Environmental Assessment map (SEA) is a visual representation that evaluates the potential environmental effects of proposed strategic actions before they are implemented. This technique was inspired by Carson's work, created in the 1970s.
	M&E map	Monitoring and evaluation (M&E) is an integral representation of project management and data analysis to enhance processes in various fields by centres, governments, and organisations(e.g. UN, WHO, WFP, IMF,…). This technique was developed by many teams and emerged in the 1950s.
	System thinking map	Systems thinking mapping, is a visual representation to analyse complex systems, relationships, and interactions. This technique became more widespread with the work of Jay W. Forrester in the 1950s.
	System dynamic map	System dynamics is a method used for understanding and evaluating complex systems. This technique was developed by Jay W. Forrester in the 1950s.

Types: Critical thinking Creative thinking Systemic thinking

Map 1.6 Knowledge mapping: techniques, Word. Okada (2024)

1.5 Mapping Tools and AI Apps

Only in the early 2000s did a pioneering generation of knowledge mapping software tools appear; these tools were characterised by their desktop-based nature. Notable among them were CmapTools, Compendium, Rationale, and FreeMind. These applications predominantly operated on individual computing devices and played a foundational role in the evolution of knowledge mapping (Okada et al. 2008).

The subsequent generation, which emerged in the 2010s, marked a significant shift towards cloud-based platforms that featured collaborative interfaces. This shift facilitated the creation of knowledge maps on various devices, including laptops and tablets. Prominent examples in this category included CmapCloud, LiteMap, and iMindMap. Cloud-based functionality has led to increased accessibility and the ability of multiple users to collaborate on creating knowledge maps for teaching learning and research (Mikroyannidis et al. 2020).

Currently, the domain of knowledge mapping is progressing into its third generation, marked by the integration of artificial intelligence (AI). This evolution is evident in a suite of AI-enhanced knowledge mapping apps that offer diverse features to streamline idea generation, organisational thinking, and collaborative efforts. These apps enable users to efficiently produce and refine knowledge maps via intuitive interfaces, smart designs, and functions (see further Map 1.8).

Despite the emergence of studies on AI applications in education, research on AI-enabled mapping tools in school settings is rare. AI is gaining traction in various sectors for harvesting and generating substantial amounts of data. According to Brna et al. (2001) and Cañas et al. (2004), who initiated discussions two decades ago, AI-enhanced knowledge mapping in education has an increasingly important role. Brna explored whether diagrams aid learning by simplifying tasks, transferring diagrammatic skills, and learning new representational systems alongside domain knowledge. Cañas posited that concept maps' free-form structure, when well executed, could provide extensive insights, supported by smart tools to assist users in their creation. This confluence of concept map flexibility and AI could lead to an optimal fusion of knowledge elicitation and representation.

As highlighted by Hendler and Berners-Lee (2010), AI systems present both benefits and limitations. Fadel et al. (2024) argue that the challenges posed by AI technology are more prominent than ever ranging from workforce automation to privacy concerns. However, these materials provide catalysts for innovation to improve human work and life and address global issues. A balance of critical, careful, and inquiry perspectives is key for students to leverage its benefits while critically evaluating its challenges and risks. A significant challenge for AI users involves the ability to interpret and evaluate social attributes of online information, such as accuracy and veracity, in addition to unspoken norms regarding information usage, privacy, copyright, and legal regulations. Currently, although some of this information is available on the Web, formal structures for representing and quantifying these characteristics systematically are lacking. Although studies about knowledge

Map 1.7 Knowledge mapping: recent studies, word. Okada (2024)

	Mapping tool	Journal paper or peer-review article that used the tool
2023	app.writesonic.com/photosonic	Lambert, J., and Stevens, M. (2023). ChatGPT and Generative AI Technology: A Mixed Bag of Concerns and New Opportunities. *Computers in the Schools*, 1–25
2023	textomap.com by Raijman	Pannooon, P. (2024). *Implementation of artificial intelligence for creating maps* (Thesis)
2023	mymap.ai by Victor Zhang	Moundridou, M, Matzakos, N, Doukakis, S. (2024). Generative AI tools as educators' assistants: Designing and implementing inquiry-based lesson plans. *Computers and Education: Artificial Intelligence, 7*, 100277
2022	EdrawMind by Wondershare	Chien, K. Z., Kavin, T., Jia, H., Karthivashan, G., Vigneswari, S., and Santhanam, R. (2023). Drug delivery approaches to improve the efficiency of phytoderivatives against UV induced damage-A review. *Journal of Drug Delivery Science and Technology*, 104, 793
2022	ContextMinds by LTDHUB	Stefkova, G., Michalkova, J., Dimunova, L., and Halasz, B. G. Visualisation of students' cognitive knowledge in digital concept mapping. *Int J Eval and Res Educ ISSN*, *2252*(8822), 8822
2022	RationaleOnline by Austhink	Lawrence, J. (2021). Explainable argument mining (Doctoral dissertation, University of Dundee)
2020	Rationale.jina.ai by Jina AI	Rider and Thomason (2014) Cognitive and Pedagogical Benefits of Argument Mapping: LAMP Guides the Way to Better Thinking
2020	GitMind by Wangxu Technology	Suen, J., Dyer, S., Shulver, W., Ross, T., and Crotty, M. (2023). A systematic review of typologies on aged care system components to facilitate complex comparisons. *Health Services Management Research*, 09, 514, 848, 231, 179, 176
2019	Ayoa by OpenGenius	Mubako, A. T. (2020). The Contribution of Emerging Technologies and Skills to the Agricultural and Consumer Goods Sectors in Two Countries in Africa. *Educor Multidisciplinary Journal*, *4*(1)

(continued)

Map 1.7 (continued)

	Mapping tool	Journal paper or peer-review article that used the tool
2017	Taskade	Grégoire, D. A., … and Gruber, M. (2024). Mobilising New Sources of Data: Opportunities and Recommendations. *Academy of Management Journal*, *67*(2), 289–298
2014	LiteMap by OUUK	Okada, Alexandra and Sherborne, Tony (2018). Equipping the Next Generation for Responsible Research and Innovation with Open Educational Resources, Open Courses, Open Communities and Open Schooling. Journal of Interactive Media In Education, 1(18) pp. 1–15
2013	Scapple by Scrivener	Mazumder, R., and Thompson-Hodgetts, S. (2019). Stigmatisation of children and adolescents with autism spectrum disorders and their families: A scoping study. Review Journal of Autism and Developmental Disorders, 6, 96–107
2010	Lucidspark by Lucid	Bonner, R., Desa, G., Petkova, A. P., and Baack, S. (2022). Teaching With Conceptboard: A Professional Online Tool for Student Engagement and Collaboration. *Management Teaching Review*, *7*(3), 263–275
2010	Lucidchart by Lucid	Faulkner, A., and Contributor. (2018). Lucidchart for easy workflow mapping. *Serials Review*, *44*(2), 157–162
2010	Coggle by Cogglelt	Maaravi, Y., Heller, B., Shoham, Y., Mohar, S., and Deutsch, B. (2021). Ideation in the digital age: literature review and integrative model for electronic brainstorming. Review of Managerial Science, 15, 1431–1464
2009	Twine Twine by IFTF -	Bucciero, A., et al. "Interactive Digital Narrative Authoring Tools and Hybrid Experiences in Cultural Heritage: An integrated review." (2023)
2009	Plantuml	Ozkaya, M. (2019). Are the UML modelling tools powerful enough for practitioners? A literature review. IET Software, 13(5), 338–354

(continued)

Map 1.7 (continued)

	Mapping tool	Journal paper or peer-review article that used the tool
2008	XMind by XMind	Qurotul Aini, Q. A., Mukti Budiarto, M. B., POH Putra, P. O. H., and Untung Rahardja, U. R. (2020). Exploring e-learning challenges during the global COVID-19 pandemic: A review. Jurnal Sistem Informasi (Journal of Information System), 16(2), 47–65
2007	MindMeister by Till and Michael Utesch	Liang, W. (2022). Towards a set of design principles for technology-assisted critical-thinking cultivation: A synthesis of research in English language education. Thinking Skills and Creativity, 101, 203
2006	Online.visual-paradigm.com VPI	Ramadan, A. A. (2022). Bacterial typing methods from past to present: A comprehensive overview. Gene Reports, 101, 675
2005	Cmaptools by IHMC	Jackson, A., Barrella, E., and Bodnar, C. (2023). Application of concept maps as an assessment tool in engineering education: Systematic literature review. *Journal of Engineering Education*
2000	App.diagrams.net by draw.io and JGraph	Strydom, A., Mellet, J., Van Rensburg, J., Viljoen, I., Athanasiadis, A., and Pepper, M. S. (2022). Open access and its potential impact on public health–A South African perspective. Frontiers in Research Metrics and Analytics, 7

mapping with AI are very limited, examples from technology producers (Appendix 1) indicate various advantages, including one-click map creation, language checks, automated translation, and professional formatting.

With the rapid development of AI natural language processing systems designed to understand prompts and generate human-like text using the web, such as ChatGPT (OpenAI) and Perplexity. The references of AI, BERT (Google), Claude (Anthropic), and Bing (Microsoft), even with the indicated sources and links, must be verified. There are AI mapping tools focused on searching for scientific papers and map citations, such as Elicit, Connected Papers, Scite, and Semantic Scholar. In addition, AI mapping apps feature chatbots that enrich collaborative knowledge map editing, while others foster a social media-like collaborative space with functions such as voting and sharing. The variable accuracy of references and primary sources poses a challenge. Traditional visualisation methods have faced challenges in terms of productivity, but AI-supported knowledge mapping techniques, coupled with critical socioscientific inquiry, promise to create opportunities for learning communities to enhance the search outcomes, verification, and interpretation of complex AI-generated data.

This book argues that knowledge cartography can significantly transform education by enhancing sensemaking and decision-making with mapping techniques and AI tools. This transformation occurs because it allows students to refine their knowledge and learning assisted by technologies, methodologies, and interactions with educators and experts. To achieve this goal, pedagogical approaches such as the CARE-KNOW-DO framework are designed to expand students' social-emotional-cognitive skills to address real-life issues and actionable knowledge.

With this goal in mind, to support a shift towards technologically meaningful, responsive, and collaborative educational practices, this chapter presents two maps of knowledge mapping technologies that are or can be integrated with AI. First, Map 1.7 showcases mapping and diagramming apps that have been refined over time, including examples of their use in the scientific literature. Various of these apps have combined AI to enhance human cognitive processes in knowledge management and decision-making. Second, Map 1.8 presents knowledge mapping apps with brief descriptions, types of AI integration, and their objectives.

Educators can empower students to explore modern complexities assisted by AI technologies, facilitating search, synthesis, analysis, and integration through mapping and interactions within their learning communities. AI can offload administrative tasks to optimise teaching, learning, and research planning, allowing educators, learners, and researchers to focus on personalised processes tailored to specific needs with prompt feedback.

Educational communities can harness hybrid human–machine interactions, empowering individuals with real-world competencies for sustainability. This revolutionises teaching, learning, research, and innovation, transforming rote learning into emancipatory learning.

Reflective Remarks This chapter introduced the concept of knowledge cartography, covering its historical precedents, key issues, techniques, skills, technologies, and applications.

Action Points

1. Use the 'knowledge cartography' definition to outline your own understanding of this concept.
2. Use the provided maps to select issues, techniques, and technologies based on your interests.

Next chapter will discuss the significance of knowledge mapping in education, focusing on its role in preparing learners for a sustainable future. It will trace the evolution of these tools from basic navigational aids to advanced resources that significantly enhance visual thinking, relationship awareness, and cognitive skills.

Question: What are the value and applications of knowledge mapping for educators and learners?

Map 1.8 Knowledge mapping: application tools and AI; Word. Okada (2024)

	Mapping tool	Description	AI integration	Aims
2023	App.writesonic.com/photosonic	AI writing app	AI generated content	Aid the creative writing process
2023	Textomap.com	AI geographical and contextual map app	Location mapping based on AI-prompts	Visualise locations based on specific queries
2023	Mymap.ai	AI storytelling app	Idea curation based on AI	Boost creativity
2022	EdrawMind	AI brainstorming	AI generated content	Create visual representations
2022	ContextMinds	AI generated text app	AI concept mapping	Generate concept maps
2022	Rationale Online	AI argumentation app	AI assist in feedback	Construct coherent arguments
2020	Rationale.jina.ai	AI argumentation and multicriteria app	In-context pros and cons, and SWOT analyses	Develop arguments supported by AI
2020	Gitmind	AI concept map app	AI chatbot to support users	Design with templates
2019	Ayoa	AI generated ideas and visuals app	Range of features for visual task and to manage project	Design mind maps with auto layout feature supported by AI
2017	Taskade	AI project management a visual app	It provides a collection of premade mapping templates	Create various types of maps
2014	Litemap	Concept, argument, and issue map app	Cloud-based tool, but not based on AI	Design collective dialogue maps
2013	Scapple	AI versatile mind mapping app	Employs AI to facilitate nonlinear idea generation	Structure information with automated organisation
2010	Lucidspark	AI automated structure and format map app	It automatically adjusts text formatting	Design maps with clarity and aesthetics based on AI
2010	Lucidchart	AI whiteboard for brainstorming app	Draw, write, and instantly map ideas with AI	Create organised maps and add sticky notes
2010	Coggle	AI cloud-based mind-mapping app	Help users organise and visualise their ideas	Design well-organised maps with automated AI layout
2009	Twine	Interactive fiction and storytelling app	TWINE interactive fiction code with AI GPT tool	Code and map interactive fiction multimedia games

(continued)

Map 1.8 (continued)

	Mapping tool	Description	AI integration	Aims
2009	Plantuml	UML diagram mapping app	AI generated code	Create diagram and drawing supported by code
2008	Xmind	AI knowledge management app	AI supports manage tasks and organise ideas	Design maps with AI generated ideas
2007	Mindmeister	Project planning, idea generation mapping app	An AI-powered online mind mapping platform	Map with auto layout feature supported by AI
2006	Online.visual-paradigm	Infographics, ebooks, charts, and collages app	Intuitive UML diagram maker with case examples	Create diagrams with AI generated code (UML)
2005	Cmaptools	Concept map app	Cloud-based tool not based on AI	Design concept maps using information from ChatGPT
2000	App.diagrams.net	Flowcharts, UML diagrams and charts app	AI-chatGPT code Mermaid.js or plantuml	Create diagrams with AI generated code (UML)

References

Anadol R (2020) Synaesthetic architecture: a building dreams. Architect Des 90(3):76–85

Brna P, Cox R, Good J (2001) Learning to think and communicate with diagrams: 14 questions to consider. Artif Intell Rev 15:115–134

Cañas AJ, Carvalho M (2004) Concept maps and AI: an unlikely marriage? In: Brazilian symposium on computers in education (Simpósio Brasileiro de Informática na Educação-SBIE), vol 1, pp 1–10

Canas AJ, Leake DB, Wilson DC (2004) Managing, mapping and manipulating conceptual knowledge. In: AAAI workshop technical report WS-99-10, Menlo Calif, July, 1999. http://www.ihmc.us/users/acanas/Publications/AAAI99CmapsCBR/AAAI99CmapsCBR.pdf. Accessed Nov 2004

Cañas AJ, Novak JD (2014) Concept mapping using CmapTools to enhance meaningful learning. Knowledge cartography: software tools and mapping techniques. Springer, London, pp 23–45

Escher MC (2000) MC Escher: the graphic work. Taschen

Fadel CB, Taylor AR, Slesinski J, Dunn K (2024) Education for the age of AI. The Center for Curriculum Redesign, Boston, MA

Fuller RB (1980) Autobiographical monologue-scenario. St Martin's Press

Harley JB, Woodward D (eds) (1987) The history of cartography. University of Chicago, Chicago

Hawking S (2009) A brief history of time: from big bang to black holes. Random House

Hendler J, Berners-Lee T (2010) From the semantic web to social machines: a research challenge for AI on the worldwide web. Artif Intell 174(2):156–161

Holmes W, Porayska-Pomsta K (2023) Artificial intelligence and the future of learning and work

Holmes W, Persson J, Chounta IA, Wasson B, Dimitrova V (2022) Artificial intelligence and education: a critical view through the lens of human rights, democracy and the rule of law. Council of Europe. https://unsdg.un.org/sites/default/files/UNDG-UNDAF-Companion-Pieces-6-Monitoring-And-Evaluation.pdf

Jonassen D (2000) Computers as mindtools for schools: engaging critical thinking. Merrill, Upper Saddle River

Jonassen DH, Carr C, Yueh H (1998) Computers as mindtools for engaging learners in critical thinking. http://tiger.coe.missouri.edu/~jonassen/Mindtools.pdf

Liang X, Luo L, Hu S, Li Y (2022) Mapping the knowledge frontiers and evolution of decision making based on agent-based modelling. Knowl Based Syst 250:108982

Luckin R, Holmes W (2016) Intelligence unleashed: an argument for AI in education. UCL Knowledge Lab, London

MacEachren AM, Robinson A, Hopper S, Gardner S, Murray R, Gahegan M, Hetzler E (2005) Visualising geospatial information uncertainty: what we know and what we need to know. Cartogr Geogr Inform Sci 32(3):139–160

Miao F (2022) K-12 AI curricula: a mapping of government-endorsed AI curricula. UNESCO Publishing. https://unesdoc.unesco.org/ark:/48223/pf0000380602

Miao F, Holmes W (2021) AI and education: a guidance for policymakers. UNESCO Publishing

Miao F, Holmes W, Huang R, Zhang H (2021) AI and education guidance for policy-makers. UNESCO, Paris. https://unesdoc.unesco.org/ark:/48223/pf0000376709. Accessed 18 Nov 2021

Mikroyannidis A, Okada A, Correa A, Scott P (2020) Inquiry-based learning on the cloud. In: Information resources management association cognitive analytics: concepts, methodologies, tools, and applications. IGI Global, pp 529–549

OECD (n.d.) An overview of diversity, equity and inclusion in education. OECD iLibrary. https://www.oecd-ilibrary.org/sites/0c767cb5-en/index.html?itemId=%2Fcontent%2Fcomponent%2F0c767cb5-en

Okada A, Buckingham Shum S, Sherborne T (2008, 2014) Knowledge cartography: software tools and mapping techniques. Springer, London

Okada, A. (2024). Knowledge Cartography for Young Thinkers: Sustainability Issues, Mapping Techniques, and AI Tools. Figures. The Open University. CCBY. https://doi.org/10.21954/ou.rd.27963327

Okada A, Sherborne T, Panselinas G, Kolionis G (2024) Fostering Transversal Skills through Open Schooling supported by the CAREKNOW-DO Pedagogical Model and the UNESCO AI Competencies Framework.

Okada A, Gray P (2023) A climate change and sustainability education movement: networks, open schooling, and the 'CARE-KNOW-DO' framework. Sustainability 15(3):2356

Okada A (2006) Cartografia Investigativa: interfaces epistemologicas comunicacionais para mapear conhecimento em projetos de pesquisa [Investigative cartography: epistemological and communicational interfaces to map knowledge in research projects]. Pontifícia Universidade Católica de São Paulo. https://tede2.pucsp.br/handle/handle/9889

Okada A (2010) Eliciting thinking skills with inquiry maps in CLE. In: Torres P, Marriot R (eds) Handbook of research on collaborative learning using concept mapping. Information Science Reference IGI Global, Hershey, pp 52–80

Paul RW (1992) Critical thinking: what, why and how. In: Barnes CA (ed) Critical thinking: educational imperative. Jossey-Bass, San Francisco

United Nations (2021) Our common agenda: report of the secretary-general. https://www.un.org/en/content/common-agenda-report/assets/pdf/Common_Agenda_Report_English.pdf

Wolodtschenko A, Forner T (2007) Prehistoric and early historic maps in Europe: conception of Cd-Atlas. E-perimetron 2(2)

Chapter 2
What Are Maps?

Abstract This second chapter presents three learning objectives:

1. Understand the historical significance of maps, noting that they predate both writing and the number system.
2. Identify and categorise the various formats of knowledge maps based on content, structure, and shape.
3. Explore the diverse applications of knowledge maps across different fields.

Keywords Origin · Application · Format · Thinking · Development

The "map" is a widely used concept in geography and refers to the representation of a region. The practice of mapmaking and cartography has a long history dating back thousands of years to various civilisations, including the Greeks and Romans (Edney 2019). The word 'map' has ancient roots and was derived from the Latin term 'mappa', which originally referred to a cloth or napkin used for cleaning or wiping (Online Etymology Dictionary 2001). Later, sheets of parchment, such as pieces of fabric or paper with drawings or visual representations, were described. It visually represents a three-dimensional space in the two-dimensional plane and includes several components, such as scale, projection, and source. Several types of maps, such as climate maps (climate), hydrographic maps (rivers), geomorphological maps (relief), political maps (cities), and demographic maps (population), are used to represent different aspects of an area. On the other hand, the word 'diagram' more recently than maps has its origins in the Greek word '*diagramma*', which means a drawing or a written illustration (Online Etymology Dictionary 2001). The relationship between maps and diagrams lies in their shared objective of communicating information visually (Moore 1993). Both are tools for visualisation that help users understand, explore, and communicate complex data or relationships more effectively. A schematic map such as a subway map may resemble a diagram because it simplifies details to clarify routes and connections, focusing more on usability than geographical accuracy (Roberts et al. 2017).

A. Okada, *Knowledge Cartography for Young Thinkers*, SpringerBriefs in Advanced Information and Knowledge Processing, https://doi.org/10.1007/978-3-031-54677-8_2

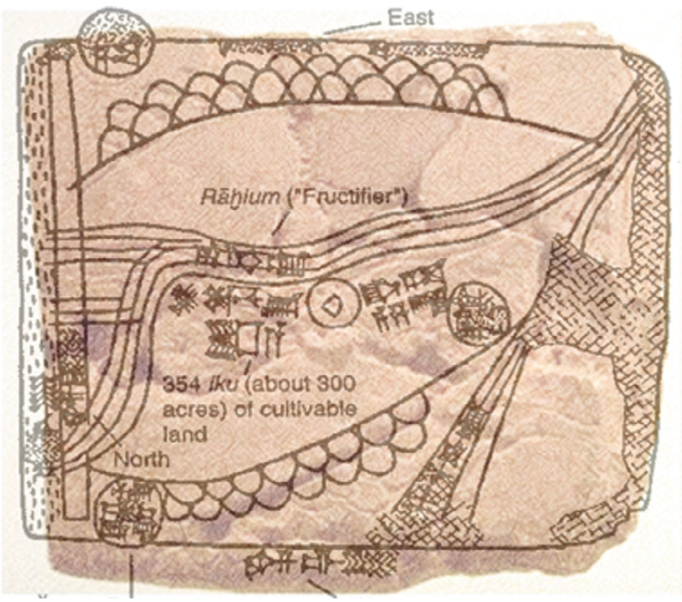
2.1 Geographical Maps

Cartography, the art of making maps, is one of the oldest instruments for representation and graphic communication. The decimal number system is believed to have originated in ancient India approximately 1000 BC; the Phoenician alphabet (1200 BCE) consisted of 22 letters, primarily consonants used by the ancient Phoenician civilisation that inspired the Greek alphabet (800 BC). The oldest known maps were found in the city of Hank Sukur (Map 2.1), Turkey, and dated back to approximately 6200 BC. These ancient maps that survived over time were etched onto clay tablets.

While maps, writing, and number systems have distinct purposes and characteristics, they are all tools that humans have developed to convey information, express ideas, and navigate the complexities of the world. They are integral to human culture, knowledge, and communication (Map 2.2).

These graphical representations come in different sizes, depicting everything from the whole world to smaller regions, local areas, and even specific buildings and grounds. However, there are differing opinions and uncertainties regarding how old these maps are, what they show, and how they can be interpreted.

Educators highlight that maps are an important tool in teaching and learning to give children a sense of space, location, representation and visual interpretation, as well as thinking and learning about print (Adams 1994).



Map 2.1 Geographic map: the oldest example, 6200 BC. Okada (2024) Adapted from CCBY Bibliotecapleyades (https://www.bibliotecapleyades.net/mapas_antiguos/ancient_webpage/100D.htm)

Map 2.2 Geographic map: Japanese school map by Bruno, 7 years old. Okada (2024)

The representation of space by the child is fundamental for the development of spatial skills (Almeida 2001), such as the relationships among dimension, proximity, separation, order, and similarity (Map 2.2).

2.2 Knowledge Maps

The term "map" is also used to describe a graphical representation of knowledge. A map can relate to the mind or mental space, providing a visual communication of thoughts, ideas, or concepts and illustrating the relationships between them. These maps help individuals organise their thinking, plan projects, or illustrate connections between different pieces of information. While they do not depict physical terrain, they serve as valuable tools for understanding and navigating mental landscapes.

In the field of cognitive sciences, knowledge maps are used for constructing and simulating mental models. Each type of knowledge map represents an aspect of knowledge, for example, concept maps for words and its meanings, mental maps for ideas, argument maps for reasoning, dialogue maps for conversation modelling, and diagram maps for schemes.

A knowledge map is generally understood as a cognitive model created using mental elements or components. According to Lévy (1998), maps are not realistic images but serve as crucial interfaces for translating and visually communicating preexisting mental models. They form the basis for new reconstructions and representations and play a vital role in mental reasoning. Maps contribute to mental activity by providing new information or cues and enhancing the flow and exploration of thinking processes.

> Unlike phonetic linguistic representations, mental models are structural analogues of the world as these represent the individual in question and (...) are of the order of the organisation chart or diagram, even if they are not presented as an image, they need a schema" (Lévy 1998, p. 102). Mental models are a set of mental images organised hierarchically. However, mental images do not always correspond to real images; "numerous abstract objects simply have no physical image (...). We can, however, associate them with a conventional image not necessarily realistic, but with the appeal of cultural elements (Lévy 1998, p. 104).

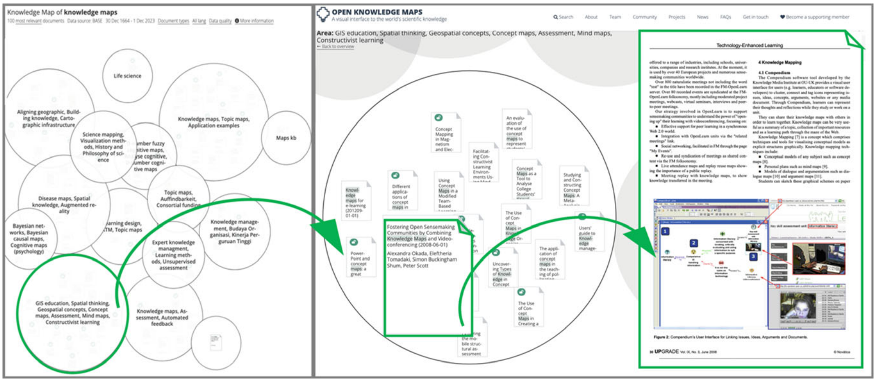
We can infer that mental images are not mere replicas of perceptions drawn on paper, cloth, or clay. Instead, a mental image allows individuals to synthetically apprehend complex material and represent absent objects, thereby enabling them to perform semiotic functions. As Sartre notes in a citation by Lévy (1998), 'The image is neither an illustration nor support of thought but is itself thought, and therefore comprises knowledge, intentions.'

Building on this foundational idea, knowledge mapping aligns with the cognitive processes described by Pascual-Leone and Goodman (1979), Pascual-Leone (1987) and Baddeley (2012), although these cognitive theorists do not specifically mention knowledge maps. Pascual-Leone highlights that a 'scheme' is a well-learned procedure activated in learners' memory for problem-solving tasks. Similarly, Baddeley's 'central executive' manages the use of various schemas, focusing on relevant information and adapting to environmental demands.

Knowledge maps facilitate these cognitive operations by helping students design, visualise, and reorganise complex information, enhancing their memory retrieval and problem-solving capabilities. This process reduces cognitive load—the amount of mental effort being used in the working memory—and leads to more efficient information processing. In educational settings, knowledge maps prove invaluable for deep learning, aiding students in understanding the interconnections between concepts and fostering the development of higher-order thinking skills. Ultimately, knowledge mapping potentially enhances learning outcomes by optimising the management of cognitive resources, proving to be a meaningful method in the application of cognitive theories to educational practices.

The human art of mapping the outer and inner world is a relevant skill. Various connections can be described between mapping and current advances, including transdisciplinary considerations related to scientific knowledge repositories, which are increasingly expanding on the internet.

In artificial intelligence (AI), visual mapping tools and techniques are utilised to represent and visualise content from scientific databases. For instance, openknowledgemaps.org is an AI-based search engine that helps users find scientific papers. Map 2.3 showcases an open knowledge map featuring articles related to 'knowledge mapping' on the left—automatically generated by an AI tool—and on the right—an example of an article by an author involving student inquiry mapping. The map aggregates the 100 most relevant articles from 1964 to 2023, organised into 15 categories. Within the categories of GIS education, the author located one of her articles titled "Fostering Open Sensemaking Communities by Combining Knowledge Maps and



Map 2.3 Knowledge map on the web, OpenKnowledgeMap. Okada (2024)

Video-Conferencing”. This study examined teachers’ community knowledge maps as a learning path for students to create their own maps.

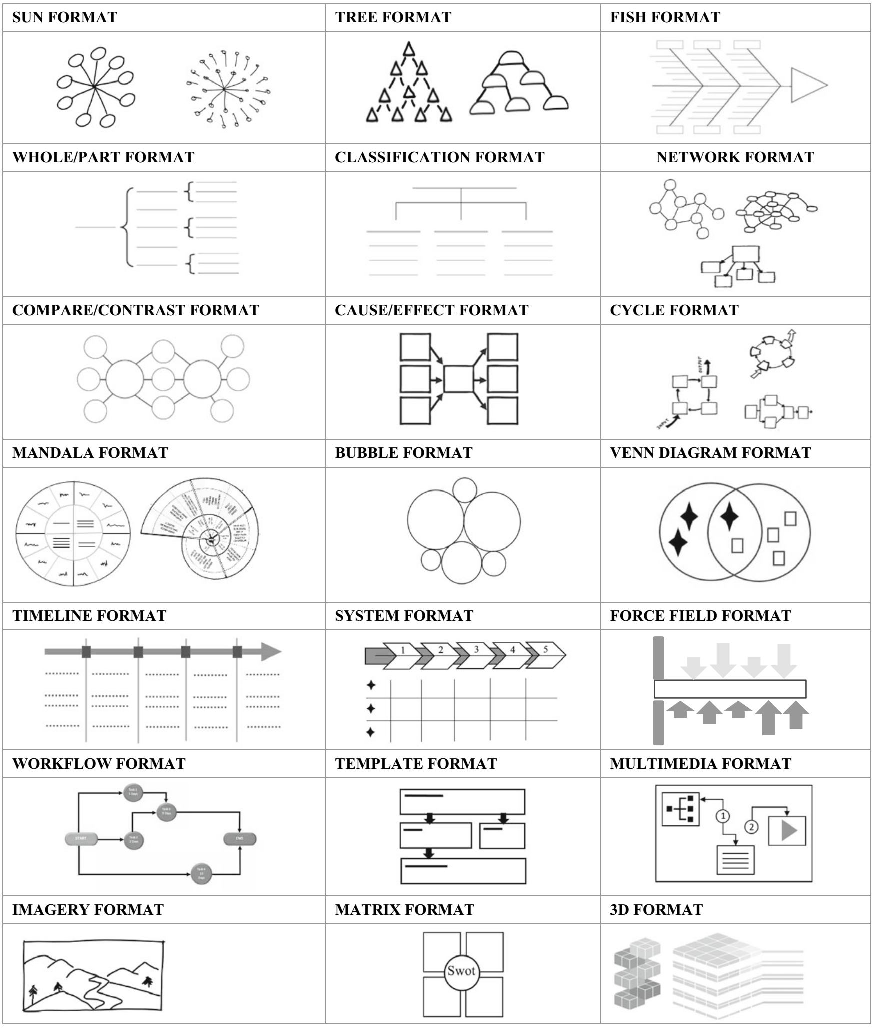
As spatial arrangements on a plane such as paper or digital canvas, knowledge maps have been produced to cover any type of subject or field in the natural, social, and formal sciences. Mapping has been used as a strategy to address large quantities of theoretical or empirical information, enabling important interrelations of interest to be extracted. Knowledge maps can be used to represent concepts, information, ideas, dialogue, and reasoning, referring to the present, past or future, respectively. Their components can include graphic, textual, audio, and video information. Words and concepts can be selected, classified, and interpreted through semantic relationships and spatial patterns.

Knowledge maps thus serve to elucidate the structures of knowledge (Jonassen 2000) and reveal the semantic connections among concepts and ideas in development. These associations can span various scales, ranging from simple and general to intricate and detailed. Educators emphasise that the use of knowledge maps has significant pedagogical value in nurturing children’s cognitive, creative, and affective abilities (Okada 2014), including skills such as organising and applying knowledge, imagination, critical and creative thinking, language, and meaningful learning.

Additionally, knowledge mapping approaches are frequently used to represent scenarios, phenomena, or processes. These techniques serve as powerful tools for enhancing the clarity, comprehensibility, and impact of research. They provide a means for authors to communicate complex ideas effectively and help readers understand and engage with content more easily, for example, in research papers, professional proposals and educational projects. Diagrams and maps are invaluable tools for researchers and learners because they improve communication among complex information, concepts, and relationships. They provide a visual medium that simplifies the comprehension of intricate scientific ideas, bridges language barriers, and fosters effective communication in international scientific communities. Knowledge mappers benefit from the ability to convey information concisely, particularly when illustrating data, models, or frameworks. Concise maps help readers quickly grasp essential points.

2.3 Formats and Examples

There are several knowledge map formats available to support students, educators, and researchers. Map 2.4 provides examples of how to design maps, featuring 21 types categorised by shape. Certain formats may be more suitable than others, depending on the context and the need for clarity in the content represented. Additionally, the significance of a map's content can be enhanced by its composition. Selecting an appropriate format is crucial for facilitating idea development and the comprehension or construction of knowledge.



Map 2.4 Formats of knowledge maps. Okada (2024)

Students can choose the format of their map based on their pedagogical goals or follow recommendations from educators or researchers. The upcoming section provides examples of these formats, designed to aid teachers and students in planning teaching and learning resources.

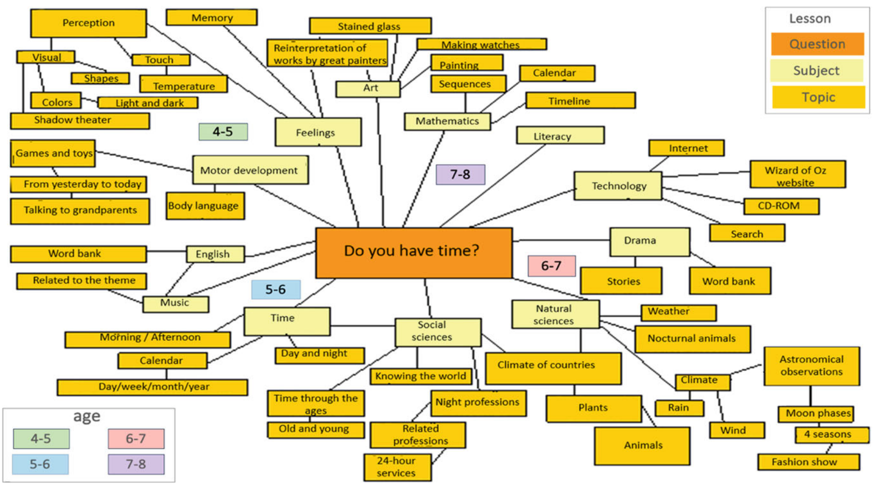
These formats are grouped into seven categories based on the kind of content and connections the map focuses on:

1. **Shape**: Sun, Tree, and Fish
2. **Connection**: Whole/part, classification, and network
3. **Relationships**: Compare/contrast, cause/effect, cycle format
4. **Structures**: Mandala, bubble, Venn diagram
5. **Sequences**: Timeline, systems, force field
6. **Flows (arrows)**: Workflow, template, multimedia
7. **Compositions**: Imagery, matrix, 3D format

The following ten examples illustrate various formats and also provide different applications of knowledge maps, demonstrating how each can be utilised to organise information, visualise relationships, and enhance understanding across diverse subjects and contexts.

2.3.1 Network Format for a Curriculum Map of Elementary and Primary Schools

Map 2.5 created a curriculum designed to present an interdisciplinary curriculum for primary pupils with interdisciplinary activities about "time". Teachers used this map



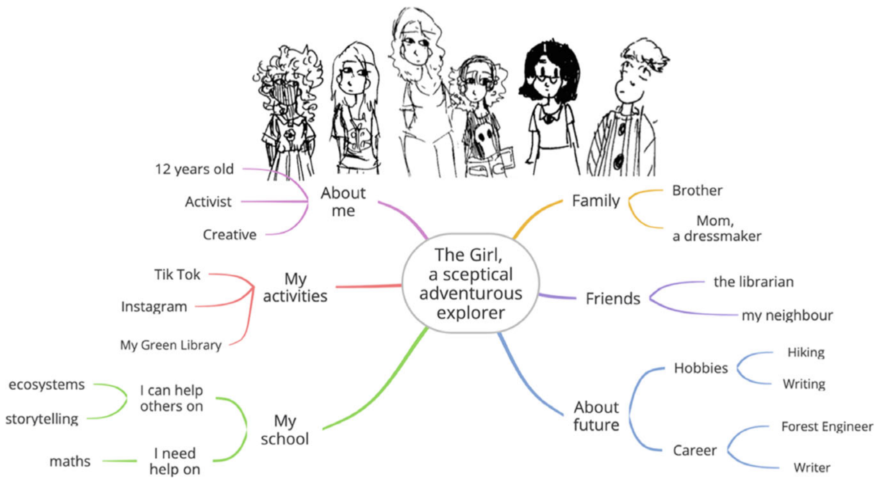
Map 2.5 Network format: curriculum map, CmapTools. Okada (2024)

as a multidimensional tool to create and structure lesson plans that are age-appropriate and integrate various subjects and sensory experiences. The network map connects different subjects, such as art, mathematics, literacy, and social sciences. The map also segments information by age group (4–5, 6–7, etc.), helping teachers select content that is developmentally suitable for their students.

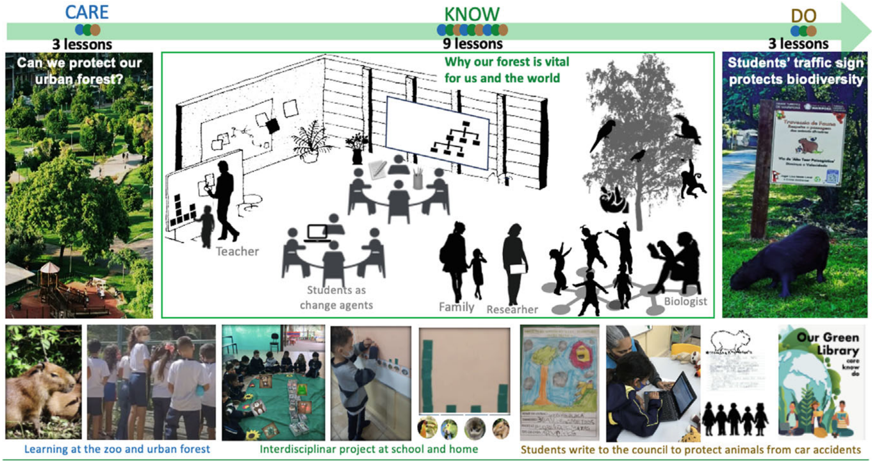
2.3.2 Sunformat for a Storytelling Map of Primary and Secondary Schools

Map 2.6, crafted by a student and inspired by the book 'Green Library: care-know-do' (Okada 2024), employs storytelling mapping to enhance creative writing through knowledge maps. This technique supports:

- **Organisation**: helps structure thoughts and record ideas on a topic.
- **Summary**: simplifies complex topics for easier understanding.
- **Creativity**: facilitates the exploration of open-ended possibilities and alternatives.
- **Grouping**: assists in organising information into coherent groups.



Map 2.6 Sun format: map of the book "our green library", Ayoa. Okada (2024)



Map 2.7 Timeline format: open schooling map, Canva. Okada (2024)

2.3.3 Timeline Format Map for an Open Schooling Project

Map 2.7 refers to an open schooling project with primary students aged 5–7. Research shows that mapping activities can foster early learning skills (Prieto et al. 2006). Teachers highlighted various benefits of knowledge maps:

- Concentration: focused thinking on a theme or goal interacting with family and professionals.
- Problem identification: creating new questions and finding motivation in challenges.
- Multiliteracies: combining words, numbers, sentences, and expression fluency.
- Criticality: recognising issues, societal problems and elaborating solutions.

2.3.4 Multimedia Format Map for Immersive Learning with HoloLens

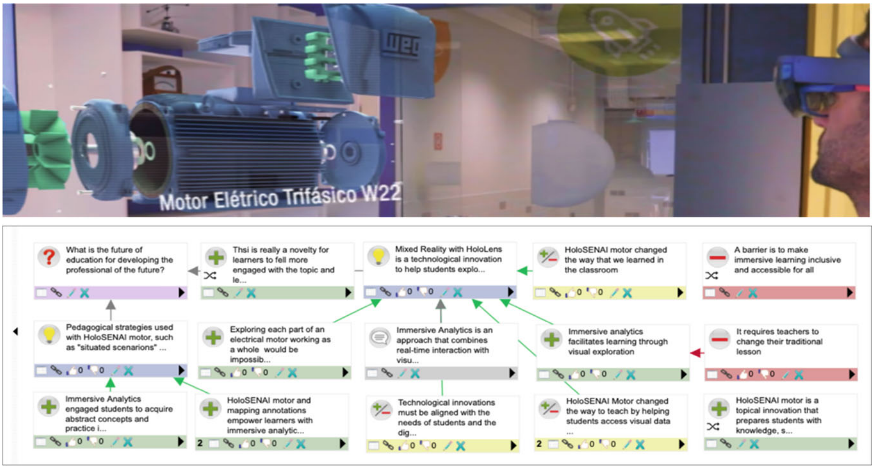
Map 2.8 explored the benefits of MR in a mechanics course for technical students aged 16–19 years and highlighted the following:

Originality: Immersive learning offers an engaging exploratory experience.

Connection: Students link abstract concepts with practical visualisation of parts and functions.

Personalisation: Each student interacts with and visualises content according to their unique curiosity and interests.

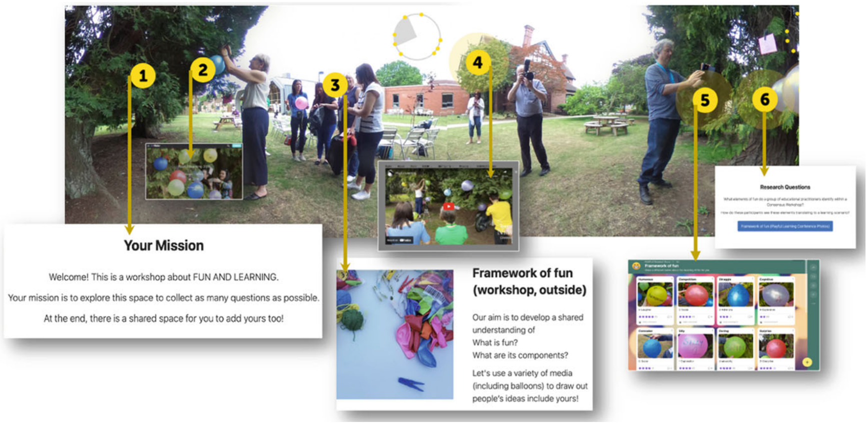
Understanding: This approach enhances explanations and aids in clarifying misunderstandings (Ramos et al. 2019).



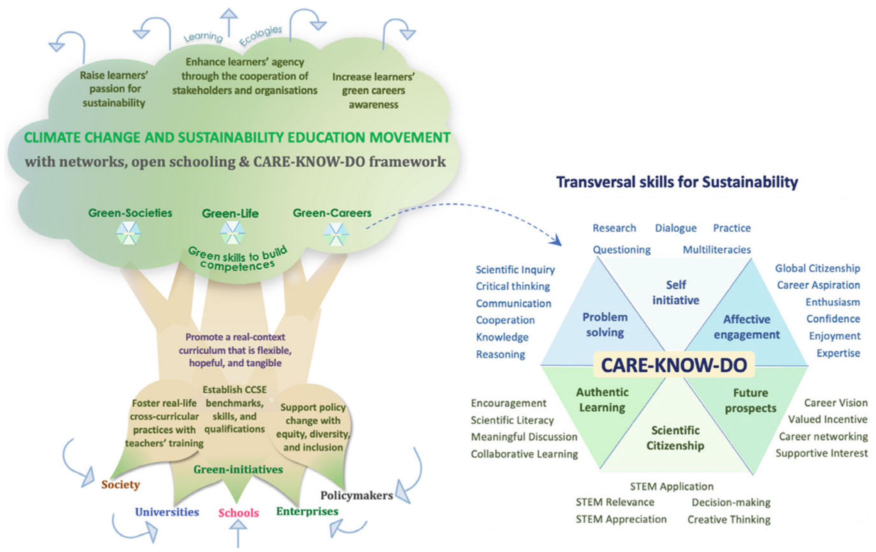
Map 2.8 Multimedia format: immersive learning map, LiteMap. Okada (2024)

2.3.5 3D Format Map for 360 Virtual Non-formal Learning

Map 2.9 shows a 360 VR activity to explore immersive learning. This immersive gamification activity was based on a face-to-face workshop fun in learning (Ferguson et al. 2020). This activity was designed through a 360 virtual image that was mapped with ThingLink to enable participants to experience and reflect on the online learning and fun (Okada and Sheehy 2020) of a workshop. Most of the participants highlighted key benefits: to learn effectively, students must enjoy their learning. To learn meaningfully, students must be happy while learning, and this should involve fun.



Map 2.9 3D format: fun in learning map, ThingLink. Okada (2024)



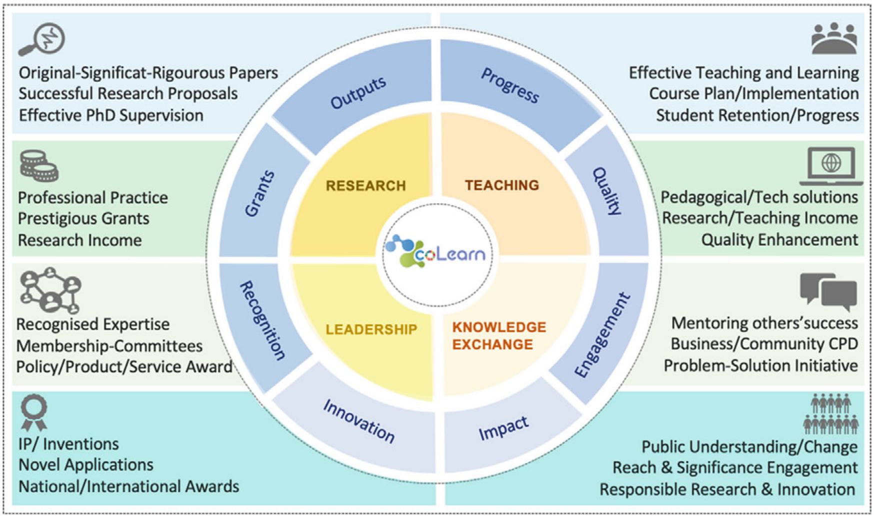
Map 2.10 Tree format: education for sustainability map, ThingLink. Okada (2023, 2024)

2.3.6 *Three-Format Map of Sustainability Education for Policymakers*

Map 2.10 showcased the findings of the research article 'A Climate Change and Sustainability Education Movement: Networks, Open Schooling, and the 'CARE-KNOW-DO' Framework' (Okada and Gray 2023), visualising the framework of sustainability education as a tree. The roots symbolise the nurturing of students' engagement in sustainability, collaborative empowerment, and awareness of green careers. The trunk represents a commitment to a dynamic and relevant curriculum, branching into educational strategies such as setting standards and providing in-depth teacher training. The tree canopy above represents the goals of achieving success in green careers through ecopreneurship, green living, and eco-leadership. It encompasses the hexagon of transversal skills needed to collaboratively lead sustainable living and foster a green society with ecological and societal governance.

2.3.7 *System Format Map for Academic Research Development*

Map 2.11 is an integrated model of academic practice that combines research, teaching, leadership, and knowledge exchange as key domains. It uses a circular system design to show the interconnectedness of these elements, emphasising that excellence in one area can bolster the others. For research groups, this diagram could



Map 2.11 System format: academic practices map, ThingLink. Okada (2024)

serve as a framework to ensure a balanced and comprehensive approach to their activities.

- **Research**: This involves tracking performance in producing quality research papers, securing funding, and supervising PhD students, aiming for professional recognition and contributions in the research area.
- **Teaching**: Emphasises integrating research findings into teaching to improve course quality and pedagogy while focusing on student retention and success to demonstrate the impact of teaching methods.
- **Leadership**: Guides research groups to foster innovation and impactful results, with an emphasis on gaining recognition and influencing policy or product development through expertise and awards.
- **Knowledge Exchange**: Stresses the importance of community engagement, mentoring, and contributing to professional development, aiming for initiatives that enhance public understanding and responsible innovation.

Research groups can create a balanced portfolio of activities, ensuring that they not only are advancing knowledge but are also contributing to teaching, leading in their field, and engaging with society.

Map 2.11 can be expanded as a template map to reflect on the following questions:

Research: How can we measure and track our research performance more effectively to ensure that we produce high-quality papers and make meaningful contributions to our field?

Teaching Domain: How can a knowledge map guide us in creating a balanced portfolio of academic activities that reflects excellence across research, teaching, leadership, and knowledge exchange?

Leadership Domain: What strategies can we adopt to foster innovation within our research group, and how can we leverage our expertise to influence policy or product development?

Knowledge Exchange Domain: How can we improve our engagement with the wider community and contribute more significantly to public understanding and professional development in our field?

Balanced Approach: How can a knowledge map guide us in creating a balanced portfolio of academic activities that reflects excellence across research, teaching, leadership, and knowledge exchange?

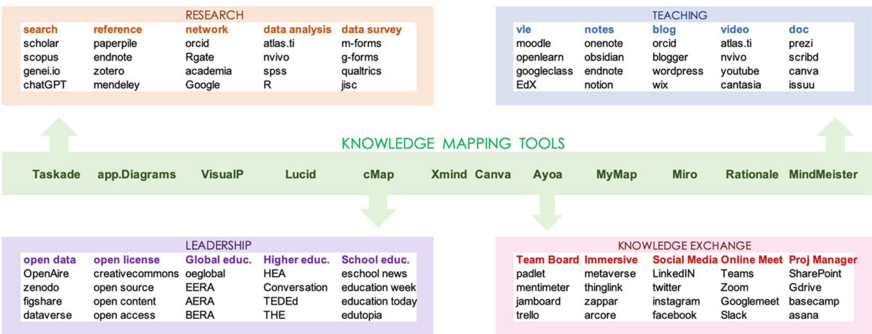
Strategic Alignment: How can we align our individual and group activities with the broader strategic objectives of our institution to promote a holistic approach to academic excellence?

Interconnectedness: How can we ensure a synergistic effect among the domains where success in one area reinforces and supports the others?

Assessment and Adaptation: How often should we assess our progress using mapping, and how can we adapt our strategies in response to these assessments to maintain or enhance our academic practice?

2.3.8 Template Format Map of the Apps for Academic Research Groups and Individuals

Map 2.12 is a categorised visual directory of digital tools and platforms tailored for academic and professional use, specifically within the realms of research, teaching, leadership, and knowledge exchange. It serves as a resource map for research groups, allowing them to identify technological solutions that align with various operational needs.



Map 2.12 Template format: technologies and AI map, ThingLink. Okada (2024)

This template map can be personalised with selected digital tools to enhance academic and professional activities, quickly guiding research groups supported by knowledge mapping. Providing curated resources aids in the digital literacy of group members and supports the integration of technology in research, education and leadership.

How Can It Be Used?

For Research: Groups can identify software and platforms that assist in mapping bibliographic research, managing references, networking, data processing, and distributing research findings.

For Teaching: Educators can find tools to create and manage digital classrooms, map and share notes, create blogs, produce videos, and distribute documents.

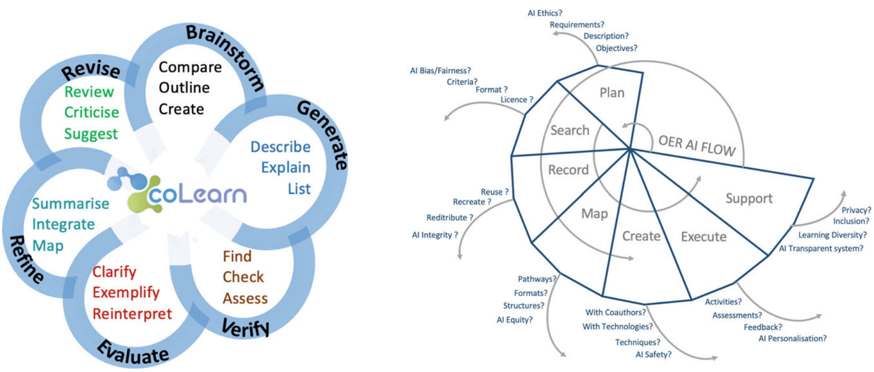
For Leadership: Leaders in the education field can explore resources for global education initiatives, open data and licensing, as well as mapping news and developments in the education sector.

For Knowledge Exchange: Teams can utilise collaboration tools for board meetings, immersive tools for interactive experiences, social networks for dissemination, and project management software for task mapping.

2.3.9 Mandala Format Map for Using AI Generation Content

Map 2.13 is designed to assist colearners in creating prompts using AI tools such as ChatGPT with iterative steps:

Brainstorming: Utilise AI-generated content for brainstorming, creative thinking, mapping and writing.



Map 2.13 Mandala format: maps to support AI use, Thinglink. Okada (2024)

Generate: Explore particular ideas further with more elaborate prompts or from the description of maps.

Verify: Ensure accuracy and reliability by checking content against primary sources or one's own knowledge.

Evaluate: Perform critical evaluation to ensure the quality of context, language, and audience appropriateness.

Refine: Adjust prompts based on evaluations, specifying language and detail levels to enhance AI results.

Revise: Continuously refine and revise to tailor AI outputs to user needs.

This map is complemented with the OER AI FLOW map, helping open educators to plan, search, record, map, create, execute, and support learning materials with the aim of enriching open education.

2.3.10 Matrix-Format Map for Planning, Monitoring and Evaluating Knowledge Mapping

In knowledge mapping, critical reflection is essential for learning both how to create maps and how those maps facilitate learning. Formative and self-assessment, supported by feedback from teachers and experts, are valuable in this process. Map 2.14 aids these assessments by providing a comprehensive list of questions for planning, developing, and evaluating knowledge maps. This list helps experts, teachers, and researchers systematically reflect on the map's content, connections, and alignment with learning objectives. The aim is to improve understanding and engagement and to identify areas for growth while integrating diverse perspectives and AI mapping tools to enhance educational practices. These questions are suitable for various activities and should be adapted to accommodate different age groups and educational levels, thereby meeting the specific needs of students and curricula.

Reflective Remarks This chapter examined the historical significance of maps,

explained how knowledge maps enables the reflection and representation of external reality into mental models.

Action Points: Highlight knowledge maps formats and applications based on your interests.

Next chapter will present the developmental journey of children's graphic representations, guided by the insights of Luquet, Piaget, and other researchers.

Questions: How does the transition from drawing to mapping evolve as children grow older, and what further complexities and opportunities does this evolution introduce to their cognitive development and learning processes? How can educators and curriculum designers further harness the power of mapping to enrich education and foster a deeper understanding of the lifeworld?

	Planning	Monitoring	Evaluation
Design	What are the subject, purpose, and objectives of the map?	What key components should be included?	Are the elements, title, goals, and content, clearly presented?
Content	Does the map present clear and relevant content?	Are categories such as concepts, facts, data, and evidence well described?	Does the map facilitate an understanding of parts and offer an appealing visual of the whole?
Concepts	Are the components of the map relevant?	Does the map provide relevant information about the subject?	Are the connections on the map clear and easy to comprehend?
Categories	Are the classification (types, groups, and categories) clear?	Are examples included?	Are any components missing from the map?
Diversity	Does the map include any question?	Does the map present various opinions or perspectives with the necessary backing information?	Does the map provide well-substantiated answers from different perspectives?
Gaps	What's next? What's missing that needs to be added?	What is unrelated and should be removed?	Is there any aspect of the map that is unclear and requires further explanation?
Connection	Are all elements connected? Is any connection missing?	How are the links on the map described? In what ways can the map be improved?	Are all the map's connections concise and coherent?
Links	Does the map integrate all relevant components?	Are the content and relationships aligned with the map's objectives?	Does the map clearly communicate its content and relationships?
Structure	How can the map's structure be improved?	Should the positions of elements be changed to enhance the map's structure?	Does the map display a clear and coherent structure?
Description	Does the map include a title, tools used, and the topic?	Were the components and connections well organised? Is the provided information sufficient?	Does the map effectively support the achievement of its stated goal?
References	Does the map include relevant references, data, facts, and concepts?	Are the references well categorised and grouped for easy navigation?	Are source references adequately included in the map?
Final Aesthetics (design)	Is the map design clear? Were colours and text used effectively without cluttering the map?	Are the component descriptions and connections easy to understand?	Is the content organised into maps and submaps? Have the map's illustrations, such as figures and icons, been used effectively?

Map 2.14 Matrix format: monitoring and evaluation map, Word. Okada (2024)

References

Adams MJ (1994) Beginning to read: thinking and learning about print

Almeida R (2001) From drawing to map: cartographic initiation in school. SP: Context

Baddeley AD (1986) Working memory. Oxford University Press, Oxford

Baddeley AD (1992) Is working memory working? The fifteenth Bartlett lecture. Quart J Exper Psychol 44:1–31

Baddeley A (2012) Working memory: theories, models, and controversies. Annu Rev Psychol 63:1–29

Cañas AJ, Novak JD (2014) Concept mapping using CmapTools to enhance meaningful learning. Knowledge cartography: software tools and mapping techniques. Springer, London, pp 23–45

Edney MH (2019) Cartography: the ideal and its history. University of Chicago Press

Ferguson R, Childs M, Okada A, Sheehy K, Tatlow-Golden M, Childs A (2020) Creating a framework of fun and learning: using balloons to build consensus. In: ECGBL 2020 14th European conference on game-based learning. Academic Conferences limited, p 151

Jonassen DH (2000) Toward a design theory of problem solving. Educ Technol Res Develop 48(4):63–85

Lévy P (1998) The dynamic ideography towards an artificial imagination. Ed. Loyola, St. Paul

Moore PJ (1993) Metacognitive processing of diagrams, maps and graphs. Learn Instr 3(3):215–226

Niaz M (1989) Relation between Pascual-Leone's structural and functional M-space and its effect on problem solving in chemistry. Int J Sci Educ 11:93–99

Niaz M, Logie RH (1993) Working memory, mental capacity and science education: towards an understanding of the 'working memory overload hypothesis.' Oxford Rev Educ 19(4):511–525

Okada A (2014) Scaffolding school pupils' scientific argumentation with evidence-based dialogue maps. In: Knowledge cartography: software tools and mapping techniques. Springer, New York, pp 131–162. https://doi.org/10.1007/978-1-84800-149-7_7

Okada A (2023) Inclusive open schooling with engaging and future-oriented science: evidence-based practices, principle and tools. The Open University, Milton Keynes

Okada A (2024) A self-reported instrument to measure and foster students' science connection to life with the CARE-KNOW-DO model and open schooling for sustainability. J Res Sci Teach

Okada A, Gray P (2023) A climate change and sustainability education movement: networks, open schooling, and the 'CARE-KNOW-DO' framework. Sustainability 15(3):2356

Okada A, Sheehy K (2020) The value of fun in online learning: a study supported by responsible research and innovation and open data. Revista e-Curriculum 18(2): 319–343.

Okada, A. (2024). Knowledge Cartography for Young Thinkers: Sustainability Issues, Mapping Techniques, and AI Tools. Figures. The Open University. CCBY. https://doi.org/10.21954/ou.rd.27963327

Okada A, Panselinas G, Bizoi M, Malagrida R, Torres PL (2024) Fostering transversal skills through open schooling with the CARE-KNOW-DO framework for sustainable education. Sustainability 16(7):2794

Online Etymology Dictionary (2001). www.etymonline.com/word/map

Pascual-Leone J (1987) Organismic processes for neo-Piagetian theories: a dialectical causal account of cognitive development. Int J Psychol 22:531–570

Pascual-Leone J, Goodman D (1979) Intelligence and Experience. Instruct Sci 8:301–367

Prieto MD, Parra J, Ferrándo M, Ferrándiz C, Bermejo M, Sánchez C (2006) Creative abilities in early childhood journal of early childhood research. Sage Publ 4(3):277–290

Ramos AL, Korb T, Okada A (2019) Immersive analytics through holosenai motor mixed reality app. In: Intelligent computing: proceedings of the 2019 computing conference, vol 2. Springer, pp 1259–1268

Roberts MJ, Gray H, Lesnik J (2017) Preference versus performance: investigating the dissociation between objective measures and subjective ratings of usability for schematic metro maps and intuitive theories of design. Int J Hum Comput Stud 98:109–128

Sartre JP (1940) The imaginary: a phenomenological psychology of the imagination

Winn W (1991) Learning from maps and diagrams. Educ Psychol Rev 3:211–247

Chapter 3
From Drawing to Mapping

Abstract This third chapter presents three learning objectives:

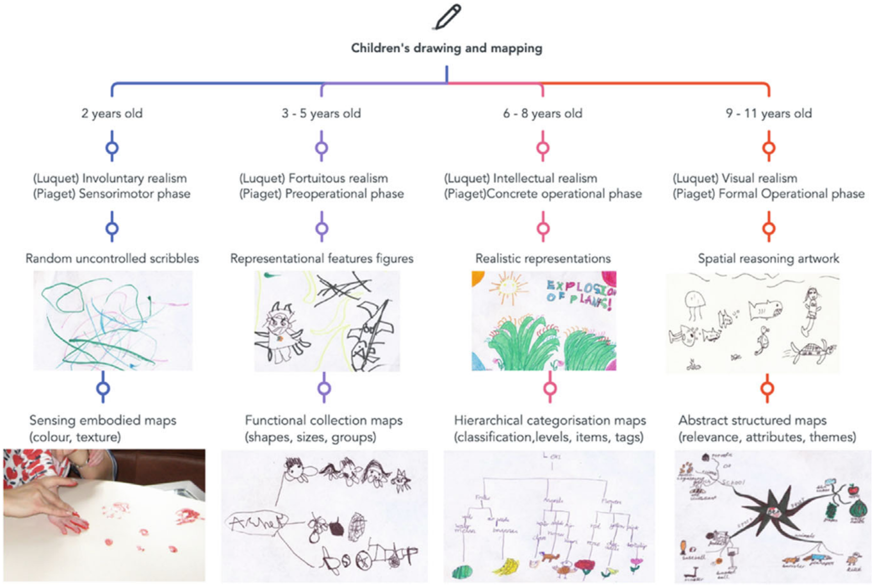
1. Understand and describe the progression of children's graphic representations from simple scribbles to detailed and thematic drawings based on the research by Luquet and Piaget.
2. Identify and analyse the evolution of children's drawing concepts from abstract shapes to conceptual themes such as food, plants, and ecosystems, demonstrating an understanding of the developmental stages.
3. Learn strategies to effectively guide children in transitioning from drawing to mapping, emphasising the need for structured support to facilitate this developmental stage.

Keywords Visual representation · Drawing · Cognitive development · Construction · First map

This chapter discusses how early visual representation skills including pictures, text, and drawing underpin the ability to use and create maps. By understanding how children develop spatial awareness through drawing and games, educators can better guide their skills in map navigation and creation from an early age. Mapping techniques can be fostered in primary schools through playing activities for children aged 6–10. Children's drawings initially manifest as simple scribbles and, over time, transform into elaborate forms. As they progress through developmental stages, their artwork becomes increasingly complex, reflecting their cognitive growth. This progression makes them suitable for being introduced to AI mapping tools in lower secondary school (ages 11–13), as illustrated in Chap. 7.

Luquet and Piaget, renowned for their research into children's cognitive development, have significantly enhanced our understanding of how children's use of visual representations develops with age. These insights have profoundly influenced educational methods and our recognition of children's developmental milestones in visual expression.

A. Okada, *Knowledge Cartography for Young Thinkers*, SpringerBriefs in Advanced Information and Knowledge Processing, https://doi.org/10.1007/978-3-031-54677-8_3



Map 3.1 From representation to cognition, MindMeister. Okada (2024)

Jean Piaget, a Swiss psychologist, is noted for his four-stage model of developmental psychology introduced in 1929, which includes the sensorimotor, preoperational, concrete operational, and formal operational stages. This model, as explained in Piaget and Inhelder (1982), demonstrates a strong link between cognitive development and the progression of children's drawing abilities. Preceding Piaget, George Luquet, a French art historian, meticulously analysed his daughter's drawings. He delineated four distinct stages of children's art development—Casual Realism, Failed Realism, Intellectual Realism, and Visual Realism—as depicted in his 1927 publication.

According to Luquet (1979), when children depict specific objects or concepts, they project their mental model, which may not correspond to the actual visual input. Thus, a child's drawing or map can reveal not only their conceptual understanding but also how they relate these concepts to one another. Piaget (1976) posited that knowledge originates from learners' actions when they interact with objects and their existing mental structures. Children's drawings and maps, therefore, are tools that enable the visualisation of these structures, fostering the development of refined models and the rectification of misconceptions facilitated by educators.

Map 3.1 is a simplified summary of Luquet and Piaget's research, which also underpins my analysis of first maps in pedagogical activities with children aged 2–11 years.

Extensive analyses of children's graphic representations by Luquet (1979) and Piaget (1993) have been based on copious documentation. These studies have shown that as children develop mental schemas and interact with their environment, they expand their creative abilities, incorporating internal and external influences, intentions, ideas, and memories (Luquet 1979, pp. 23–35). While they investigated the development of children's visual representation, they did not explore the connection between drawing and mapping. This chapter bridges that gap by analysing the relationship between children's drawings and first maps across various ages, offering guidance for educators on integrating drawing techniques with mapping skills for all age groups.

3.1 Drawings and Playful Maps for 2-Year-Old Children

Luquet calls this phase "Involuntary Fortuitous Realism." The child is not aware that the lines drawn by him can represent an object. There is no intentionality in representing something.

At this stage, "voluntary fortuitous realism" also occurs. The child begins his representation with an intention that may not coincide with the interpretation of the final production because the child, when finishing his drawing, interprets it according to what is similar to him. (Luquet 1979, pp. 135–143).

In Piaget's studies, this phase is considered the "Sensorimotor Phase". This is the doodling phase. The figure is non-existent or can appear in an imaginary way. Colour plays a secondary role, with interest in contrast appearing, but there is no conscious intention.

Map 3.2 shows the markings created by a 2-year-old child using painting and then coloured pencils. The drawing consists solely of lines oriented in different directions, resembling a fast-paced scribble composed of green, blue, and pink strokes. This abstract drawing lacks a specific subject or identifiable thought.

How can educators support children's visual representation skills? Between the ages of 2 and 3 years, children still develop fine motor skills, spatial awareness, and artistic expression that can be encouraged in a ludic way. Encouraging play and exploration in a safe and supportive environment can help children develop these skills over time.

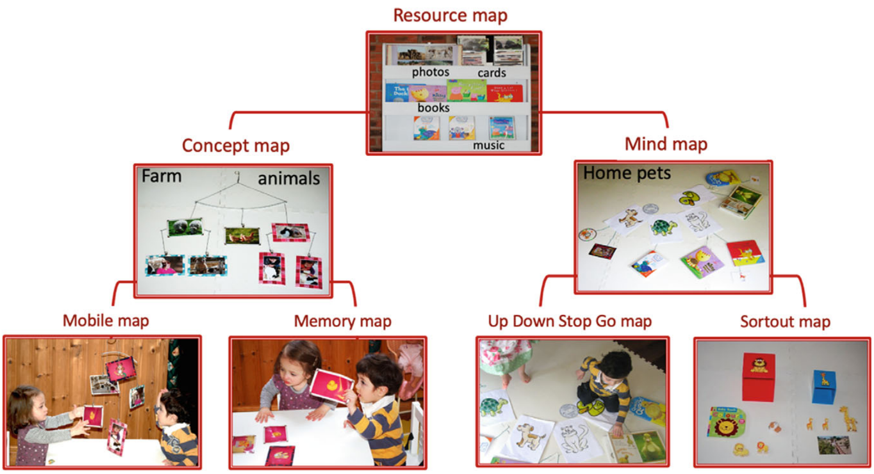
Map 3.2 From foot painting to scribbling, children aged 2–3 years. Okada (2024)

Mapping Games to Develop Visual Thinking in 2-Year-Olds

No studies found have evaluated the use of maps in 2-year-olds. As an educator, I have incorporated mapping into early childhood activities. These activities were designed to engage toddlers in exploratory instincts and sensory experiences, which are vital for developing motor skills and sound-image associations. Playful activities with first maps that incorporate toys, photos, and real objects are valuable for children aged 24–36 months, as they begin to recognise and interact with images across various media. These activities help children identify and select familiar items, support vocabulary development, enhance communication skills, and facilitate the expression of choices.

Parents and teachers can utilise these maps to narrate stories, expand vocabulary, and foster language development. Interactive activities such as moving magnetic figures on whiteboards or assembling elements on first maps encourage both motor and speech development. For example, Map 3.3 displays an age-appropriate categorisation of animals, facilitating cognitive and linguistic growth.

Furthermore, concept and mind maps prove to be excellent resources for educational games. A mobile concept map can engage children in identifying animals on a farm, serving both as an interactive activity and a memory enhancement tool on a tabletop. A mind map laid out on the floor can promote active engagement by introducing children to common household pets, especially through the use of real photos of the toys and animals they frequently see. In addition, a sorting map that allows children to match objects with similar objects aids in developing their ability to categorise through play.



Map 3.3 From toys to playful maps, children aged 2–3 years. Okada (2024)

3.2 Drawings and Maps of Children Aged 3–5 Years

Luquet termed this developmental stage ‘Synthetic Incapacity’ or ‘Failed Realism’, in which a child’s drawings may omit or exaggerate features based on their subjective importance. At this stage, children often represent their immediate surroundings and social environment, with the selective inclusion of details reflecting their cognitive limitations (Luquet 1979, pp. 147–149).

Piaget describes a similar phase as ‘Preoperational’, characterised by the presence of distinct elements and visible relationships in children’s graphic representations, such as separation and proximity. However, the sequence of elements may be absent, with drawings often appearing scattered and unrelated.

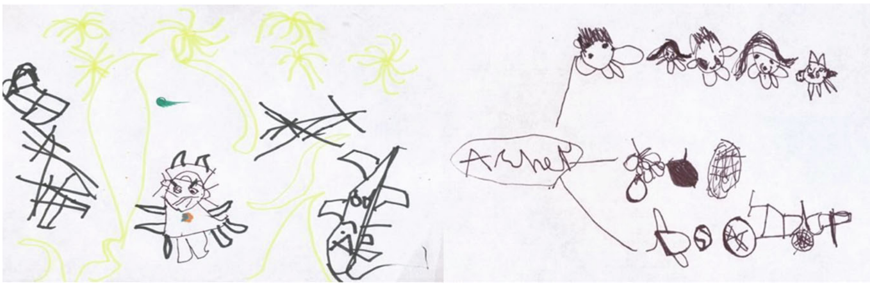
In Map 3.4, we present a compelling example of a free drawing by a 5-year-old boy named Asher. He depicted a central black figure with multiple arms, suggesting an intention to take action amidst difficulty. The figure’s expressive eyes, eyebrows, and mouth suggest emotions of anger or concern. The four black, puzzle-like shapes surround the figure and add to the complexity of the scene. Additionally, an object resembling a spaceship also carries expressions of agitation. Asher’s artwork provides insight into the dynamic and imaginative world of a child at this developmental stage.

What Should Educators Expect from Children’s Drawings at This Age?

Educators could encourage creativity, provide exploratory opportunities, and provide positive reinforcement to aid children’s artistic growth.

Skills to support include the following:

- Initiating basic shapes such as circles, squares, and triangles;
- Attempting to draw simpler forms of recognisable objects such as houses, trees, and animals;
- Exploring tools such as pencils, crayons, and markers for identifying fine motor skills;
- Creating visual representations using clipart, photos, figures, and other illustrations;



Map 3.4 From drawing to cartography, children aged 3–5 years. Okada (2024)

- Using a broader range of colours and patterns and beginning to depict imaginative scenes;
- Engaging with storytelling, discussing emotions, and fostering narrative skills;
- Enhancing spatial awareness and understanding of layouts;
- Integrating imaginary elements to increase creativity in their artwork.

Maps of Children Aged 3–5 Years

Research into map use during early childhood has identified pedagogical activities that involve children selecting and grouping figures, linking them with lines without the need to articulate their relationships (Badilla 2004; Cassata-Widera and French 2006; Cassata-Widera 2008). Some studies showcase first maps completely drawn by children (Birbili 2006; Cesarina 2006). At this developmental stage, children's drawings typically feature landscapes, houses, flowers, vehicles, people, and animals with varied and realistic colours (Mancinelli et al. 2004; Mancinelli 2006). Human figures, such as hair, feet, and hands, are shown in detail, and drawings are arranged on the page with logical distribution. Topics for these map-based activities include the study of different plant types, tree habitats, pets, transportation modes, and food varieties, such as fruits.

For example, a 5-year-old Asher created a personalised mind map (Map 3.4) to share about himself and his interests. The map displays his favourite things, categorised into animals, fruits, and sports. Using the map, Asher presented a structured narrative about himself, saying, "*I am Asher, my favourite toy is my elephant. I like animals. I also have a cat, rabbit, dog, and octopus. I like to eat fruits, grapes, oranges, and pineapple. My favourite activities are playing with my airplane, tennis ball, basketball, and bike.*" This exercise provided valuable insights into Asher's cognitive development as he effectively expressed and categorised his preferences. Asher's mind map demonstrated the early stages of childhood cognitive mapping and representation, showcasing the diverse aspects of his interests.

Although Asher's example alone does not form a basis for general statements about childhood cognitive mapping, it provides valuable insight into what can be nurtured at this stage using personal knowledge mapping:

- **Personal expression**: This factor facilitates children's expression of personal preferences and interests creatively, as demonstrated by Asher's categorisation in his mind map.
- **Organisation**: Help children structure their ideas, objects, or concepts into distinct groups, enhancing their cognitive scheme.
- **Communication skills**: These skills promote the development of language and communication skills by encouraging children to verbalise their preferences and thoughts, as Asher did when he introduced himself using his mind map.
- **Creativity**: Support children in expressing their creativity and imagination by allowing them to draw and represent their ideas visually.
- **Cognitive development**: We recognise that such exercises offer insights into a child's cognitive development as they learn to structure and communicate their thoughts and preferences effectively.

3.3 Drawings and Maps of Children Aged 6–8 Years

For Luquet, this phase is categorised as "Intellectual Realism". The child represents all the knowledge he has of the object, and for this he uses other resources for its representation, such as transparency, in which the child represents everything he knows of an object; for example, when representing a house, it also draws the furniture that is inside the house, or when drawing a human body, it also represents its internal organs. (Luquet 1979, pp. 162–175).

According to Piaget, this phase is termed "schematism". It is a phase of representative schemes, affirmation of self through flexible repetition of the scheme. The topological notions of neighbourhood, separation, order, circumscription, and continuity are sufficient to engender thinking about the notions of space and the construction of significantly more elementary spatial relations (Piaget and Inhelder 1982). All sensorimotor assimilations, even perceptual assimilations, involve assigning meanings, even if they are elementary.

Lexi, a 7-year-old girl, created a garden scene based on her observations. She included bright sun and large clusters of leaves providing shade to the flowers below. Lexi's drawings also emphasise the significance of water and sunlight for flower health. Lexi titled her drawing to highlight the variations in plant growth at different times, indicating that plants change as they grow. Overall, her artwork underscores the importance of nature, water, the sun, and land. Lexi's drawing showcases her keen observation skills and her understanding of how these factors influence plant growth and health.

Maps of Children Aged 6–8 Years

According to the studies of maps found in this phase, the pedagogical activities are the most varied. Various types of maps are used, such as mind mapping to promote brainstorming and concept mapping to describe themes through concepts and their relations. Some early examples of argument maps were found in activities prepared by pedagogues but in a very simple way. In these activities, the proposal is to encourage learners to choose symbols to identify and relate questions with answers and justifications that confirm the ideas (arguments) or that reject them (counterargument). Some symbols can be used for this purpose, such as positive or negative signs, "+" or "−", and thumbs up or down.

Some of the themes of these activities with observed maps address healthy foods, sports activities, types of materials, types of animals, and mathematical operations.

Lexi also created a concept map (Map 3.5) to share her preferences. She started by showcasing her favourite fruits, watermelon (with seeds) and banana (without seeds). Lexi also depicted her favourite animals in their natural habitats: clams in water, horses in fields, and kiwi birds in the air. Last, she drew her preferred flowers, categorising them by colour: red roses, yellow daffodils, and pink tulips. When asked to introduce herself using the concept map, Lexi found it helpful in presenting her preferences in a detailed manner. She confidently said, "I'm Lexi, and I like fruits because they're healthy. My favourite fruit with seeds is watermelon, and my

Map 3.5 From drawing to cartography, children aged 6–8 years. Okada (2024)

favourite fruit without seeds is banana. I also have a fondness for animals in different environments, such as clams in water, horses in fields, and kiwi birds flying in the air. Among flowers, I love red roses, yellow dandelions, and pink tulips."

What could be encouraged at the age of 6–8?

At the age of 6–8, when encouraging knowledge mapping, children can benefit from the following approaches based on Lexi's example:

1. **Visual Representation**: Encourage children to create concept maps or visual diagrams to organise and present information. Lexi used drawings and categories to share her preferences, making it engaging and understandable.
2. **Categorisation**: Teach children how to categorise information into meaningful groups, such as Lexi, with fruits, animals, and flowers. This helps them understand how different pieces of information relate to each other.
3. **Detail-Oriented**: Emphasise the importance of including details within their maps. Lexi provided specific information about her favourite fruits, animals, and flowers, making her presentation more informative.
4. **Communication Skills**: Encourage children to use maps as tools for effective communication. Lexi confidently introduced herself and explained her preferences using the concept map, promoting verbal expression and clear communication.
5. **Creativity**: Allow children to express their creativity through drawings and colour choices. Lexi's map reflected her personal style and interests, making it a unique representation of her preferences.
6. **Reflection**: After creating the map, the children were prompted to reflect on what they learned or conveyed. Lexi realised how her map helped her present her preferences in a structured way, indicating the value of knowledge mapping as a communication tool.

Overall, at this age, knowledge mapping can help children develop organisational, communication, and creativity skills while encouraging them to explore and express their interests and knowledge in a visually engaging manner.

3.4 Drawings and Maps of Children Aged 9–11 Years

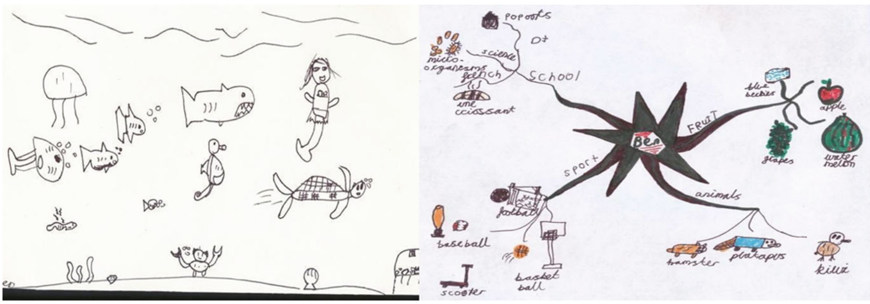
Luquet noted that in this phase of “Visual Realism”, the child can mentally store the proportions of the object the way he sees it and has mastery of the size of the object as a function of distance (Luquet 1979, pp. 190–194). Piaget describes this phase as “Realism” or “Phase of concrete operations”. In this phase, geometric shapes appear, and drawing permeates the understanding of conceptual notions in the construction of relations of knowing, recognising, reconstructing and transforming. The semiotic function occurs when the child manages to have an evocative representation of an absent object or of a past event and, therefore, involves the construction of different signifiers. The drawing or image is then a semiotic function that mediates the symbolic game and the construction of the mental image.

Ben, a 9-year-old boy, skilfully created a free illustration (Map 3.6) depicting an underwater scene. He rendered fifteen distinct sea creatures with visually intricate details, demonstrating a keen eye for expressions and consistent sizes, shapes, and features. His artwork commences at the bottom of the sea, showcasing algae, shells, and a crab.

Progressing upwards, it reveals a small eagle ray, various fish species, a grand seahorse, and a majestic sea turtle. Above them, an artful portrayal of an octopus, a squid, and additional fish, including a shark, adds depth and diversity to the composition. Finally, the illustration culminates with the depiction of a mythological creature—a mermaid showing Ben’s imagination and exploration of non-fiction. Ben’s artistry manifests a remarkable talent for capturing the vibrant marine world, with impressive attention given to visual intricacies and thematic coherence.

Maps of Children Aged 9–11 Years

In the studies analysed in this age group, several activities with maps were found, and many of them used map software and projects with maps carried out on a computer. The themes are already more complex and involve descriptions of processes or steps beyond the descriptions of concepts and their relations. The contents of these mapping activities are quite varied, and different map styles can be combined. The most



Map 3.6 From drawing to cartography, children aged 9–11 years. Okada (2024)

common themes were “ecosystem”, “food chain”, “habitat”, “human body”, “plant reproduction”, and “characteristics of indigenous peoples” (Okada et al. 2014).

Ben used visual illustrations, such as a mind map (Map 3.6), to represent his favourite activities and objects. He categorised them into groups such as sports, animals, fruits, and school subjects, adding detailed drawings and colours. In his introduction, Ben shared, “*I am Ben. I enjoy creating free drawings and mind maps. I picked an underwater scene because I love sea animals and observe creatures while snorkelling. Mind maps help me organise my preferences better. I like fruits like blueberries, apples, watermelons, and grapes; favourite animals are hamsters, platypuses, and kiwis; top sports are football, basketball, scooter riding, and baseball; and at school, I enjoy science, especially learning about microorganisms, and French, where I talk in a different language, like explaining how to make croissants.*” Ben’s creative and organised presentation reflects his ability to convey information visually and thoughtfully.

Ben’s artistic expression and thoughtful representation of his interests showcase his ability to present information in a visually engaging and organised manner. Between the ages of 9 and 11, children can benefit from the following approaches when encouraging knowledge mapping:

1. **Visual Organisation**: Teach children to use visual tools such as mind maps to present their thoughts and preferences in a structured manner. This helps them connect information as seen with Ben’s mind map.
2. **Categorisation**: Encourage children to categorise their interests and information into meaningful groups, such as hobbies, favourite animals, foods, and school subjects. This fosters logical thinking and organisation.
3. **Creative Expression**: Allow children to express their creativity through detailed drawings and colours, making their maps visually engaging and reflecting their personal style. Ben drew and connected various types of icons.
4. **Introduction Skills**: Teach children to introduce themselves using their maps and explain their preferences and interests, which enhances their communication skills. Ben wrote a long paragraph about himself using his map.
5. **Reflective Thinking**: Encourage children to reflect on why they chose specific categories or themes for their maps, helping them understand their own interests and thought processes across their different ages.
6. **Organisation and Clarity**: Emphasise the importance of clear organisation and presentation, such as how Ben used a central topic and connected branches to convey his preferences coherently.
7. **Effective Communication**: Show children that knowledge maps enabling them to present information in an organised and thoughtful way. Ben’s map and paragraph could both be part of his personal portfolio.

Overall, knowledge mapping at this age can help children develop skills in creativity, communication, and self-reflection while allowing them to visually represent their interests and preferences in an engaging and structured manner.

Reflective Remarks This chapter detailed the progression of children's graphic representations, tracing their development from simple scribbles to detailed and thematic drawings, as researched by Luquet and Piaget.

Action Points: Based on the transition from drawing to mapping list the recommendations that you found useful.

Next chapter will explore the significance of visual thinking in educational contexts, discussing various principles to enhance students' social-emotional learning, meaningful learning, mastery learning, critical socioconstructivism, inquiry-based learning, and experiential learning.

Question: How can educators integrate the principles of the CARE-KNOW-DO framework into their teaching to foster holistic student development? What strategies based on these principles that can support different educational settings and learners' needs?

References

Badilla S (2004) Teaching experience: concept maps in preschool. In: Memorias V (ed) Congreso Nacional de Educadores, Programa Nacional de Informática Educativa MEP-FOD (Preescolar, I y II Ciclos), San José, Costa Rica

Birbili M (2006) Mapping knowledge: concept maps in early childhood education. In Early childhood research and practice, vol 8

Cassata-Widera AE, French LA (2006) Using concept mapping to facilitate metacognitive control in preschool children. In: Cañas AJ, Novak JD (eds) Proceedings of the second international conference on concept mapping, vol 1. Universidad de Costa Rica, San José, pp 598–605

Cassata-Widera AE (2008) Concept mapping and early literacy: a promising crossroads. In: Canas A, Reiska P, Ahlberg M, Novak JC (eds) Proceedings of the third international conference on concept mapping. Tallinn, Estonia & Helsinki, Finland

Cesarina M (2006) Learning while having fun conceptualisation itineraries in kindergarten. In: Proceedings of the 2nd international conference on concept mapping. San José, Costa Rica

Lave J, Wenger E (1991) Learning in doing: social, cognitive, and computational perspectives. Situated Learning: Legitimate Peripheral Participation 10:109–155

Luquet GH (1979) Children's drawing. Trad. Maria Teresa Goncalves de Azevedo. Civilisation Bookstore, Porto

Mancinelli C, Gentili M, Priori G, Valitutti G (2004) Concept maps in kindergarten. In: Proceedings of the first international conference on concept mapping. Universidad Pública de Navarra, Pamplona

Mancinelli C (2006) Learning while having fun: conceptualisation itineraries in kindergarten children experiences with C-maps in an Italian school. In: Proceedings of the second international conference on concept mapping. Universidad de Costa Rica, San Jose

Okada A, Buckingham Shum S, Sherborne T (eds) (2014) Knowledge cartography: software tools and mapping techniques (2nd ed). Advanced information and knowledge processing. London: Springer.

Okada, A. (2024). Knowledge Cartography for Young Thinkers: Sustainability Issues, Mapping Techniques, and AI Tools. Figures. The Open University. CCBY. https://doi.org/10.21954/ou.rd.27963327

Piaget J (2000) Piaget's theory of cognitive development. Child Cognit Develop Essent Read 2:33–47

Piaget J (1976) The balancing of cognitive structures. Trad. Marion Merlone of the Saints Penna. Zahar, Rio de Janeiro

Piaget J (1993) The representation of space in the child. Trad. Bernardina Machado of Albuquerque. Porto Alegre

Piaget J, Inhelder B (1982) The psychology of the child. Trad. Octavio Mendes Cajado, 7th ed. Diefel, São Paulo

Chapter 4
CARE-KNOW-DO to Map Knowledge in Education

Abstract This fourth chapter presents three learning objectives:

1. Examine the six principles of the CARE-KNOW-DO framework: social-emotional learning, meaningful learning, mastery learning, critical socioconstructivism, inquiry-based learning, and experiential learning.
2. Identify and describe pedagogical strategies for leveraging the CARE-KNOW-DO framework in teaching and learning processes.
3. Understand principles in action and explore the relationships between theory, practice, and application.

Keywords CARE-KNOW-DO · Learning theories · Pedagogical principles · Well-being

4.1 A Pedagogical Framework for Knowledge Mapping

This chapter offers a comprehensive explanation of the CARE-KNOW-DO model, detailing its relationship with mapping techniques and its six pedagogical principles, which are all grounded in a set of influential educational theories. It provides theoretical insights aimed at assisting teachers in designing, reflecting on, and refining their teaching practices, complemented by illustrative examples of mapping techniques in Chap. 6 and case studies in Chap. 7.

The CARE-KNOW-DO model is a pedagogical framework designed to engage students in caring about real-world issues with curiosity (CARE), acquiring contextual knowledge with interest (KNOW), and applying problem-solving and analysing decision-making skills with a sense of agency (DO). Students engage with issues significant to their lives, their communities, society, and the planet. They learn curriculum knowledge purposefully to address these issues and take action towards solutions. This process aims to make education relevant, fun, and engaging by empowering students with purpose and actionable knowledge in their lives, community, and world.

A. Okada, *Knowledge Cartography for Young Thinkers*, SpringerBriefs in Advanced Information and Knowledge Processing, https://doi.org/10.1007/978-3-031-54677-8_4

- CARE component focuses on students' emotional engagement with issues that matter to them as individuals, community members, and global citizens.
- KNOW component encourages intellectual engagement through inquiry-based learning, where students develop knowledge about significant issues.
- DO component involves applying knowledge and emotional engagement to address real-world problems, embodying scientific attitudes in everyday actions.

Designed to empower students as proactive agents of change, CARE-KNOW-DO fosters socioscientific thinking, self-efficacy, and self-concept within the realms of well-being and sustainability (Okada et al. 2024; Okada 2023; Okada and Sheehy 2020). Students are prepared to become active participants in decision-making and problem-solving, taking others' perspectives, analysing evidence, and considering socioethical views for healthy lives and the planet. This model suggests a holistic educational approach that not only equips students with the knowledge and skills needed for addressing complex issues but also encourages them to apply and consolidate competencies in ways that contribute to a better and sustainable future. This model aligns with the principles of responsible research and innovation (RRI)—diversity and inclusion, anticipation and reflection, openness and transparency, and responsiveness and adaptive change (RRI-Tools 2017). It cultivates transversal skills vital for the twenty-first century, equipping students to address future challenges with empathy, knowledge, and action (Okada et al. 2024). This holistic approach CARE-KNOW-DO aims to offer comprehensive and adaptable education, preparing students for a world that is both interconnected and in constant evolution, with a focus on sustainable development.

Knowledge mapping can be used in each phase of the CARE-KNOW-DO framework, facilitating real-life issue connections with students' curiosity and concerns, enhancing critical thinking in context through knowledge acquisition, and providing a structured pathway for informed action.

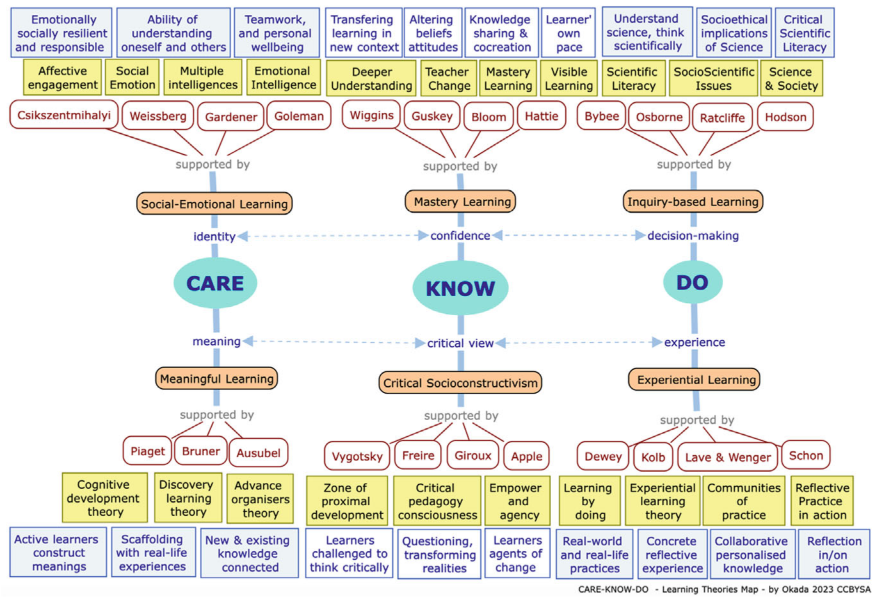
In the CARE phase, learners employ mapping to pinpoint and delve deeper into issues of significance, sparking new ideas and fostering discussion. This process connects new insights with existing knowledge, clarifies understanding, and identifies necessary learning to address the issues at hand.

During the KNOW phase, students utilise mapping to sift through sources, highlight relevant information, and organise it coherently linked to their previous knowledge, bolstering critical thinking and concept comprehension. Such practices enrich their understanding and strategically integrate new knowledge with their mental frameworks.

Knowledge mapping becomes pivotal in the DO phase, illustrating how acquired knowledge can be applied in practical, impactful actions. Here, it serves to refine skills in argumentation for problem-solving and evidence-based decision-making, guiding students in designing effective resources for their initiatives within their communities. They can use their maps to prepare multichannel and multimodal communication, including infographics, social media banners, video blogs, campaigns, online consultations, deliberations, action plans, and agendas. This approach not only clarifies the path from knowledge to action but also emphasises the practical application of learning in real-world scenarios. Supported by collaborative efforts and diverse sources, knowledge mapping enables students to observe, connect, and interrogate, visualise, reflect on, and discuss real-life issues and potential solutions.

Integrating CARE-KNOW-DO principles with mapping techniques facilitates a richer understanding of real-life contexts, envisioning possibilities, and actions beneficial for both the present and future. Although not an inherent part of the framework, knowledge mapping aligns with the model's objectives, significantly enhancing student engagement with relevant issues, strengthening student knowledge, and inspiring actionable insights. Rooted in six theoretical approaches (Map 4.1), the CARE-KNOW-DO framework and knowledge mapping serve as complementary approaches, bolstering the goal of fostering informed and motivated students as agents of change.

The CARE stage emphasises social and emotional learning through the effective engagement of students with the topics they are learning. This approach recognises the crucial role of emotions in the learning process, where students are more likely to connect with issues that matter to them because they resonate with their lives on a personal level. Meaningful learning also supports cognitive and emotional connections between students and learning activities, making each topic not only an abstract concept but also something they can relate to and care about deeply. By tapping into students' passion, interests and existing knowledge and linking new concepts to these affective domains, we create a more engaging and meaningful learning experience.



Map 4.1 CARE-KNOW-DO: pillars of educational principles, CmapTools. Okada (2024)

This emotional and cognitive connection not only enhances students' motivation but also deepens their understanding and appreciation of the subject matter.

The KNOW stage of the framework revolves around mastery learning and critical socioconstructivism. To develop a deep understanding of scientific concepts, it is vital that students go beyond surface-level understanding and are encouraged to build and transfer their knowledge to new scenarios. Mastery learning creates opportunities for all learners to build a thorough comprehension of concepts at their own pace. This is done by scaffolding complex topics, so they are the right level of challenge for each student. Additionally, critical socioconstructivism acknowledges that learners are active participants in creating knowledge. They do not merely discuss isolated facts; they engage in critical thinking by reflecting on concepts in local and global contexts, including social, cultural, historical, political, scientific, technological, environmental, and ethical aspects, among others. This involves students collaborating to build knowledge with teachers, scientists, and community members. Students build critical thinking and confidence to become agents of change, which means that they use knowledge in problem-solving to contribute to well-being and sustainability.

In the DO stage, students focus on translating knowledge into action. Inquiry-based learning theory equips students with the skills to use knowledge in decision-making or problem-solving to produce an output, such as a solution to a socio-scientific issue or campaign, to engage their community to change policy together. Experiential learning theory is key to problem-solving and taking action aligned with responsible research and innovation. Students ask meaningful questions and investigate and make informed decisions involving their community, for example, family members and scientists, for informed recommendations drawn collaboratively. It encourages evidence-based thinking and develops communication skills. Students gain practical insights by applying what they have learned in real-world contexts, making their education more relevant and impactful.

4.2 Six Pedagogical Principles

4.2.1 Social-Emotional Learning

> **Principle 1: Social-emotional learning emphasises the importance of sustained involvement by understanding one's thoughts and emotions in context with their real-life issues.**

Social-emotional learning (SEL) assists students in understanding and managing emotions, setting, and achieving significant goals, demonstrating and feeling empathy, and forming and maintaining positive relationships. It plays a vital role in nurturing emotionally intelligent, responsible, and resilient individuals and promotes an emotional and social understanding of environmental and societal issues, inspiring a connection and motivation to learn. The CARE component of the framework lays the groundwork for students to engage in self-exploration by identifying social-emotional aspects and expressing their interests in real-life issues, supported by affective engagement with a learning approach—one that integrates multiple intelligences and emotional skills—that can foster enhanced outcomes for both individuals and the broader society. The depth of learners' emotional engagement shapes, guides, and maintains their educational journeys.

Affective engagement, as suggested by Czikszentmihalyi (1990), indicates that when students are deeply immersed in activities, they find engaging and enter a state of intense focus, leading to fulfilment and well-being. This 'flow' state is vital for resilience and ongoing learning, igniting enjoyment for learning that aligns closely with the principles of social-emotional learning. Such engagement not only is beneficial for individual well-being but also enhances learning, as it encourages students to become more active and participative in activities.

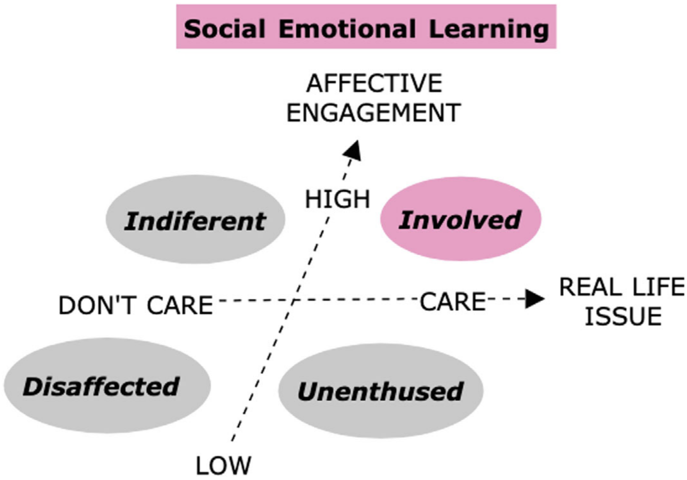
Social emotion, presented by Weissberg (2019), underlines the importance of creating environments for healthy interactions with social-emotional learning. The development of empathy and understanding among students is key to fostering emotional and social competencies. This, in turn, equips them to be empathetic community members, leading to an increased ability to collaborate, understand diverse perspectives, and integrate various viewpoints in complex knowledge domains.

Emotional intelligence, described by Goleman (2020), comprises self-awareness, self-regulation, motivation, empathy, and social skills. It forms the foundation for leadership, teamwork, and personal development. These skills are crucial for collaborative work and problem-solving. Emotional intelligence plays a significant role in learning by facilitating group dynamics, managing conflicts, and ensuring effective communication, all of which are essential for successfully navigating complex informational landscapes.

Multiple intelligences, presented by Gardner (2008), include interpersonal and intrapersonal intelligence. Interpersonal intelligence refers to the ability to understand and interact effectively with others. Intrapersonal intelligence refers to the capacity to understand oneself and to appreciate one's feelings, fears, and motivations. His work advocates for an inclusive educational system that recognises and celebrates diverse student strengths.

In the CARE-KNOW-DO framework, the CARE component is vital because it seeks to cultivate both emotional engagement and concern for socioscientific issues, thereby fostering a learning environment where students are not only knowledgeable but also emotionally **involved** and **engaged** in taking action.

Map 4.2 shows a matrix that categorises students' attitudes towards socioscientific issues based on their level of affective engagement and whether they care about the



Map 4.2 CARE-KNOW-DO social and emotional learning. Okada (2024)

issue. This can be contextualised within the 'CARE' aspect of the CARE-KNOW-DO framework as follows:

- **Disaffected**: Students in this category have low affective engagement and do not care about the issue. This lack of engagement and concern can be a significant barrier to the educational process. Under the CARE framework, these students need interventions to boost both their interest in the issue and their emotional connection to the learning environment.
- **Unenthused**: These students care about the issue but exhibit low affective engagement. This could indicate cognitive recognition of the issue's importance without a corresponding emotional investment. In terms of the CARE framework, strategies might be needed to emotionally engage these students, possibly by making the issue more personally relevant or by using teaching methods that elicit emotional responses.
- **Indifferent**: Students in this quadrant show high affective engagement but do not care about socioscientific issues. This suggests that while they may be emotionally or socially engaged in their environment, this engagement does not extend to the issue at hand. In the CARE framework, these students may require targeted strategies to connect the importance of the issue to their existing concerns or interests.
- **Involved**: Here, students not only care about socioscientific issues but also demonstrate high affective engagement. This is the ideal scenario within the CARE framework, indicating that students are emotionally and intellectually invested in the issue, which can drive meaningful learning and informed action.

Map 4.2 serves as a formative assessment tool to tailor educational strategies that meet students at their current levels of care and affective engagement. The recommendations for using this map are as follows:

- Pinpoint areas where students are engaged and show concern for real-life issues.
- Craft strategies that transition students from disaffection or indifference to increased involvement.
- Harness real-life issues that resonate with students to enhance their affective engagement, facilitating learning alongside peers who provide mutual support.
- Create lesson plans that include social-emotional objectives alongside academic objectives should be created to promote holistic development.
- Tailor interventions for individual students' needs recognise that engagement is a spectrum and that different students may require different approaches to become more involved in their learning.

In sum, knowledge mapping supported by social-emotional learning can help educators assist students in visualising and connecting their thoughts and emotions to real-life issues, fostering deeper emotional engagement and understanding.

4.2.2 Meaningful Learning

Principle 2: Meaningful Learning Fosters Engaged Students Who Connect Prior Knowledge and with New Information Within Real-Life Situations.

Meaningful learning involves deeply understanding content, integrating new knowledge with existing cognitive structures, and applying this knowledge to new situations. Meaningful learning is important in the CARE stage because it emphasises cognitive development through the active role of the learner and the integration of new knowledge with existing cognitive structures to form advanced organisers.

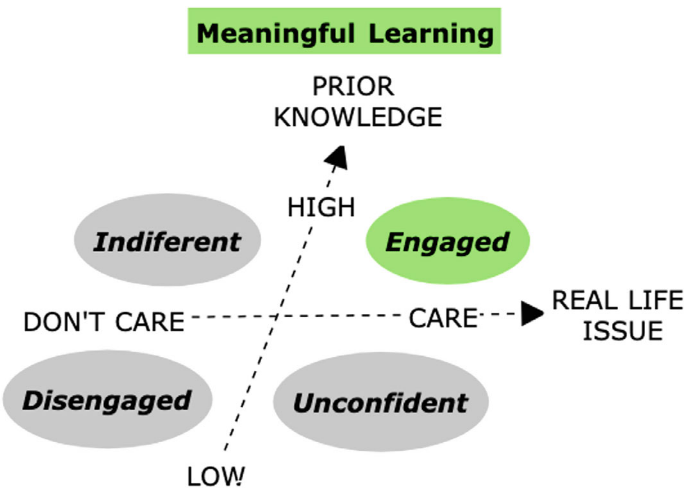
The cognitive development theory of Piaget (2000) highlights the importance of experiential learning and active knowledge construction through assimilation and accommodation. This approach encourages students to engage actively in their learning, constructing understanding rather than passively receiving information. Piaget's principles underscore the need for interactive and experiential methods that enable students to map new ideas connected with their existing knowledge structures.

Discovery learning, by Bruner (1973), is a scaffolding concept that advocates guiding learners to explore complex content. This approach supports the idea that even intricate concepts can be understood by younger learners if presented in a structured, clear, and age-appropriate manner, linked to their existing knowledge and the use of carefully designed scaffolds. His work discusses how education should be structured to facilitate learning that builds upon the knowledge students already have, which aligns with the idea of scaffolding—providing support to students as they develop new skills and understanding.

Advanced organisers theory by Ausubel (2000) focuses on integrating new information into preexisting knowledge structures. He emphasises the importance of anchoring new learning in what the learner already knows, ensuring that learning is significant and relevant. His theory suggests the importance of contextualising new information within the broader framework of existing knowledge, thereby making mapping more meaningful for extending students' learning.

In the context of the CARE-KNOW-DO framework, Map 4.3 categorises students' attitudes towards socioscientific issues based on their prior knowledge and whether they care about the issue. This finding aligns with the CARE component of the framework, which emphasises affective engagement with the learning environment.

- **Disengaged**: Here, students exhibit low prior knowledge and do not care about the issue. This detachment from the issue can be a significant obstacle to learning. Within the CARE framework, a dual focus is needed: to build the students' knowledge base and to create affective links between the students and the issue.
- **Unconfident**: Students in this quadrant care about the issue but have low prior knowledge, which may lead to a lack of confidence in their ability to contribute



Map 4.3 CARE-KNOW-DO meaningful learning. Okada (2024)

meaningfully. The CARE component would address this by building their knowledge and reinforcing their understanding, empowering them to engage with the issue confidently.

- **Indifferent**: Students with high prior knowledge but who do not care about socioscientific issues fall into this category. They have the cognitive foundation to understand the issue but lack affective connections. In the CARE framework, the challenge is to foster a sense of personal relevance and emotional investment in these students to spur them into caring and, subsequently, action.
- **Engaged**: These students care about the issue and possess a high level of prior knowledge. They are ideally positioned within the CARE framework, as they are likely to be affectively engaged and can leverage their understanding to undertake meaningful action. The goal for educators is to maintain this engagement and help these students apply their knowledge constructively.

Map 4.3 serves as a guide for educators to assess students' prior knowledge and interests, helping to design targeted interventions that foster a more engaged and informed approach to socioscientific issues. The recommendations for teachers on using this map are as follows:

- Engage disinterested students with low prior knowledge by using foundational and interest-building activities to spark curiosity.
- Support students who care about real-life issues but have low prior knowledge with resources and scaffolded learning to build confidence and knowledge.
- For indifferent learners with high prior knowledge but low engagement in real-life issues, content becomes more relevant to their lives or interests.
- Offer more advanced, group-based, and student-led activities that connect classroom learning to real-world applications, enhancing engagement and collaborative learning for students who are already engaged.

In sum, knowledge mapping supported by meaningful learning helps students integrate new information with their existing knowledge, creating connections that enhance real-life learning experiences.

4.2.3 Mastery Learning

Principle 3: Mastery Learning is a Commitment to Ways of Adapting Teaching, Learning and Assessment, to Ensure that All Students Succeed.

Mastery learning is an educational approach that integrates four distinct theories, each contributing to the 'KNOW' stage of the CARE-KNOW-DO framework. They emphasise the importance of deeper understanding, adaptable teaching practices, personalised learning paces, and self-regulation via visible learning. These theories collectively establish principles that assist students in building the necessary knowledge for problem-solving and decision-making.

Deeper understanding, by Wiggins and McTighe (2005), focuses on the transfer of learning to new contexts. This concept is essential for enabling students to apply their knowledge in diverse situations, ensuring that students not only acquire information but also comprehend it sufficiently, building on their previous knowledge. He proposed six components to describe deep understanding, which include the capacity to explain, interpret, apply, shift perspective, empathise, and self-assess.

Teacher change, by Guskey (2010), centres on emphasises emphasised the need for educators to modify their beliefs and practices in line with the mastery learning model. This perspective is crucial for learning, as it suggests the need for adaptable teaching strategies that facilitate a more personalised and effective learning process.

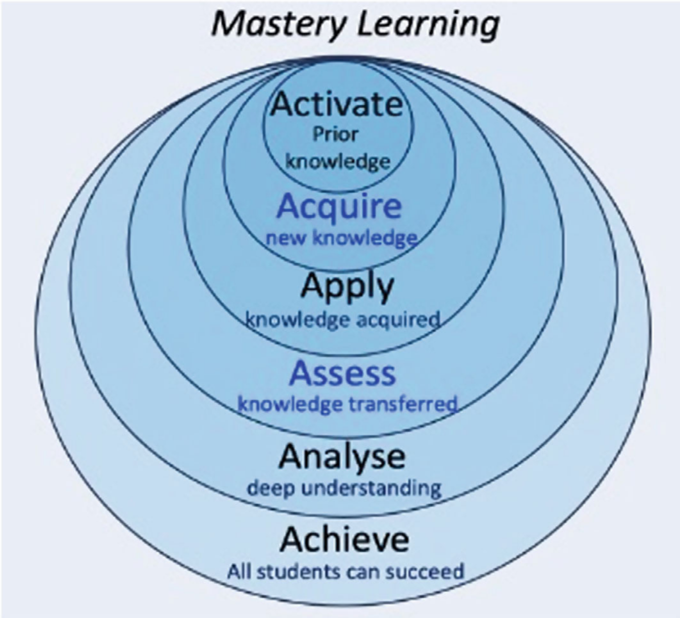
Mastery learning, by Bloom (1985), posits that with sufficient time and suitable pedagogical strategies, every student can achieve mastery learning. His theory has significantly influenced the idea that education should be tailored to each student's pace and capabilities rather than expecting uniform progression. Activities can be used to check understanding to ensure that students fully appropriate each concept before moving to the next concept.

Visible learning, by Hattie (2008) emphasises evidence-based strategies that work best for improving student achievement. He advocates teaching students how to self-regulate their learning, a key principle in mastery learning. This approach encourages students to be active participants in their learning journeys, and activities are used to help them identify gaps in their understanding and track their progress effectively.

The mastery learning approach is integral to the KNOW component of the CARE-KNOW-DO framework, ensuring that learners not only acquire but also effectively utilise, transfer, and reflect on their knowledge to achieve mastery.

Mastery learning, as depicted in the visual map (Map 4.4), is a process that begins with "Activate," where students use their prior knowledge as a foundation. Moving to "acquire," they develop new understandings through the connection between prior and new knowledge. In the "apply" stage, students use their newly acquired knowledge in various contexts to solidify their understanding. "Assess" checks whether students have built adequate understanding to transfer knowledge to unfamiliar scenarios, and "Analyse" deepens understanding through critical thinking, developing students' confidence and ensuring that all students can "achieve".

The mastery learning map to enhance KNOWs in the CARE-KNOW-DO can be used by teachers as a pedagogical guideline. The recommendations for using this map are as follows:



Map 4.4 CARE-KNOW-DO mastery learning. Okada (2024)

1. **Activate Prior Knowledge**: Engage students' existing knowledge as a foundation for new content using concept maps or initiating conversations.
2. **Acquire New Knowledge**: Employ a mix of teaching methods that cater to various learning styles, such as mapping explanations, readings, discussions, and creating multimedia content.
3. **Apply Acquired Knowledge**: Encourage students to solidify their understanding through hands-on projects or simulations that mimic real-world scenarios.
4. **Assess Transferred Knowledge**: Use assessment tasks and self/peer reviews to evaluate students' grasp of the material and its practical applications.
5. **Analyse Deep Understanding**: Encourage critical thinking through tasks that require students to analyse, evaluate, and synthesise information.
6. **Achieve (All Students Can Succeed)**: Offer review sessions and provide individualised feedback to guide each student towards a high level of mastery in both understanding and skill.

In sum, knowledge mapping supported by mastery learning provides a visual tool for students to track their progress and identify areas needing improvement, enabling personalised learning paths and mastery.

4.2.4 Critical Socioconstructivism

Principle 4: Critical Socioconstructivism Empowers Students to Actively Learn with Others, Develop Critical Thinking and Foster Societal Transformation.

Integrating theories of critical pedagogy and socioconstructivism into KNOWs significantly enriches their ability to create CARE-KNOW-DO practices where students become active, critical, and conscious agents of change. It merges social constructivism (learning as a socially mediated process) with critical pedagogy (education as a means of challenging and changing societal structures). Students critically engage with real-life socioscientific issues and are challenged to develop critical understanding of the world to **transform** their realities.

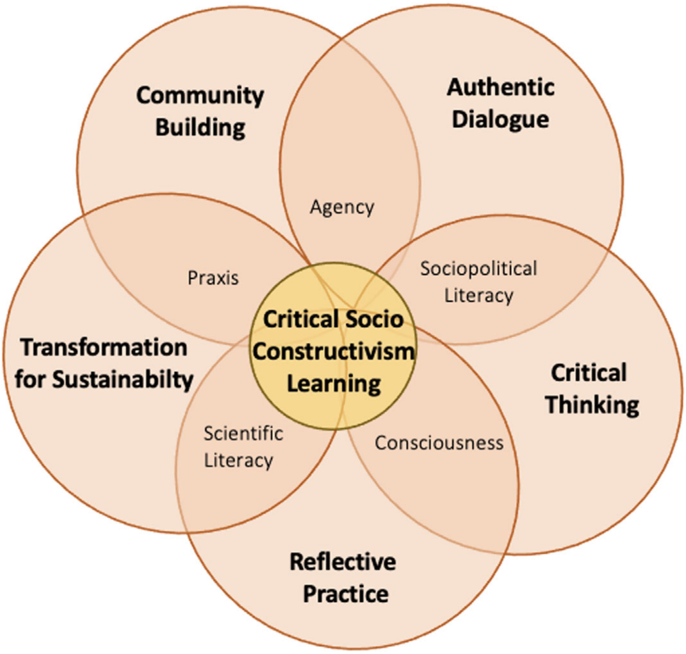
The **Zone of Proximal Development** ZPD, by Vygotsky (1978), underlines the importance of learning with others to develop autonomy and agency.

Critical Pedagogy and consciousness by Freire (2000) emphasise critical engagement as the foundation for transformative action.

Empower and agency by Giroux (1997) and Apple (2012) advocate for an educational environment that is not only informative but also transformative, preparing students to participate as agents of change considering the challenges actively and critically of their time, culture, and society.

Critical socioconstructivism, depicted in the diagram map (Map 4.5), is important for the CARE-KNOW-DO framework, particularly in regard to enabling learners to develop their ability to critically understand the world with others. The core of critical socioconstruction learning is the interplay of these elements, emphasising a collaborative, reflective, and applied learning approach, with the goal of empowering learners to become proactive, informed citizens capable of driving social transformation. This approach is crucial for designing and implementing a curriculum that transcends the mere transmission of information and instead empowers learners to collaboratively construct knowledge as critical thinkers and change agents within their communities. Vygotsky, Freire, Giroux, and Apple provide invaluable principles for critical socioconstructivist learning.

Vygotsky (1978) posits that social interactions within a **learning community** and **authentic dialogue** scaffold the learning process, which is tailored to students' needs to achieve their learning objectives. Collaborative learning fosters the development of higher cognitive functions through **social cultural interaction**, equipping individuals with the skills and confidence to act autonomously **with agency** and effect changes in their environment. Freire (2000) builds on this by defining **consciousness**s as a deep awareness of one's social reality, which, in turn, fuels **praxis**—the practice of reflecting and acting upon the world to transform it. Freire (1967), Giroux (1997), and Apple (2012) contributed to the concept of **critical literacy**, which



Map 4.5 CARE-KNOW-DO critical socioconstructivist learning. Okada (2024)

involves analysing societal, cultural, political, and economic contexts with **critical thinking** to understand and challenge power dynamics. This empowers individuals to use **scientific and sociopolitical literacies** critically, fostering the development of new identities and societal **transformation** towards well-being and **sustainability** within various dimensions. These interconnected elements shape a learning paradigm in which knowledge construction is dynamic, reflective, and intrinsically linked to societal change to address global and local challenges.

These categories of critical socioconstructivism collectively inform the 'Know' aspect of the CARE-KNOW-DO framework by promoting a learning environment where students critically engage with ideas, reflect on their learning, and apply this knowledge for societal transformation. The recommendations for using this map include the following:

1. **Community Building**: Foster a classroom environment that promotes collaboration and shared learning experiences through group projects, peer learning, and discussions, thereby creating a strong community.
2. **Authentic Dialogue**: Engage students in meaningful conversations about real-world issues that resonate with them, thereby enhancing their capacity for sociopolitical discourse and critical thinking and fostering personal and group agency.

3. **Critical Thinking**: Encourage students to question assumptions, evaluate evidence-based arguments, and synthesise information across disciplines, which cultivates a deeper level of consciousness. They were guided to critically analyse societal structures and their roles within these contexts, including discussions about current events, societal norms, and civic responsibilities.
4. **Reflective Practice**: Provide regular opportunities for students to engage in socio-scientific thinking and reflect on their learning processes and outcomes. Tools such as journals, research projects, informed discussions, and portfolios with evidence-based views can be used to enhance socioscientific thinking in context.
5. **Transformation for Sustainability**: Integrate sustainability education into the curriculum to enhance scientific and sociopolitical literacy. Encourage students to consider the impact of their actions on creating a sustainable future and connect theory to practice by involving them in activities that apply classroom learning to real-life contexts, thus developing practical skills and agency.

In sum, collaborative knowledge mapping supported by critical socioconstructivism encourages teamwork and dialogue, enabling students to co-construct knowledge and critically analyse societal issues together.

4.2.5 Inquiry-Based Learning

Principle 5: Inquiry-Based Learning Develops Students' Critical Thinking so They Can Make Informed Judgements About Socioscientific Issues.

Inquiry-based learning (IBL) transforms DO into a dynamic process that not only disseminates scientific knowledge but also fosters **scientific literacy and** awareness of its **societal impacts**. Students are empowered to take socially responsible actions based on their scientific understanding.

Inquiry-based learning is an educational approach that encourages students to learn by engaging in inquiry, exploration, and investigation. This method emphasises student-led learning, where students pose questions, explore problems, and seek solutions through active participation rather than passive reception of information. In the context of responsible research and innovation, which means the alignment of advanced research and innovation with societal needs and priorities, inquiry-based learning with real-life socioscientific issues enables the development of various students' skills, for example, interrogating media, applying ethics, devising questions, analysing patterns, estimating risks, drawing conclusions, critiquing claims, communicating ideas, and justifying conclusions (Okada and Sheehy 2020). It fosters critical thinking, creativity, and independent problem-solving skills by allowing students to explore and understand concepts through their inquiries, becoming scientifically literate citizens.

Scientific literacy, according to Bybee (2012), refers to students not only learning scientific facts but also developing the ability to think scientifically. This literacy is crucial because it enables students to critically analyse scientific information, connect it to broader concepts, and apply it to complex **global issues** and **real-world problems**.

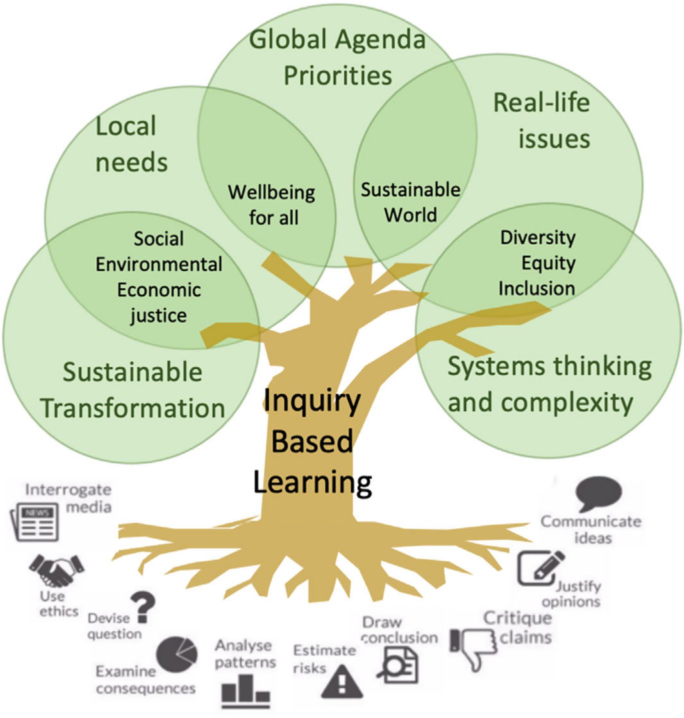
Socioscientific issues relate to Jonathan Osborne's (2010) and Mary Ratcliffe's (1997) work, which highlights the importance of understanding science within its **social context and local needs**. This approach encourages the integration of ethical, moral, and social considerations into scientific concepts, providing a more comprehensive and multidimensional view of scientific endeavours for **well-being** and **responsible citizenship.**

Science and Society, based on Hodson (2011), focuses on the interplay between scientific and technological advancements and societal forces relevant to the current context of social **environmental justice, including diversity, equity, and inclusion**. This perspective is vital for students to learn not only scientific and technological concepts but also their societal implications, influences, and consequences **locally and globally.**

Map 4.6 is a visual tool that illustrates 'learning by doing research,' aligned with both global and local challenges, emphasising sustainable transformation and addressing complex real-world issues. The central concept, 'inquiry-based learning' (IBL), is depicted as a growing tree, with its branches labelled with broad educational themes: local needs, global agenda priorities, real-life issues, systems thinking and complexity, and sustainable transformation. These branches illustrate the scope and direction of IBL topics, while the roots represent the foundational skills necessary for effective inquiry, emphasising responsible research and innovation (RRI) skills, which are critical for students to develop.

Foundational Inquiry-based Learning Skills for RRI (Okada and Sheehy 2020) (Roots) include the following:

1. Critically assessing media and information sources for credibility.
2. Integrating ethical discussions into problem-solving activities.
3. Formulating probing questions that lead to deeper research and understanding.
4. Recognising patterns and connections in data and narratives.
5. Discussing the implications and potential risks of various decisions and actions.
6. Fostering the ability to draw evidence-based conclusions.
7. Creating opportunities for students to critically evaluate claims and arguments.
8. Practising clear and effective communication of complex ideas.
9. Emphasising the importance of justifying conclusions with logical reasoning and evidence.



Map 4.6 CARE-KNOW-DO inquiry-based learning. Okada (2024)

By following these guidelines, teachers can foster rich, engaging, and active learning experiences that encourage critical thinking, problem-solving, and real-world application skills. These are central to the inquiry-based learning process and are crucial for students to become agents of change. The recommendations for teachers using the map include the following:

- **Local Needs**: Engage students with projects addressing community issues, applying classroom learning to local challenges.
- **Global Agenda Priorities**: Help students connect local issues with global trends such as sustainability and well-being, encouraging global thinking.
- **Real-life Issues**: Utilise case studies and current events to discuss diversity, equity, and inclusion, making learning relevant and fostering critical thinking.
- **Systems Thinking and Complexity**: Introduce systems thinking by analysing complex problems, showing how different factors are interrelated.
- **Sustainable Transformation**: Guide students to propose and develop sustainable solutions to real-world problems, emphasising actionable knowledge and agency.

In sum, knowledge mapping supported by inquiry-based learning aids in organising and visualising information gathered during inquiries, helping students to systematically analyse and draw informed conclusions about complex issues.

4.2.6 Experiential Learning

Principle 6: Experiential learning argues for open learning by doing and building schema out of reflection on action individually and collaboratively within communities of practice.

Experiential learning combines direct experience, reflection, social interaction, and community engagement. This strategy not only helps students master content but also equips them with critical life skills such as collaboration, critical thinking, and adaptive learning—essential for taking informed actions and making sound decisions.

Experiential learning forms the backbone of DO, where student action and decision-making are paramount. DO activities encompass experiential learning by encouraging students to actively construct their understanding, reflect on their experiences, engage with others in a community of practice, and see the practical application of what they learn.

Learning-by-doing, by Dewey (1938), asserts the value of engaging students in practical, real-world applications of their learning. Instead of passively receiving information, students actively participate in activities, projects, or actions related to environmental issues. This hands-on approach enhances the understanding and retention of knowledge.

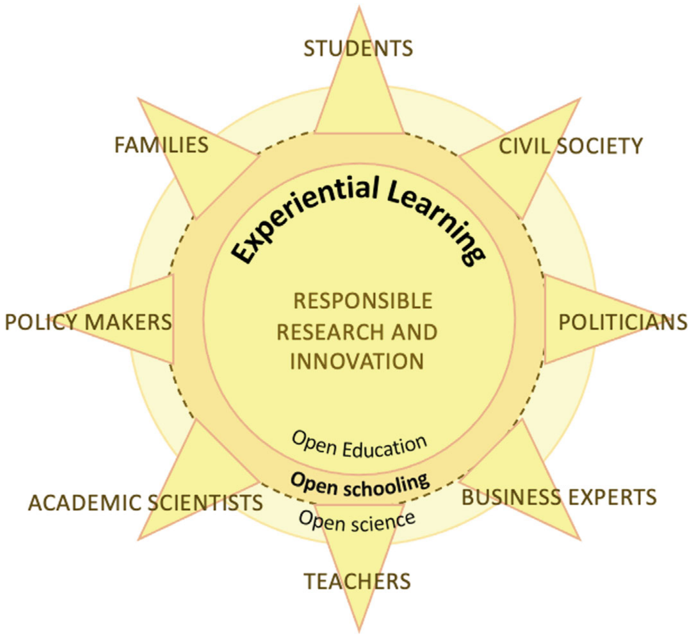
Experiential learning, based on Kolb (2014)'s work, refers to a cyclical process of learning. Students actively engage in a cycle of "Concrete experience" and "Reflective observation". Which promotes a deeper understanding and retention of knowledge through active experimentation and reflection. This practice deepens their understanding and helps them to connect new knowledge with existing cognitive structures.

Reflective practice in action, by Schon (2017), emphasises the importance of reflection before, during, and after action. This practice encourages learners to think about their experiences continuously to improve their decision-making and problem-solving capabilities. Reflective practice suggests that students should reflect not only after taking action but also in the midst of adapting their learning as their understanding evolves.

Communities of practice, a concept developed by Jean Lave and Etienne Wenger (1991), bring a social dimension to experiential learning, suggesting that learning occurs most naturally within a social context. It speaks to collaborative engagement, where learners construct knowledge collaboratively and share practices within a community, leading to a personalised and communal learning experience. By working within communities of practice, students can cocreate, share different perspectives, and collaboratively build a more comprehensive understanding of the subject matter. This social learning aspect can lead to richer, more diverse knowledge.

Map 4.7 illustrates how experiential learning is supported by open education practices, open schooling, and open science, all aimed at involving a wide range of societal actors, such as students, families, civil society, policymakers, business experts, teachers, and academic scientists, in hands-on problem-solving. This map represents the 'DO' component of the CARE-KNOW-DO framework, emphasising experiential learning as a core method for achieving responsible research and innovation (RRI). It encourages collaboration among these groups to address real-life challenges, thereby fostering a more inclusive, practical, and engaged learning experience aligned with RRI principles.

Recommendations for teachers using Map 4.7 include the following:



Map 4.7 CARE-KNOW-DO experiential learning. Okada (2024)

1. **Incorporate RRI**: Teach students the importance of ethical considerations and societal impacts in research and innovation. Encourage reflection on the long-term effects of their projects.
2. **Leverage Open Education Resources**: Use open-access materials and courses to enhance the accessibility and collaborative nature of education.
3. **Engage in Open Schooling**: breakdown barriers between schools and communities by involving external experts in education and organising real-world learning activities.
4. **Promote Open Science**: Motivate students to engage in scientific processes, such as data collection and analysis, and to openly share their findings to enhance transparency and public engagement.
5. **Collaborate with Families and local citizens**: Involve families and local civil society organisations in the educational process through at-home or neighbourhood projects that foster discussion and collaboration.
6. **Interacting with Policymakers and Politicians**: Help students understand and engage in political processes and policymaking, possibly through simulations or guest speakers.
7. **Connect with Business Experts**: Form partnerships with local businesses to provide practical insights and address real-world problems.
8. **Partner with Academic Scientists**: Foster connections with universities or research institutes to expose students to advanced scientific research and methods.

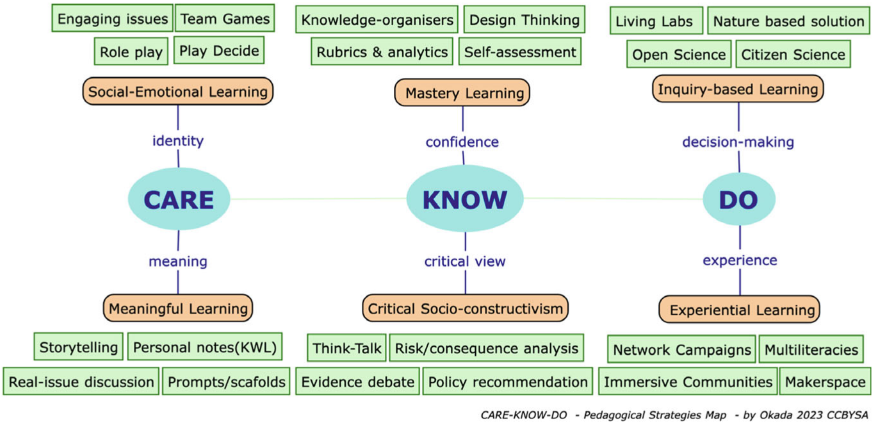
By actively engaging with each stakeholder and embracing the core elements of the map, teachers can provide a dynamic and immersive educational experience that prepares students to be responsible, innovative, and actively engaged (Ambrose et al. 2010).

> In sum, through knowledge mapping supported by experiential learning, students can design their experiential learning journeys, reflecting on their actions and building schemas that link experience with theoretical knowledge.

4.3 Twenty-Four Pedagogical Methods

A set of different approaches can be used by educators to enhance learning at each stage of the CARE-KNOW-DO framework. Map 4.8 provides six groups of four pedagogical methods, each relevant to the six educational principles.

The strategies used to enhance **social-emotional learning** help learners develop social intelligence and enhance affective engagement, which are important outcomes of the CARE stage.



Map 4.8 CARE-KNOW-DO pillars of pedagogical strategies. Okada (2024)

- **Engaging issues**: Engaging issues serve as catalysts for empathy, relevance, and active learning. By addressing real-world challenges, educators can create a learning environment that not only imparts knowledge but also nurtures a sense of care, responsibility and commitment to positive change.
- **Team games**: Using game elements in learning makes the process more interactive and enjoyable and appeals to students with a variety of different learning preferences.
- **Roleplaying**: Here, students play out roles in a simulated context, which can help them develop empathy, communication skills, and understanding of different perspectives.
- **Play decide**: A strategy that combines gameplay with decision-making to engage students in scenarios where they must consider various options and their personal views. This interactive approach helps students engage with familiar situations and make informed decisions, often based on relevant local issues.

The four strategies associated with **meaningful learning** are designed to deepen the learning experience and ensure that knowledge is not only acquired but also understood and applicable in various contexts.

- **Storytelling**: The use of narratives to convey information is a powerful tool in education. Through stories, complex concepts can be contextualised, making them easier to understand and remember. Storytelling can also connect emotionally with learners, which enhances their engagement and the meaningfulness of the learning experience.
- **Personal notes (KWL)**: This refers to a strategy in which learners are encouraged to note what they already know about a subject, what they want to know, and, later, what they have learned. This technique helps learners organise their thoughts and track their learning progress, promoting a deeper understanding and retention of information.

- **Real-issue discussions**: This strategy involves engaging learners in conversations about contemporary issues and challenges that are relevant to their lives or society at large. By discussing real-world problems, learners can find more significance in subject matter and are more likely to integrate this knowledge into their worldview.
- **Prompts and scaffolds**: This strategy involves providing learners with prompts or structured guides (scaffolds) to support their learning process. Prompts can stimulate deeper thinking or reflection, while scaffolds can help learners construct knowledge by providing a framework that they can build upon incrementally.

Mastery learning is vital for affective knowledge building in the KNOW stage. The four strategies related to this educational pillar are designed to support all learners in acquiring a deep and long-term understanding of content, with the aim of fostering a sense of achievement and confidence in their capabilities.

- **Design thinking**: This is a solution-focused process that encourages students to think creatively, empathise with users, define problems, and ideate, prototype, and test. It is iterative, allowing students to learn from failures and build confidence as they see that their ideas evolve into viable solutions.
- **Knowledge Organisers**: These are tools that outline the key information, vocabulary, and concepts that students must master within a topic. By organising knowledge in a clear and structured way, students can better understand and recall information, which supports confidence in their mastery of the subject.
- **Self-assessment**: Self-assessment is integral to mastery learning because it aligns with the principles of individualised progress, fosters a sense of ownership, and promotes continuous improvement. It is a powerful tool that empowers students to become active participants in their learning journey, contributing to a more effective and personalised educational experience.
- **Rubrics and analytics**: Rubrics provide a set of criteria for evaluating a student's performance, which can guide learning and self-improvement. Analytics can offer insights into a student's learning patterns and progress. Together, they can help students understand expectations, track their progress, and gain confidence in their ability to meet learning objectives.

The four pedagogical strategies associated with critical socioconstructivism are designed to cultivate a critical perspective where learners actively construct knowledge through social interaction, critical reflection, and engagement with real-world issues.

- **Policy Recommendation**: This strategy involves students formulating their own recommendations for change or improvement. This approach encourages them to critically evaluate the implications and effectiveness of existing policies, thereby enhancing their critical thinking and analytical skills.
- **Think and Talk**: This strategy emphasises collaborative learning where students engage in discussion in smaller groups, which can lead to improved understanding and critical thinking with the learning material.
- **Evidence-Based Debates**: In this approach, students engage in debates that require them to research and present arguments supported by evidence. This

strategy strengthens their ability to critically assess information sources, construct coherent arguments, and consider multiple perspectives.
- **Risk/Consequence Analysis**: This strategy teaches students to evaluate the potential risks and consequences of actions or decisions. It involves critical thinking to anticipate outcomes and consider both short-term and long-term effects, fostering a deep understanding of cause and effect in various contexts.

Inquiry-based learning utilises strategies that develop decision-making skills based on evidence-based thinking. It centres on the idea of encouraging students to ask questions and research answers and to engage with the material actively rather than passively receiving information.

- **Open science**: This strategy promotes transparent and collaborative learning, where students can access and contribute to scientific research—content, data, and methods—openly. It fosters a culture of sharing and critical evaluation, which is crucial for making informed decisions.
- **Nature-based solution**: This refers to learning strategies that use natural systems or mimic processes found in nature to address various challenges, for example, the use of plants to create biodegradable plastics. Students are encouraged to consider sustainable practices and ecological principles when making decisions.
- **Citizen science**: Involves students in scientific research projects where they can contribute to the data and participate in real-world experiments. This democratisation of science empowers students to make decisions based on the empirical evidence they have helped them gather.
- **Living labs**: These are real-life test environments where students can experiment with innovative ideas and technologies in real time. By engaging directly with the iterative process of testing and learning in authentic contexts, students enhance their ability to make practical and impactful decisions.

Experiential learning is centred around engaging learners directly in the learning process, ensuring that they build knowledge through experience supported by reflection and practices. They will also understand its application by actively participating in experiences that simulate or replicate real-world scenarios.

- **Multiliteracies**: encourage students to apply their knowledge and skills in real-life communication through language literacy (reading and writing), digital literacy (using technology and digital media), visual literacy (creating and interpreting images, maps and visuals), and other forms of communication by addressing actual problems or projects that have tangible outcomes. This approach helps learners understand the relevance of communication to real-world situations, thereby effectively enhancing their actions.
- **Network campaigns**: Engaging students in campaigns provides them with the opportunity to work on community-oriented projects. This type of active participation fosters leadership skills, social awareness, and the ability to work collaboratively towards a common goal.
- **Immersive communities**: This involves creating or utilising environments where students are fully engaged in the learning process. Technologies such as virtual

reality can provide immersive experiences that simulate real-world settings, allowing students to practice and learn in a controlled yet realistic environment with others.

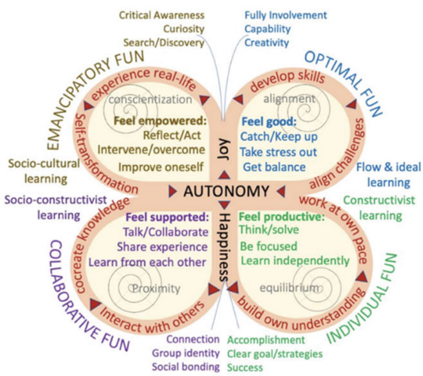
- **Makerspace**: This promotes learning through doing, specifically in the context of creating, building, and tinkering. It emphasises hands-on learning and encourages creativity, innovation, and the development of practical skills. It can also involve FabLabs with 3D printers and electronics, fostering an entrepreneurial spirit and problem-solving mindset.

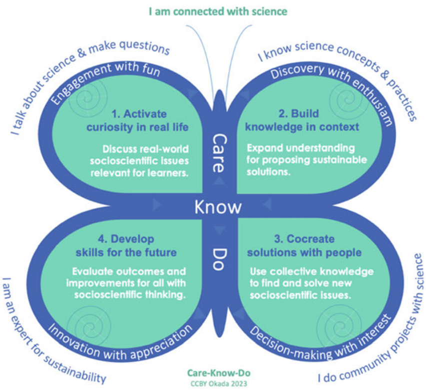
4.4 Pedagogical Strategies

Map 4.9 provides two butterfly maps to illustrate the application of the principles and strategies presented in this chapter with the aim of fostering enjoyable and effective learning experiences. The first approach, termed the 'Butterfly of Autonomy,' focuses on nurturing students' independence through activities that promote 'Optimal Fun,' 'Collaborative Fun,' 'Individual Fun,' and 'Exploratory Fun'. This model underscores a socioconstructivist framework, emphasising critical awareness, curiosity, empowerment, and the joy of discovery. It encourages students to engage in sociocultural learning, share experiences, and foster social bonding through autonomy in their journey (Okada and Sheehy 2020).

Complementing this, the 'butterfly of CARE-KNOW-DO' forms the second approach, which is centred on a cyclical process of growth and application. The learning process within this model unfolds as follows:

- **Engagement**: Students engage actively and enjoyably by discussing and questioning real socioscientific issues.
- **Discovery**: Enthusiasm and understanding are expanded through contextual knowledge.





Map 4.9 CARE-KNOW-DO principles in practice. Okada (2024)

- **Decision-making**: Interest is cultivated through the cocreation of solutions using collective knowledge.
- **Innovation**: Outcomes are improved and appreciated through evaluation, employing socioscientific thinking skills.

The ultimate goal is to cultivate an environment where students are not only capable of designing, discovering, and deciding but also passionate about the learning process itself to address real-world challenges, thus promoting authentic inquiry and independent thinking with enjoyment (Okada et al. 2024).

Map 4.10 shows an overview of the theoretical empirical approaches, pedagogical principles, and learning models used in the CARE-KNOW-DO framework presented in this chapter.

- **First**, it outlines the theoretical empirical pillars that enhance pedagogical practices for integrating mapping activities presented in the following chapters.
- **Second**, it provides recommendations designed to guide teaching and learning processes through knowledge mapping. These approaches incorporate various pedagogical strategies and engagement techniques.
- **Third**, it introduces specific learning models applied within educational settings, which are enhanced by the aforementioned principles and recommendations. These models demonstrate diverse methods of learning guidance, interaction, and assessment, emphasising their contributions to the learning experience.

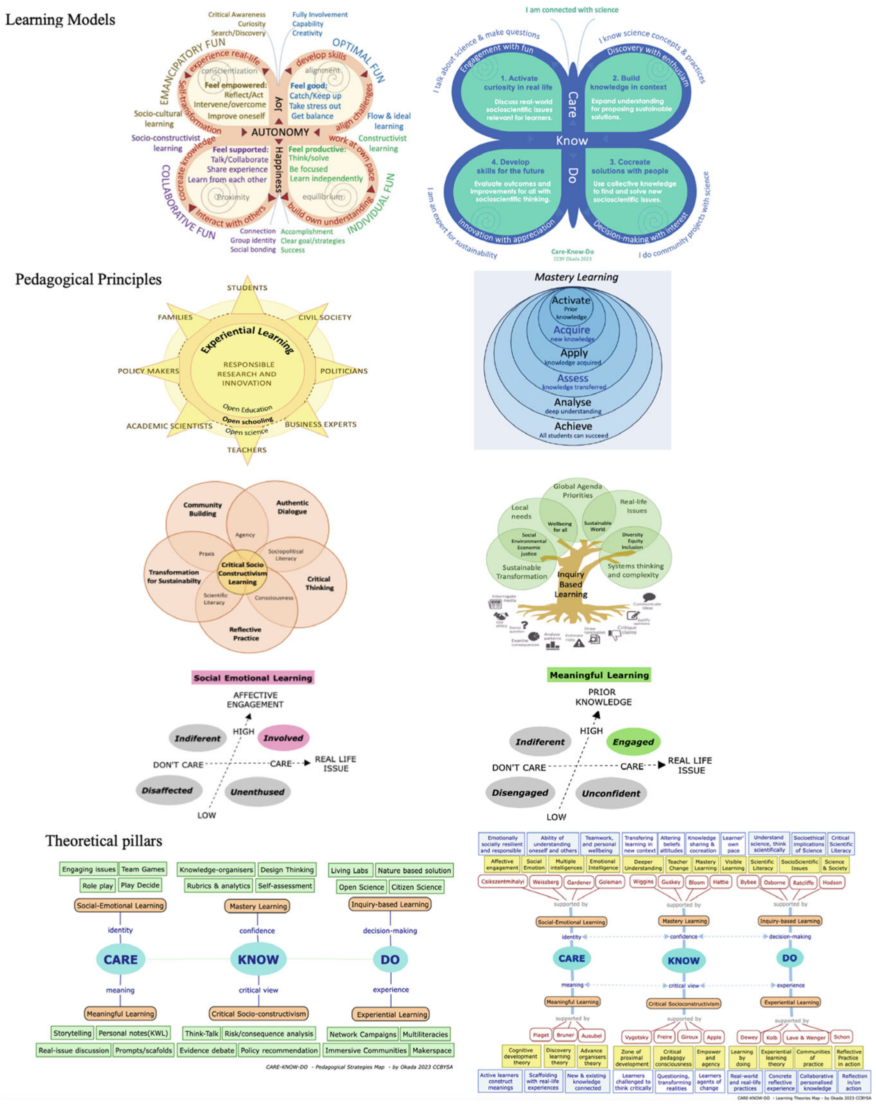
Each section of the Map 4.10 breaks down complex educational concepts into more manageable segments, enabling educators to visualise the relationships between theory, practice, and application. This segmentation supports the integration of case studies and techniques discussed in Chaps. 6 and 7, facilitating a comprehensive understanding of the learning environment.

Reflective Remarks This chapter examined the six principles of the CARE-KNOW-DO framework: social-emotional learning, meaningful learning, mastery learning, critical socioconstructivism, inquiry-based learning, and experiential learning.

Action Points: Use the techniques descriptions and examples provided to outline principles and strategies in teaching and learning with examples that you found relevant.

Next chapter will present and discuss 19 techniques for knowledge mapping, which can be underpinned by these principles to foster significant teaching/learning experiences (see examples in Chap. 6).

Questions: What mapping techniques can help educators and students create more effective and dynamic learning experiences? Which real-life scenarios



Map 4.10 CARE-KNOW-DO overview. Okada (2024)

for science-related problem-solving and project development are relevant to exploring these techniques?

References

Ambrose SA, Bridges MW, DiPietro M, Lovett MC, Norman MK (2010) How learning works: seven research-based principles for smart teaching. Wiley
Apple MW (2012) Can education change society? Routledge
Ausubel DP (2000) The acquisition and retention of knowledge: a cognitive view. Kluwer Academic Publishers
Bloom BS (ed) (1985) Developing talent in young people. Ballantine Books, New York
Bruner J (1973) The relevance of education (No. 690). WW Norton & Company
Bybee RW (2012) Scientific literacy in environmental and health education. Sci Environ Health towards Renew Pedag Sci Educ 12:49–67
Czikszentmihalyi M (1990) Flow: the psychology of optimal experience
Dewey J (1938) Experience and education. Macmillan, New York
Freire P (1967) Education as a practice of freedom. Peace and Earth, Rio de Janeiro
Freire P (2000) Pedagogy of freedom: ethics, democracy, and civic courage. Rowman & Littlefield Publishers
Gardner HE (2008) Multiple intelligences: new horizons in theory and practice. Basic books
Giroux H (1997) Pedagogy and the politics of hope: theory, culture, and schooling. Westview Press, Boulder
Goleman D (2020) Emotional intelligence. Bloomsbury Publishing
Guskey TR (2010) Lessons of mastery learning. Educ Lead 68(2):52–57
Groves C (2017) Review of RRI tools project, http://www.rri-tools.eu. Journal of Responsible Innovation 4(3):371–374
Hattie J (2008) Visible learning: a synthesis of over 800 meta-analyses relating to achievement. Routledge, New York
Hodson D (2011) Looking to the future. Springer
Kolb DA (2014) Experiential learning: experience as the source of learning and development. FT press
Lave J, Wenger E (1991) Learning in doing: Social, cognitive, and computational perspectives. Situated learning: Legitimate peripheral participation, 10, 109–155.
Okada A (2023) Inclusive open schooling with engaging and future-oriented science: evidence-based practices, principle and tools. The Open University, Milton Keynes
Okada, A. (2024). Knowledge Cartography for Young Thinkers: Sustainability Issues, Mapping Techniques, and AI Tools. Figures. The Open University. CCBY. https://doi.org/10.21954/ou.rd.27963327
Okada A, Panselinas G, Bizoi M, Malagrida R, Torres PL (2024) Fostering transversal skills through open schooling with the CARE-KNOW-DO framework for sustainable education. Sustainability 16(7):2794
Okada A, Sheehy K (2020) Factors and recommendations to support students' enjoyment of online learning with fun: a mixed method study during COVID-19. Front Educ 5(1)
Osborne J (2010) Arguing to learn in science: the role of collaborative, critical discourse. Science 328(5977):463–466
Piaget J (2000) Commentary on Vygotsky's criticisms of language and thought of the child and judgement and reasoning in the child. New Ideas Psychol 18(2–3):241–259
Ratcliffe M (1997) Pupil decision-making about socio-scientific issues within the science curriculum. Int J Sci Educ 19(2):167–182
Schon DA (2017) The reflective practitioner: how professionals think in action. Routledge, New York

Vygotsky LS (1978) Chapter 6: interaction between learning and development. Mind in society: the development of higher psychological processes. Harvard University Press, Cambridge, pp 79–91

Weissberg RP (2019) Promoting the social and emotional learning of millions of school children. Perspect Psychol Sci 14(1):65–69

Wiggins GP, McTighe J (2005) Understanding by design. Ascd

Chapter 5
Techniques and Application of Knowledge Mapping

Abstract This fifth chapter presents three learning objectives:

1. Explore examples about how knowledge maps can promote critical, systemic, and creative thinking in teaching, research, and learning environments.
2. Examine 19 mapping techniques that facilitate the development of these key skills and understand how they can be integrated into the knowledge construction process.
3. Consider new scenarios to apply knowledge mapping techniques and AI tools drawing on real-world examples.

Keywords Mapping · Components · What · How · Challenges · Skills · AI

Introduction

Understanding the different types and purposes of knowledge maps helps educators, learners, and researchers select the most appropriate techniques for their specific needs. Knowledge maps come in many forms, each serving a unique function in organising and representing information. From concept maps and mind maps to argument maps and inquiry diagrams, these techniques help visualise relationships, enhance comprehension, and facilitate critical thinking in various ways. The diversity in mapping types addresses different learning objectives and cognitive needs. This chapter introduces 19 distinct types of knowledge maps, illustrating their applications, benefits, and skills (see Map 1.5).

A. Okada, *Knowledge Cartography for Young Thinkers*, SpringerBriefs in Advanced Information and Knowledge Processing, https://doi.org/10.1007/978-3-031-54677-8_5

5.1 Dialogue Mapping

Dialogue map is a visual representation that teams use to record and organise the components of a discussion, such as questions, ideas, pros, and cons. Sierhuis and Shum (2014) utilised dialogue maps in computer science to document and analyse discussions during NASA's Mars exploration field trials. These maps act as graphical annotations, effectively capturing and preserving the content of scientific meetings.

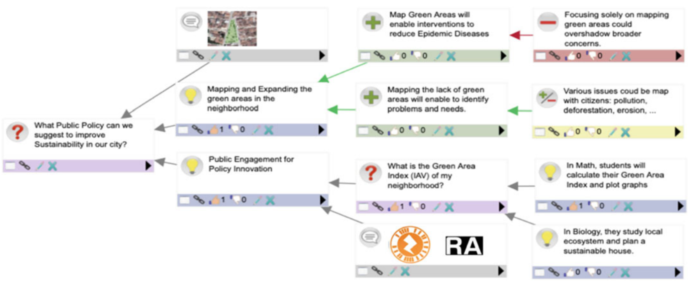
What is Dialogue Mapping?

Dialogue mapping is a technique that emerged in the early 1970s based on the IBIS (issue-based information system) system created to solve problems and challenges through three basic elements: questions or premises, positions, and arguments. The IBIS assumes that for each premise, positions and arguments can be established (Kirschner et al. 2003). Thus, we start first with general premises, which imply more specific premises. For example, through questions, positions are established, which once also questioned, allowing the definition of arguments that support or reject the initial positions. New questions arise, and the process continues recursively.

The dialogue map uses these elements: issues, positions, and arguments for or against mapping the solution of a problem. Various points of view can be coherently articulated both individually and collectively. These maps are very useful for understanding complex issues and for decision-making. The elaboration of a dialogue map is carried out first, with a theme or subject to be discussed. The theme is questioned by recording questions. For each question, positions are established that must be reflected upon and questioned. What supports this idea? What can oppose this idea? Is there any additional information that can serve as a basis? (Fact, example, theory). With these elements, new questions may arise, as well as answers and grounds for or against them. When the mapped information is sufficient to determine a conclusion or make a decision, the process ends with the synthesis of what has been completed.

How Can Dialogue Mapping Be Used for Learning Supported by AI?

The dialogue Map 5.1 was created by the author with the CONNECT team, which focuses on green areas and sustainable houses and draws on the secondary students'



The dialogue map is a robust tool for visualizing and planning sustainability efforts in an urban context. It incorporates various dimensions of community and educational engagement, but the map could further detail other stakeholders, such as local businesses, environmental NGOs, or community groups, and describe how they can participate or contribute to these initiatives. (ChatGPT, 2023)

Map. 5.1 Dialogic map of green areas and sustainable houses, LiteMap. Okada (2024) project in Bahia, UNEB Brazil. It also includes an augmented reality (AR) resource from the '*RA nas escolas'* project developed by the UFSC to plan sustainable houses using the Zappar app. Students used their smartphones to scan the orange circle to access AR, and AI was used for evaluation using the map as input for assessment.

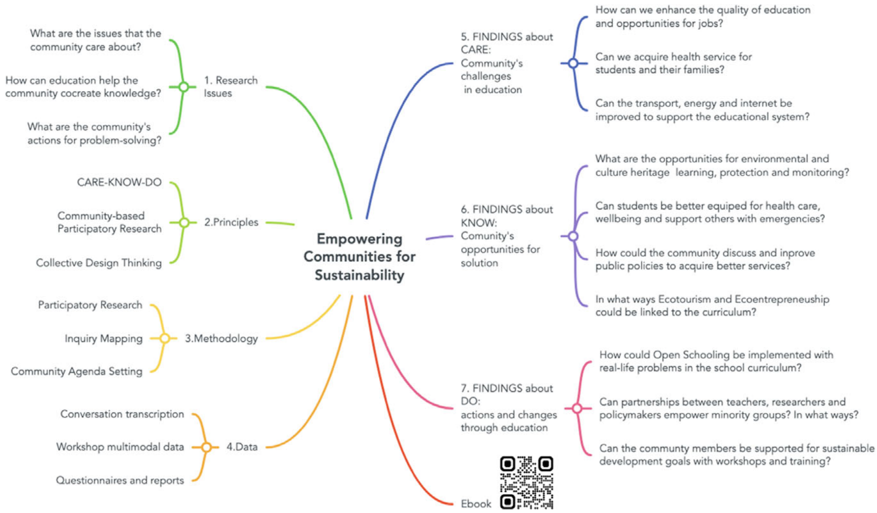
5.2 Inquiry Mapping

Inquiry map is a visual representation to conduct research on a specific topic. Two studies provide examples. Okada et al. (2023) developed inquiry maps supported by community-based participatory research methods to examine the impact of climate change on the sustainable reserves of the Amazon rainforest. Another example by Tao and Zhang (2021) explores how 5th-grade students built research frameworks related to human body systems over the course of a school year. At the centre of these frameworks was an "investigation cycle" that facilitated the development of students' research skills and their ability to engage in effective argumentation. These cases demonstrate how this mapping technique empowers students to develop well-founded problems and research inquiries.

What is Inquiry Mapping?

This technique was created by the author during her PhD study "*Investigative Cartography: Epistemological and communicational interfaces to map knowledge in research projects*" (Okada 2006) that helps individuals organise and explore their questions and lines of inquiry on a particular topic or subject. It is a technique used in inquiry-based learning and research processes.

The research and inquiry concepts can be described as a systematic and systemic process of gathering, organising, analysing, and interpreting information to generate new knowledge, validate existing theories, or answer specific questions. Research can encompass both investigations and inquiries, depending on its nature. An inquiry map, also known as an investigative map or research map, typically consists of a central question or topic surrounded by related subquestions or areas of investigation. This mapping guides the inquiry process and allows for the exploration of various perspectives or aspects of the main research question. The map helps learners navigate their research, make connections between different ideas, and develop a deeper understanding of the topic supported by theories and evidence, including data generation, data interpretation, discussions of findings, and conclusions (Okada 2008, 2014).



Map 5.2 Inquiry map of sustainable communities, mind meister. Okada (2024)

How Can Inquiry Mapping Be Used for Learning Supported by AI?

The inquiry map (Map 5.2) shows the research project steps developed by the author with a community in Amazon rainforest. AI was used to evaluate clarity and relevance for further improvements.

According to ChatGPT-4, **Clarity**: *The map efficiently uses space to communicate a complex process. Each segment is briefly labelled, and the main ideas are highlighted without excessive detail. The use of different categories to delineate various aspects of the research process (Research Issues, Principles, Methodology, Data, Findings about CARE, KNOW, DO and the e-book) aids in visually separating and emphasising these components.*

Relevance: *The map is highly relevant to the goals of community-based participatory research as it focuses on empowering communities through sustainability. It integrates essential elements of such research—identifying common issues, involving members in setting agendas, and using data collected through participatory methods.*

5.3 Argument Mapping

Argument map is a visual representation for forming persuasive reasoning by visually organising arguments and counterarguments, aiding in decision-making. Eftekhari et al. (2016) explored the benefits of teaching argument mapping in EFL contexts by comparing the use of Rationale software to traditional paper and pencil methods. The study concluded that computer-aided argument mapping is more effective at improving students' critical thinking abilities. This technique allows students to more thoroughly comprehend the structure of arguments, discern the relationships between different statements, and evaluate the arguments' credibility and logical coherence.

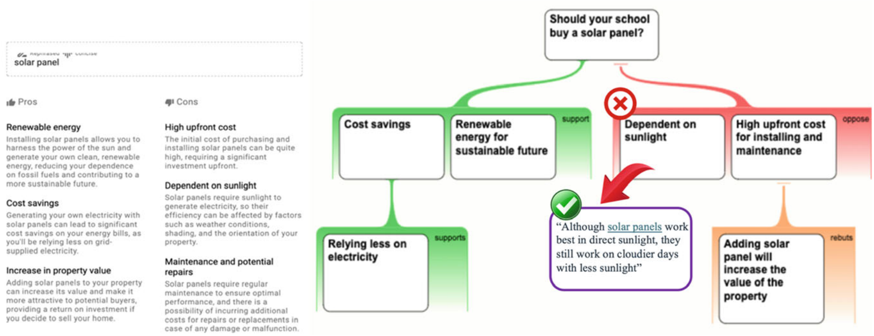
What is Argument Mapping?

This technique first emerged with J. H. Wigmore in law for case studies and for the teaching of argumentation techniques. The objective of this technique is to map the structure of the argumentation, that is, to identify the premises, copremises, reasons, objections, arguments that support the main contention and the counterarguments that reject it as well. Argument mapping is useful for facilitating the visualisation of these components of argumentation. The analysis of the connections also contributes to understanding the logical structure of the argument, evaluating coherence and restructuring aimed at improvement.

Currently, argument maps have been used not only for the elaboration and analysis of cases in law (Carr 2003) but also in several areas of knowledge, such as medicine (Edmondson 1995; Hicks-Moore et al. 2006), computer science (Rowe and Reed 2008), education, psychology, and philosophy (Van Gelder et al. 2004). The applications of argument maps are also diverse: problem solving, the scientific foundation and development of critical thinking, and writing elaboration. Several studies on argumentation have provided different techniques for mapping arguments. The Toulmin diagram, for example, is an approach that represents argumentation through six components: data, conclusion, guarantees, refutation, support and qualifier.

How Can Argument Mapping Be Used for Learning Supported by AI?

The argument map (Map 5.3) created by students about renewable energy was supported by the author. They explored the advantages and disadvantages of solar panels. Initially, students shared their perspectives, formed two teams (pro and against), searched the web for references and integrated insights from the AI tool Rationale.jia.ai. The final map was constructed in rationale online to visualise the arguments with more clarity and includes two arguments that support the acquisition of a solar panel and one counterargument accepted but with a rebuttal. In addition, students also found that the first counterargument was a misconception, which was verified in various sources, not only blogs but also scientific articles. Students were engaged by the task and tools when they were challenged to determine what was wrong with AI (hallucinations). They found that the activity was useful and fun. Additionally, through the LAMP ('lots of argument mapping practice') approach, described by Rider and Thomason (2008), students intensively practised



Map 5.3 Argumentative map of solar energy, Rationale.jina and rationaleonline. Okada (2024)

mapping arguments and counterarguments, ultimately recognising that the quality of evidence—reliable, verifiable, and trustworthy—matters more than the quantity of arguments.

5.4 Concept Mapping

Concept map is a visual representation to enhance understanding by connecting existing knowledge with new information. In the context of science education, Eggert et al. (2017) investigated this technique, specifically studying its effect on students' comprehension of climate change. The authors evaluated the quality of the students' concept maps and their performance on tests covering knowledge, reasoning, and decision-making. Their findings indicate that concept mapping positively impacts learning. This study emphasises the importance of a balanced educational approach that combines adequate instructional support with allowing students autonomy to guide their own learning through concept mapping.

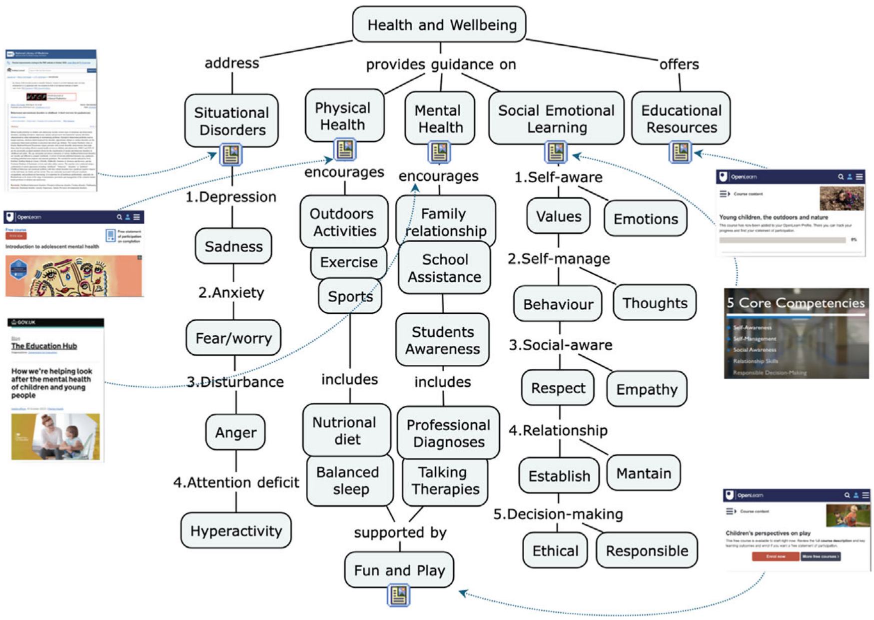
What is Concept Mapping?

Concept Mapping is a technique for establishing relationships between concepts and systematising meaningful knowledge. It was developed by Prof. Joseph D. Novak at Cornell University in 1972. His work was grounded in the theory of David Ausubel, who highlighted the importance of meaningful learning arising from the assimilation of new concepts and propositions through existing cognitive structures. Meaningful high-level learning requires prior knowledge and involves new problem solving and creativity supported by well-organised domains of knowledge. In addition, practical thinking and experience are also facilitated. "The more we learn and organise our knowledge in a given domain, the easier it is to acquire and use the new knowledge in that domain" (Novak 1998:24). With this, the author stresses that when an individual knows little or has their knowledge poorly organised, meaningful learning is more difficult, and the time involved in the process is greater. According to Novak (1998:58), concepts that have already been constructed are essential for learning new subjects. These existing concepts, called subsumers, were coined by Ausubel. The subsumer concept refers to the previous knowledge already elaborated and assimilated in the cognitive structures of the learner, serving as a dynamic basis for articulating new knowledge through relationships with existing knowledge. As the learner expands his knowledge base, he also expands his subsumptive notions, favouring new learning situations. This means that “the information that is learned in a significant way associated with the subsumers in the cognitive structures of the learner, can be retrieved …” (Novak 1998:61).

Concept maps are also based on constructivist theory. The learner constructs his knowledge and meaning from relations between new elements and those that are already known to him. Such relationships facilitate the systematisation of new concepts (Novak 1998:63). When the cognitive structure expands, the learner develops his ability to learn new things.

How Can Concept Mapping Be Used for Learning Supported by AI?

Map 5.4 concept map about Learners’ Health and Wellbeing was created by the author with educators using initially Mymap.AI. Three categories were selected: physical health, mental health and social emotional learning. Perplexity AI tool was also used to check the latest references. Students—preservice teachers—discussed the references and raised health issues that they were curious about, for example, depression and anxiety. The aim of AI to help teachers explore categories and references to



Map 5.4 Concept map of mental health and well-being, Cmap Clouds. Okada (2024)

increase awareness about the topic. The final version of the map was produced with the Cmap Clouds tool.

5.5 Decision Tree Mapping

A decision tree is a visual representation used to select choices and establish criteria for ranking and making decisions. An example from the field of energy and building engineering was developed by Mikučionienė et al. (2014). The researchers utilised the decision tree map supported by different scientific fields: energy, environment, economy, and construction. This decision tree protocol helped scientists increase the sustainability of renovations by evaluating criteria for energy efficiency measures that reflect a sustainable attitude. The authors noted that the decision tree map is useful for decision-makers, whether machine or person.

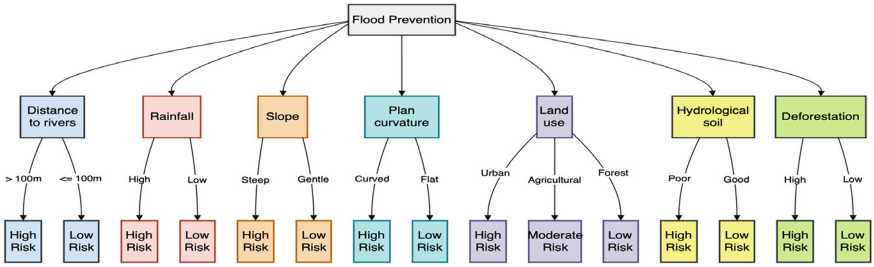
What is Decision Trees Mapping?

Decision analysis and decision trees offer a structured approach for making informed choices under conditions of uncertainty, helping decision-makers visualise and evaluate their options effectively. Decision trees display all possible outcomes of a decision. The decision itself is placed at the beginning, with branching lines or arrows leading to a clear set of mutually exclusive outcomes or options. In addition, a decision analysis table may be used to quantify the probability and value of each outcome, facilitating more informed decision-making. Decision trees also serve as algorithms in machine learning and data analysis.

The concept of decision trees has been utilised for several decades, with significant contributions from fields such as computer science, statistics, and artificial intelligence. They are particularly valuable for evaluating scenarios with multiple uncertain outcomes. One of the earliest and most influential decision tree algorithms, ID3 (Iterative Dichotomiser 3), was developed by Ross Quinlan in the 1980s.

Decision trees are crucial in decision analysis and risk management because they provide a structured method to model and evaluate different actions and their associated risks. They support risk and prevention analysis in six key ways:

1. **Identifying Risks**: Decision trees help identify potential risks and their consequences, with each branch representing a decision or event and associated probabilities and outcomes assigned to each branch.
2. **Evaluating Prevention Strategies**: Prevention strategies can model various strategies or actions to mitigate risks, with probabilities assigned to the success or failure of each measure.
3. **Quantifying Risks**: Decision trees allow for the quantification of risks by calculating expected values at various decision points and assessing the overall risk associated with specific actions or decisions.



Map 5.5 Decision tree map for flood prevention, App.diagrams.net. Okada (2024)

4. **Comparing Alternatives**: They enable comparisons of different actions or strategies based on their expected outcomes and associated risks, aiding in selecting the most effective approach.
5. **Sensitivity Analysis**: Decision trees are useful for conducting sensitivity analysis to determine how changes in outcome probabilities affect the overall risk assessment, helping to gauge the robustness of strategies.
6. **Scenario Analysis**: They can accommodate various scenarios or combinations of events and decisions and analyse the impact of different scenarios on risk and prevention.

How Can Decision Tree Mapping Be Used for Learning Supported by AI?

Map 5.5, developed by students alongside a teacher and a STEM professional, features a decision tree designed to assess flooding risks in various regions. It begins by identifying seven key variables, such as land use, slope, and rainfall, and analyses these variables to determine whether the flooding risk is high, moderate, or low. For instance, it categorises land use into urban, agricultural, and forest, each with corresponding risk levels. This map can be further developed to aid in planning flood prevention strategies across different areas. Students can use AI to analyse local scenarios, identify relevant variables, investigate hypotheses, expand missing items with AI-generated code and update redundant branches to ensure tree clarity and accuracy. By feeding input data into real-time scenario simulations, AI and reviewers can provide actionable insights for students to discuss and refine with feedback from local experts, thus improving the accuracy, usability, and reliability of decision trees.

5.6 Ranking Mapping

Ranking mapping is a visual representation used to organise criteria based on priorities. In the field of ethnobotany, a doctoral study by Wolditsadik (2018), titled 'Ethnobotanical study of traditional medicinal plants in Ethiopia', employed this method. Direct matrix ranking was used to evaluate the benefits of 11 national plant species used for medicinal purposes.

What is Ranking Mapping?

Ranking mapping is a technique used in decision-making to determine the relative importance or acceptability of different items by placing them in order of preference. This technique aid individuals or groups in systematically evaluating and ordering items based on specific criteria, making them valuable for considering various factors and preferences when making choices. Several methods exist for ranking items:

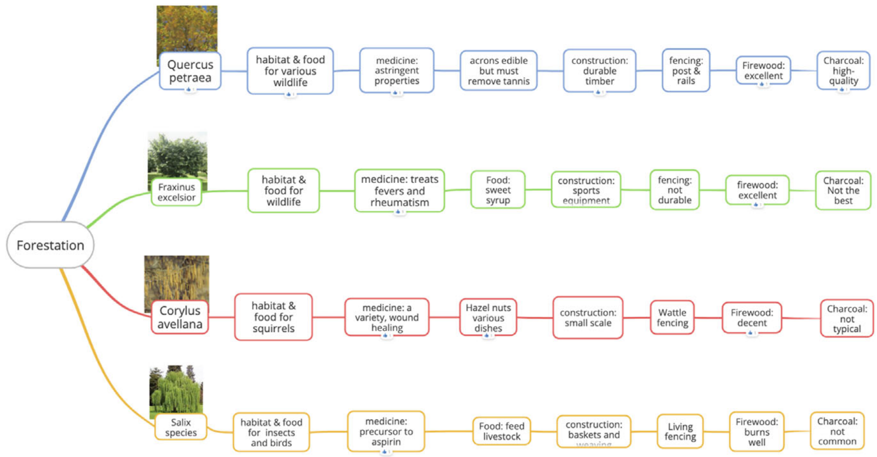
1. **Pairwise Ranking**: This method compares items in pairs. Participants, using either the items themselves or representations, choose one from each pair and explain their choice. This helps to identify the criteria for ranking, resulting in a preference order. If the number of items is large, all possible pairs or subsets are compared, and a matrix can record the comparisons.
2. **Direct Physical Ranking**: Here, participants physically arrange the items or use symbols such as pieces of paper to represent them in their order of preference based on specific criteria. This ranking is visible to all participants, which facilitates discussion.
3. **Direct Matrix Ranking (**Chambers 1988**)**: This method involves the following steps:

   - A group was selected, and a category of objects (e.g. tree species) relevant and familiar to the participants was chosen.
   - Participants name the most important items within the category, typically a small number (e.g. four to six).
   - The group discussed what was good or bad about each item (using negative or positive criteria).
   - A matrix is created with the items across the top and the criteria down the side.
   - Participants rank the items against each criterion by asking, 'Which is best?' or 'Which is worse?'
   - A consensual discussion guides the final decision: 'If you could choose only one of these, which would it be?'

How Can Ranking Mapping Be Used for Learning Supported by AI?

The ranking map (Map 5.6) created by research students was used to evaluate the suitability of four tree species—oak (Quercus petraea), ash (Fraxinus excelsior), hazel (Corylus avellana), and willow (Salix species)—for reforestation in areas such as parks, schools, or towns. Seven criteria were used for the evaluation: firewood, charcoal making, construction, fencing, food, forage, furniture, and medicine. Each species received a score from 5 for 'best' to 0 for 'no value'. Votes from the community and family members, collected through the map, identified Laggera tomentosa as the most preferred species. The following AI tools were used by the participants to:

- Search for tree species that can be useful for reforestation (Bing by Microsoft).
- Find illustration with open access (Gemini by Google).



Map 5.6 Ranking map for reforestation, Ayoa. Okada (2024)

- Synthetise content to communicate relevant criteria about tree species (chatgpt by openai).
- Collect information and references about tree species (Perplexity AI).
- Create the map and provide a collaborative platform to build consensus on the ranking outcomes (Ayoa).

5.7 Activity Mapping

Activity map is a visual representation used to plan a set of tasks aimed at achieving a goal. In the field of clean energy engineering, Ellegård and Palm (2011) focused on exploring actions related to energy consumption to promote sustainability in daily life. Their results indicated that analysing the sequence of activities with mapping was useful for understanding and reflecting on family energy consumption patterns.

What is Activity Mapping?

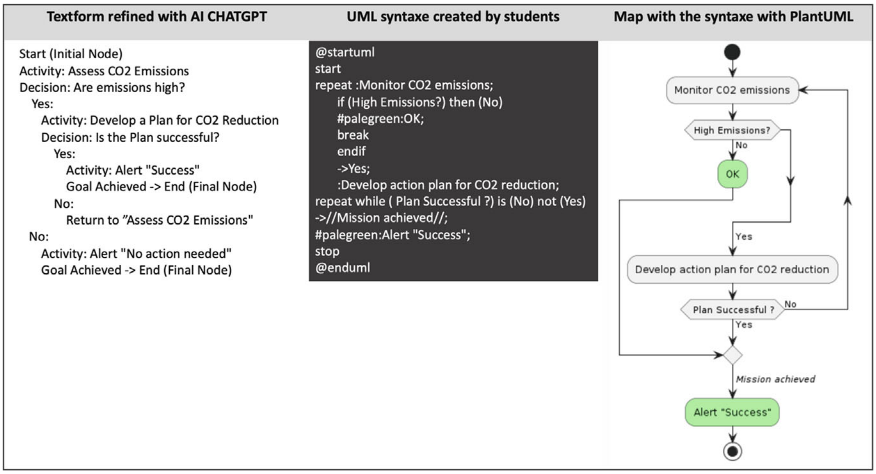
Activity mapping, also known as activity diagram, is a technique used to present an ordered set of activities over time. They are valuable for visualising processes, workflows, or sequences of events, particularly in project planning. Both activity mapping and sequence mapping are used by software developers to illustrate actions and relationships within a software system. These techniques were initially developed based on UML (Unified Modelling Language) in 1994–95 by Grady Booch, Ivar Jacobson, and James Rumbaugh, through Rational Software. In 1997, UML was adopted as a standard by the Object Management Group (OMG), an association of companies that controls the open UML standard.

Activity maps describe a set or flow of operations in a system, similar to flowcharts. They show the outcomes of each activity following specific responses. Activity maps always have a path to be followed with an initial or final state. These maps use a set of shapes connected by arrows. The most common shapes are rectangles representing actions or stages, and diamonds referring to decisions. The arrows indicate the process, illustrating the order of occurrence of actions or the progression of the workflow.

How Can Activity Sequence Mapping Be Used for Learning Supported by AI?

Map 5.7 lustrates an activity map developed by a group of students and researchers in the 'CONNECT' project. This scenario assigns students the task of providing recommendations to a café on reducing carbon emissions. The workflow of the diagram goes from the initial node to the final node, and the arrows represent possible paths according to the decisions made.

AI Chat GPT 3.5 was used to help the students plan and evaluate the UML code executed through the application Plantuml.com. The sequence starts with the café assessing its current CO_2 emissions. When emissions are high, the café identifies areas for reduction and formulates an action plan. The owners then decide on the implementation of the plan. Satisfactory progress leads to continuous monitoring, while unsatisfactory results require plan adjustments and repeated monitoring until satisfactory results are achieved. If emissions are not high, no immediate action is considered necessary. The map incorporates actions and details pertinent to the café's specific situation and its carbon reduction goals. Researchers reported that students found the activity useful for logical reasoning and programming skills. AI was a valuable tool for teaching students to readapt and recreate UML code.



Map 5.7 Activity map for CO_2 emission reduction, Plantuml.com. Okada (2024)

5.8 Sequence Mapping

Sequence map is a visual representation used in software development to visualise interactions and synchronisation between various parts of a system. In the context of urban planning, Jain et al. (2016) used sequence maps to integrate interdependent simulations and applications for sustainable urban development. Their sequence map proved effective in modelling complex interactions between land use, transportation, and transit systems in San Diego.

What is Sequence Mapping?

Sequence mapping is a technique of the Unified Modelling Language (UML). It visualises interactions and temporal sequences in a system, such as collaboration between objects and the order of their communication. These diagrams detail scenarios like end-use cases, user interactions, and system-to-system interfaces, structured by temporal and object alignment.

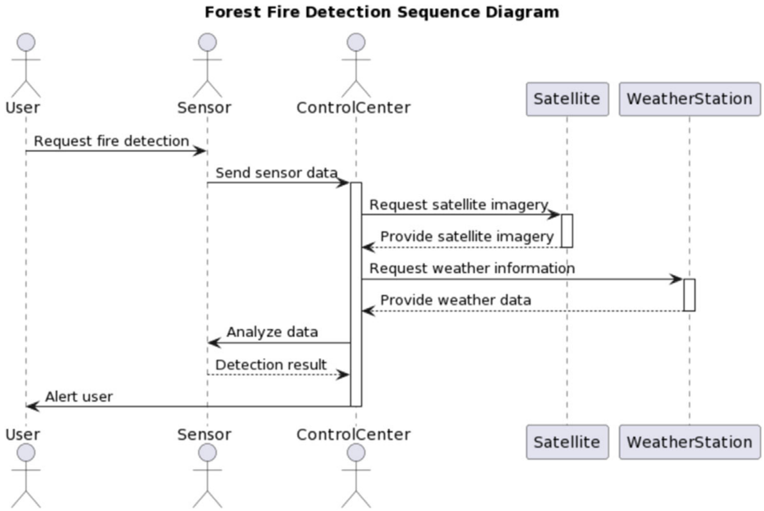
Developed in the mid-1990s by Grady Booch, Ivar Jacobson, and James Rumbaugh, sequence map also known as sequence diagram, focuses on the sequence and exchange of messages between system elements. It presents lifelines for object representation, arrows for message communication, vertical rectangles for activations, and notations for the end of lifelines. The arrows present the sequences of activities, while the bars represent the start (fork) or end (join) of simultaneous activities.

Both types of maps (activity and sequence) are valuable for modelling business processes and workflows, providing information about structured activities and object interactions in specific scenarios. The difference in relation to activity maps is that activity diagrams focus on the flow of activities, whereas sequence diagrams focus on how objects interact with each other over time.

How Can Sequence Mapping Be Used for Learning Supported by AI?

Map 5.8 was created by an educator and researcher using code generated with AI assistance, which was then readapted and revised in the App.diagram.net tool to facilitate discussions on solving real-life problems, including students' ideas to support forest fire detection. The map contains nine activities:

1. The user requests fire detection.
2. The sensor sends sensor data to the control centre.
3. The control centre requests and receives satellite images from the satellite.
4. The control centre simultaneously requests and receives meteorological information from the weather station.
5. The control centre analyses the data and provides results to the control centre.
6. The control centre sends a detection result, and the user is alerted to the detection result.



Map 5.8 Sequence map for forest fire detection, App.diagram.net. Okada (2024)

Participants found the map useful for understanding the sequence of actions, from the user's initial request to the final alert. The roles and interactions of each participant—such as the user, the sensor, the control centre, the satellite, and the weather station—were clearly represented, aiding in visualising task sequences. AI provides feedback and support during code simulation, enhancing the learning experience. Through the mapping process augmented by AI and feedback from peers, students develop critical thinking skills and can effectively plan and visualise the components that contribute to fire detection. The map also promotes creativity and logical reasoning, which are crucial for refining the sequence of events and essential steps for system efficiency and systems programming development. This example presents a practical application of a sequence involving multiple actors and activities, allowing teachers to demonstrate the application of science and technology in environmental monitoring and emergency response.

5.9 Rich Picture Mapping

A rich picture map is a visual representation that uses drawings and labels to highlight parts, components, and relationships within a system. In operational research and its applications in addressing societal problems such as food insecurity, Wang et al. (2018) utilised this technique to explore solutions for improving access to affordable fresh food in disadvantaged Welsh communities (Welsh Government 2020). Rich pictures are particularly valuable in complex problem situations where understanding and representing diverse perspectives is crucial.

What is Rich Picture Mapping?

Rich picture mapping is commonly used to gather and represent information through an illustration of a complex situation. These methods are based on soft systems methodology (SSM), which was developed by Peter Checkland in the 1970s as a way to handle multifaceted, "soft" problems that cannot be easily quantified or modelled. Rich picture mapping is a technique within SSMs used to represent complex situations and express ideas that cannot easily be conveyed with words or numbers (Checkland and Poulter 2020). The rich pictures illustrate relationships, connections, influences, cause-and-effect dynamics, and subjective elements. They harness the power of drawings, symbols, and text to represent a specific situation or issue from the perspective of the people who create them. The recommendations for rich picture maps are:

- Include compilations of meaningful drawings, images, symbols, and texts.
- Serve as "summaries" of the physical, conceptual, and emotional aspects of a current situation.
- Help describe complex situations or issues.
- Include everything relevant to the problematic situation and use words only when necessary.
- Identify the structural elements of the situation, the process, and the interactions.
- Avoid thinking only in terms of systems; focus on capturing factual and subjective information.
- Consider the roles and behaviours of participants, highlighting any potential conflicts.
- Recognise the values, beliefs, and norms that may influence perceptions.

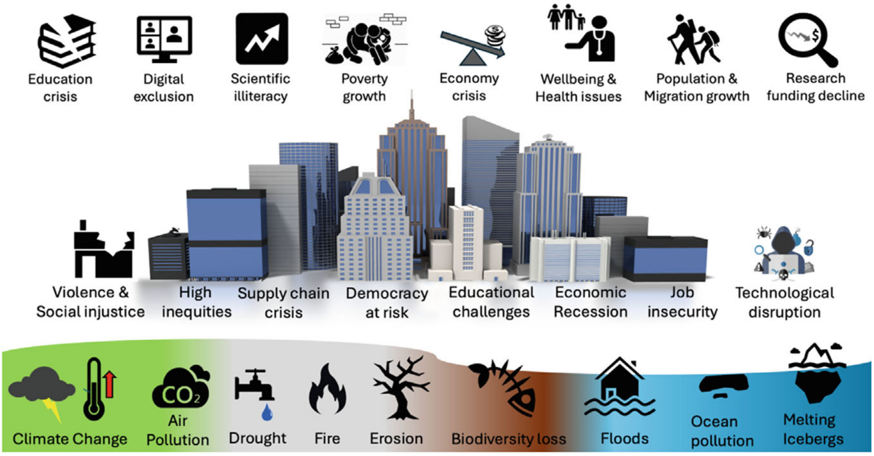
Rich pictures can be created before analysing a situation when it is unclear which aspects are essential, during and after an inquiry to track changes and communicate findings. Some of the key benefits of rich pictures are listed as follows.

- Aiding in knowledge exchange among groups with cultural or language differences.
- Fostering creative thinking and freedom in expressing ideas.
- Encouraging shared understanding among stakeholders.

How Can Rich Mapping Be Used for Learning Supported by AI?

This rich picture (Map 5.9) illustrates the intricate web of global and local challenges intensified by climate change, with educational institutions positioned at the core as vital agents combating these issues. The map highlights a spectrum of global concerns requiring sustainable solutions, including educational crises, the digital divide, scientific illiteracy, affordability, mental health, resource constraints versus population growth, and dwindling research funding.

Created collaboratively using Claude. AI and Canva, Map 5.18 feature open-licence icons and perspectives from students highlighting global warming, job insecurity, ecosystem and health impacts and teachers emphasising extreme weather,



Map 5.9 Rich picture map on sustainability challenges, Canva. Okada (2024)

such as storms, floods, droughts and fires, which affect agriculture, vulnerable people, and educational systems. The AI provided support with insights into climate change effects across the economy, environment, society and education and ideas for structuring rich pictures, including open-licence icons (e.g. Freepik, Pixabay, Flaticon), in line with the themes identified by the participants. Claude was also used to describe the map *"This rich picture map provides a comprehensive overview of the complex and interconnected challenges facing society, ranging from educational, economic, and social issues to environmental and sustainability concerns. It serves as a visual representation of the diverse problems that need to be addressed for a sustainable and equitable future."*

5.10 Web Mapping

Web mapping is a technique for representing a network of elements and connections. In geography, Fish and Calvert (2016) present an analysis of interactive solar energy web maps for urban energy sustainability. These authors developed solar energy webmaps with recommendations to a broader range of stakeholders involved in urban energy sustainability (homeowners, utility operators, city officials, and urban planners). Maps and geographic information systems (GISs) have become vital tools for decision-making, communication, and outreach in the domain of urban energy sustainability.

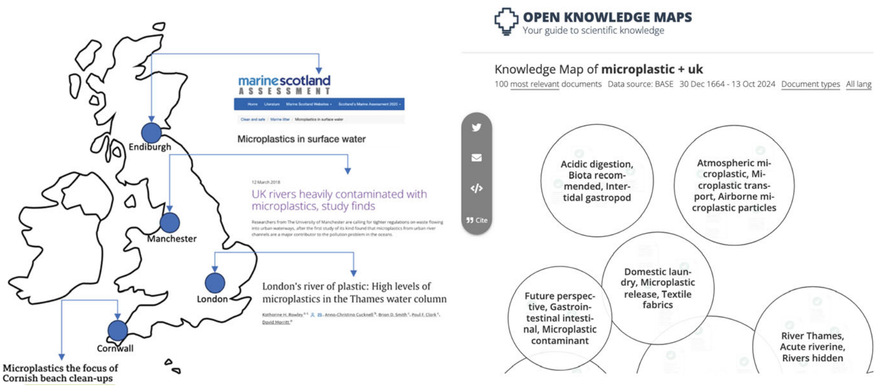
What is Web Mapping?

This technique aims to create visual representations of reference sources, navigation pathways, or interaction flows, all of which are enriched by hypermedia. They provide users with a sense of orientation and guidance within knowledge networks. Dodge and Kitchin (2001), along with Zeiliger et al. (2005), have highlighted the utility of web maps for systematising data, systematising information, and exchanging knowledge. With the rapid development of the web, digital applications, and web mapping, users can organise complex systems, structure connections, manage networks, and visualise growth. Web maps are viewed as essential tools for mapping informational territories and enhancing user experience by improving navigation, communication, and information representation.

As multimodal and AI-based environments, along with mixed realities, proliferate on the web, these emerging learning opportunities are key in helping students organise diverse information across vast, digitally immersive territories. The advantages of web maps are manifold. They assist users in organising data, bookmarking websites, and mapping essential web pages. They enable researchers to trace their inquiry paths, select semantically rich databases, plan studies, and streamline project production. By establishing connections between elements and clarifying key concepts, web maps enhance graphic visualisation, facilitate knowledge creation, and bring order to complex ideas.

How Can Web Mapping Be Used for Learning Supported by AI?

Map 5.10 displays two web map examples. The first, on the left, illustrates UK areas impacted by microplastic concentration, with data derived from the AI-powered TextoMap app and sources mapped by students. The second map showcases open access articles on microplastics collated using the AI Open Knowledge Map app. Microplastic pollution is a growing research area. Learners employed AI mapping tools to explore open access papers and articles in scientific databases. Useful tools to support webmapping:



Map 5.10 Web map of microplastics, TextoMap, OpenKnowledgeMap. Okada (2024). Open knowledge maps: (URL: https://openknowledgemaps.org/map/34bd00962c7bd0dba7ecb57b7d1c48f9%20%20https:/www.textomap.com/?MjE2OTswOzA7MA==)

1. Academic Search Engines: Google Scholar, Semantic Scholar, Scite, Elicit, Core, and Open Knowledge Maps.
2. Science-in-the-News: Science News, EurekAlert!, The Conversation.
3. Practices and Projects: Google Search, Worldwide Web (WWW).
4. Professional Networks: LinkedIn, Twitter, Facebook, Instagram.
5. Policy Reports: Government Websites and Think Tanks.
6. Academic Databases: JSTOR, ScienceDirect, CORE.
7. Translators: Google Translate, DeepL Translate, Microsoft Translator.
8. Proofreaders: Grammarly, ProWritingAid, Hemingway Editor.
9. AI Chatbots: Gemini (Google AI), GPT-3 (OpenAI), Claude (Anthropic), Perplexity.ai.
10. AI Illustrators: ChatGPT-4 (OpenAI), Leonardo.ai, Canva AI.
11. Data Repositories: Kaggle, Zenodo, Figshare.
12. Academic Social Networks: ResearchGate, Academia.edu, Mendeley.
13. Project Management Tools: Trello, Asana, Basecamp.
14. Reference Management Software: Zotero, EndNote, Mendeley.
15. Scientific Visualisation Tools: Tableau, Plotly, Gephi.

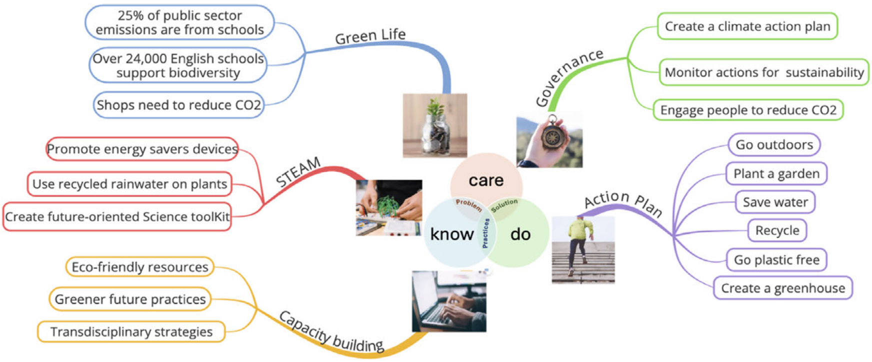
5.11 Mind Mapping

Mind map is a visual representation designed to generate ideas and connect various elements such as information, challenges, and solutions. In agriculture, Giraldo et al. (2023) applied this method to enhance the understanding and decision-making processes among farmers of maize, beans, and coffee. Their mind map meticulously detailed each decision, its timing, and the key climatic and non-climatic factors influencing these decisions. The mind map revealed critical factors such as water availability and land slope, which are impacted by climate and are crucial for developing effective climate services.

What is Mind Mapping?

Mind mapping was developed by psychologist Tony Buzan in the early 1970s. This technique enables creative, flexible, and nonlinear recording of thoughts, mirroring the way our minds work. Mind maps are frequently used to represent the thinking process in a non-sequential manner. By creating a mental map, learners can connect various pieces of information, symbols, and messages, aiding in the organisation of specific subjects and the generation of new content (Buzan 1993).

It also facilitates the transformation of abstract ideas into interconnected views. The structure of multiple connections simplifies the registration of various elements that emerge in the mind, often in an unconventional and chaotic manner. Consequently, mind maps help overcome the challenges of organising information and breaking free from the constraints of linear writing. The visual representation of mind maps not only facilitates the generation and articulation of new ideas but also aids in memorisation, reorganisation, and swift reconfiguration.



Map 5.11 Mind map of sustainable development in school, Taskade, Ayoa. Okada (2024)

Mind maps serve as visual graphics for recording data, multiple annotations, and key information. They enable the separation and integration of concepts, allowing for analysis and synthesis through a combination of images, words, colours, and arrows that help structure thought.

How Can Mind Mapping Be Used for Learning Supported by AI?

The Mind Map (Map 5.11) was drawn with teachers using the AYOA mind map tool for integrating the Sustainable Development Goals across the school. The AI tool Taskade was useful for providing ideas to develop a plan that was summarised by the group through CARE (problem, implication, needs), KNOW (concept, principles, references) and DO (solutions, strategies, practices). Eighteen subtopics were selected, discussed and voted. These areas were further summarised by participants into actionable proposals to initiate their projects in five areas.

AI was used for obtaining suggestions for evaluation (using ChatGPT-4) and references (with Perplexity.AI and Gemini) as follows. **According to ChatGPT4 three recommendations were provided**:

Comprehensiveness: *Include more specific educational outcomes or curricular integration points*

Relevance: *Link these sustainability efforts with global or national standards and frameworks (like SDGs)*

Practicality: *Provide concrete examples or case studies of schools that have successfully implemented these measures*

Perplexity.Ai suggested two references:

Birney et al. (2011). The journey of sustainable schools: developing and embedding sustainability—Inspiring leaders to improve children's lives

DCSF (2008). Planning a sustainable school: Driving school improvement through sustainable development

Gemini suggested five resources:

Department for Education (UK). (2023). Sustainability leadership and climate action plans in education

World Wildlife Fund (2023). Sustainability guide. https://www.wwf.org.uk/get-involved/schools/sustainability-guide

Eco-Schools. (2024). Eco-Schools. https://www.ecoschools.global/

Center for Green Schools. (2023). Planning a sustainable school. https://centerforgreenschools.org/

Highgate School. (2020). Environmental sustainability initial strategy plan. https://www.highgateschool.org.uk/about/sustainability-at-highgate-school/

5.12 Backcasting Mapping

Backcasting map is a visual representation for planning the steps needed to achieve a desirable future by identifying them from the end to the beginning, so that they can be implemented effectively from the present. In the context of urban planning, Svenfelt et al. (2011) applied backcasting map to explore how to achieve the national goal of reducing energy consumption in residential and commercial buildings by 50% by 2050. Their study contributes to technological forecasting and social change by focusing on strategies to meet this ambitious energy reduction target.

What is Backcasting?

Backcasting mapping is a strategic technique for identifying and implementing the necessary steps to achieve one or a set of goals. This retrospective approach is distinct from forecasting, which extrapolates future developments from current trends. In backcasting, planners start from a specified future point—be it six months, a year, or further ahead—and plan in reverse to pinpoint the actions to attain the desired state.

The concept of backcasting, which originated in future studies in the 1970s and was notably developed by figures such as John Robinson, gained prominence with the natural step (TNS) framework for sustainability. Backcasting facilitates creative and critical thinking, often through group workshops that include role-playing and brainstorming, to design sustainable pathways and strategic actions. It involves:

1. Setting a target date for the envisioned future scenario.
2. Imagining various potential futures and pathways to achieve these goals.
3. Assessing potential constraints and strategies to overcome them.

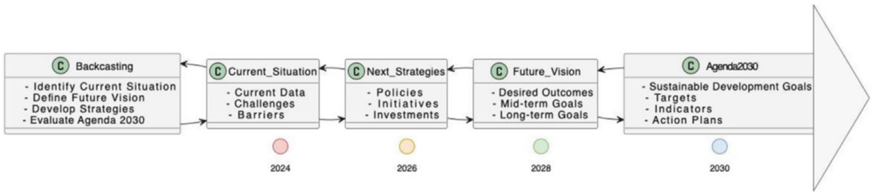
This technique, executed through collaborative creativity and critical evaluation, develops viable sustainable scenarios and actionable plans. Collective sessions are instrumental in forging consensus and fostering creativity to chart a course towards a sustainable future. Regular plan updates are advised to accommodate changing circumstances.

Working backwards, stakeholders critically assess various future scenarios, weighing their feasibility, costs, and benefits. This approach, comparable to planning a mountain ascent starting from the summit, allows for a comprehensive assessment of each necessary step. The most practical scenario is then chosen, and the planning proceeds analogously to forecasting but is oriented towards a defined goal. Backcasting is particularly effective in long-term planning for environmental policy, business sustainability, and any area requiring innovative approaches to realise ambitious objectives. It is a dynamic technique that is adapted regularly to mirror evolving conditions, enabling detailed consideration of the best route towards a preferred future.

How Can Backcasting Be Used for Learning Supported by AI?

Backcasting, as depicted in Map 5.12, was selected as a method to design an actionable plan supporting climate goals. Our aim was to create a generic map to enable secondary students to recreate their own 'backcasting' maps. This diagram outlines the stages, steps, and global strategies that serve as practical tools for learners to discuss and develop plans to achieve sustainable development objectives.

The stages include pinpointing the current situation, envisioning a future state, formulating strategies, and gauging progress in relation to Agenda 2030 goals. AI tools aided in brainstorming actions (ChatGPT), sourcing references (Perplexity, Claude), generating UML syntax (ChatGPT), and evaluating the maps (Claude). As students navigate each phase, they are encouraged to create prompts, check information with multiple sources, and consider the most relevant goals and specific actions that advance the broader aim of sustainability.



Map 5.12 Backcasting map for CO_2 reduction, App.diagrams.net app. Okada (2024)

The structured breakdown of this method and its clear procedural flow render backcasting an effective approach for setting and planning short-term, medium-term, and long-term targets based on the participants' views using content generated, checked, selected, and reorganised by the group. Claude.ai was also used to construct the BackcastingMap.

This image represents a backcasting map for CO_2 reduction. This planning approach starts with defining a desirable future state and then works backwards to identify the strategies and actions needed to achieve that future vision:

1. *Backcasting: This component outlines the four steps: identify the current situation, define the future vision, develop strategies, and evaluate the Agenda 2030 (the Sustainable Development Goals set by the United Nations)*

2. *Current_Situation (2024): This step involves analysing the current data, identifying challenges related to CO_2 reduction*

3. *Next_Strategies (2026): This step involves formulating policies, initiatives, and investments for CO_2 reduction*

4. *Future_Vision (2028): This step defines the desired outcomes, mid-term goals, and long-term goals for CO_2 reduction*

5. *Agenda2030 (2030): This refers to the culmination of the backcasting process where CO_2 reduction are established*

5.13 Multicriteria Analysis Mapping

Multicriteria analysis (MCA) map is a visual representation used to evaluate different alternatives for problem solving. In biotechnology, De Feo et al. (2023) utilised a multicriteria analysis map to assess the recycling of waste cooking oil for producing bioproducts. They specifically examined three pathways, namely, the production of biodiesel feedstock, the use of biolubricants, and the use of biosurfactants, to determine the most effective approach for this assessment.

What is MCA Mapping?

Multicriteria analysis mapping is a technique used to compare multiple options against a defined set of objectives, which are identified by decision-makers to serve as multicriteria for evaluation. MCA is invaluable for systematically managing complex information and can help in selecting the preferred policy option, ranking alternatives, shortlisting for detailed assessment, or separating acceptable from unacceptable choices.

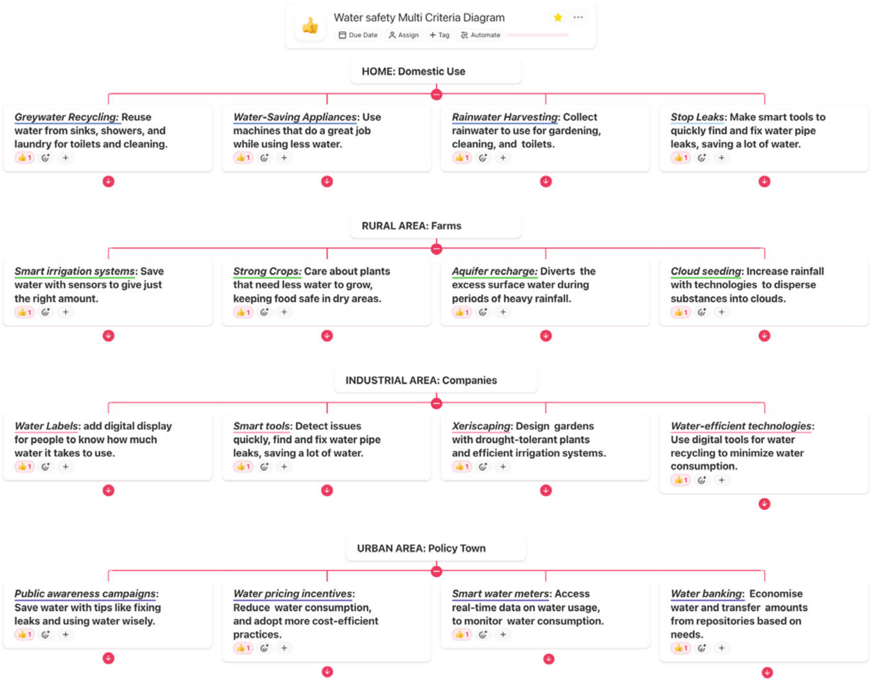
One of the simpler MCA techniques is the Kepner-Tregoe method (Kepner and Tregoe 1965; Renzi and Leali 2017), which is suitable for choosing from a limited set of options. The Kepner-Tregoe process involves the following:

1. **Developing Options**: Identifying options and evaluating them based on specific outcomes and attributes.
2. **Assigning Weights to Attributes**: Weighing each attribute (0–10) according to its importance.
3. **Scoring Attributes**: Rating each option against the attributes on a scale of 1–10 by a representative group.
4. **Calculating Weighted Scores**: Multiplying each option's score by the attribute's weight to obtain a total score.
5. **Initial Decision-Making**: The option with the highest total score is initially favoured.
6. **Considering Alternatives**: Adjusting scores and weights based on group consensus.
7. **Final Decision**: Finalising the decision after thorough discussion and ranking adjustment.

Collective discussion complements the ranking methodology, ensuring a participative decision-making process and encouraging ownership of the outcome. Across all MCA techniques, the crux lies in the judgement of the team, which includes defining objectives, assessing their significance, and evaluating how well each option meets the criteria.

How Can MCA Mapping Be Used for Learning Supported by AI?

Map 5.13 shows various strategies that can be used to manage water. Multicriteria analysis (MCA) can determine which of these strategies is the 'best' based on specific criteria such as cost, environmental impact, likelihood of success, and ease of implementation. Each criterion is ranked based on its relative importance, a personal decision determined by an individual's values. Each strategy is then scored based on how well it meets each criterion, and this score is multiplied by the rank of the criterion. Calculating the sum of these scores determines the 'best' strategy. AI can initially process vast amounts of data to identify key criteria and integrate information from various sources, helping participants prioritise actions according to their communities' priorities.



Map 5.13 Multi-criteria analysis map for water safety, Taskade. Okada (2024)

5.14 Multiple Cause Mapping

Multiple cause map also known as multiple cause diagram explores the complex interplay of factors within a system. Selman and Knight (2006) utilised this visual representation in a transdisciplinary study to articulate the dynamics of virtuous change in cultural landscapes through qualitative analysis. Similarly, Pendle (2013) employed these diagrams to investigate dynamics in estuarine and coastal sites undergoing managed realignment. Both studies highlight the value of these diagrams in visualising and understanding the intricate web of causes and effects, enhancing both forecasting and elucidation.

What is a Multiple Cause Diagram Mapping?

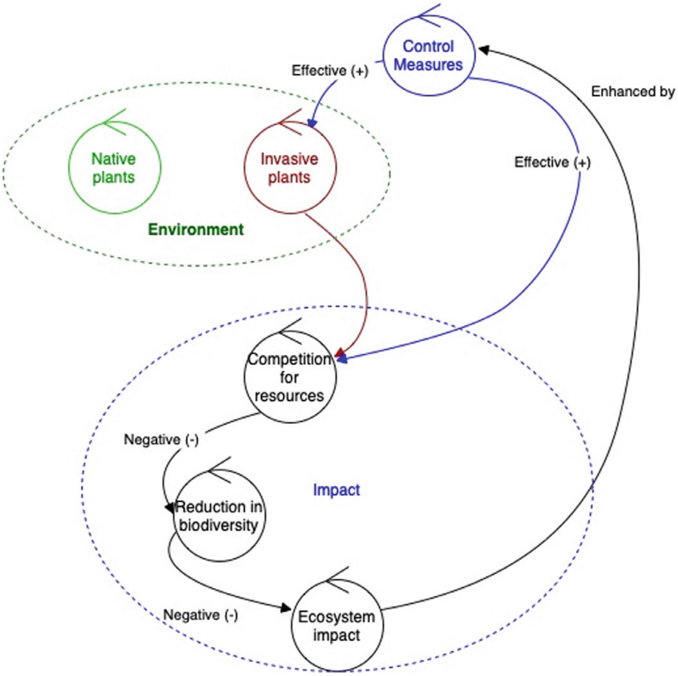
Multiple cause diagrams, similar to causal loop diagrams, are mapping techniques used in system dynamics to understand the nonlinear behaviour of complex systems over time. Unlike causal loop diagrams, which focus on predicting systemic growth, decline, or stability through feedback loops, multiple cause diagrams explore a broader range of direct and indirect factors leading to an effect. They are particularly useful for initial brainstorming and problem structuring, aiming to develop an understanding of how aspects of a situation might evolve. In contrast, causal loop diagrams are often employed to predict the behaviours of systems over time.

These tools trace their origins back to the work of Jay Wright Forrester at MIT in the 1960s, which laid the foundation for the field of system dynamics. These diagrams have been widely adopted across various domains, especially after the publication of ‘Limits to Growth’ by Donella Meadows, Dennis Meadows, Jørgen Randers, and William W. Behrens III, which applied system dynamics to global ecological and economic trends. These diagrams have also been utilised in epidemiological studies and public health research, such as during pandemics, to understand virus transmission, identify potential sources of transmission, model the impact of public health measures, and assess the effectiveness of vaccination campaigns. These visualisations are crucial for communicating findings and informing public health decisions.

A multiple cause map consists of keywords, circles, and labelled arrows, with each arrow representing a causal relationship, indicated by phrases such as [phrase at the tail of the arrow] causes/affects/leads to [phrase at the head of the arrow]. The diagram’s primary purpose is to reveal causal relationships among elements, investigating the underlying reasons or recurring patterns of events and states. This makes it an invaluable tool for uncovering the root causes of problems and identifying potential points for intervention. Such maps are instrumental in analysing events and conditions, answering questions such as ‘Why did a river flood?’ and ‘Why are roads always so congested?

How Can Multiple Cause Diagrams Be Used for Learning Supported by AI?

The multiple cause Map 5.14 was used to analyse the environmental impacts of introducing invasive plants. This diagram illustrates how invasive plants compete with native flora for resources, thereby reducing biodiversity and negatively affecting the ecosystem. It also highlights how effective control measures can mitigate these impacts. Students in fields such as geography, science, and history can use these diagrams to explore interdisciplinary connections among various variables or events. AI can support students in refining this analytical process by analysing large datasets to identify and recommend relevant variables and their interconnections, which are crucial for constructing precise multiple cause diagrams. Machine learning algorithms can detect complex patterns and relationships that might not be immediately apparent to human analysts. AI-powered mapping tools provide instant feedback on the logic and coherence of diagrams, enabling students to learn and refine their understanding in real time. Additionally, AI integrates various forms of data—quantitative, qualitative, and textual—into a coherent structure within a multiple cause diagram, thereby enhancing the educational value of the analysis, with support from educators in the field. To assess the accuracy of the map, participants can discuss it with experts and validate its relevance to their communities.



Map 5.14 Multiple cause map of invasive plants, App.diagrams.net. Okada (2024)

5.15 Causal Loop Diagram Mapping

Causal loop maps also known as causal loop diagrams are commonly used to understand the interactions and feedback loops among variables within a system. Gaertner et al. (2014) utilised this approach in biology to study the systemic impacts of invasive plant species. Their research highlights how causal loop maps can elucidate the complex relationships between ecological variables and the introduction of invasive flora.

What is Causal Loop Diagram Mapping?

Causal loop mapping is a technique used to elucidate complex systems, particularly in the realm of system dynamics modelling. First introduced by Meadows and colleagues in the 1970s, the technique has become a cornerstone in systems thinking and modelling.

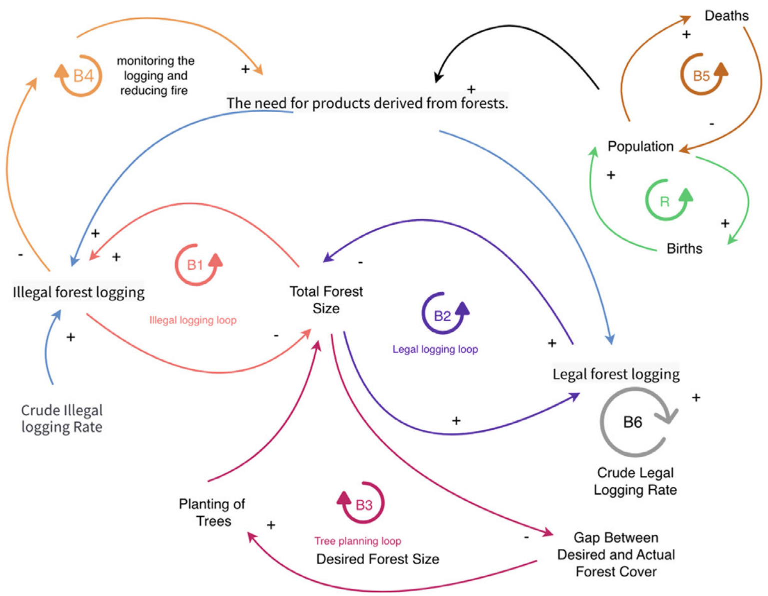
Causal loop mapping depicts feedback relationships among system components using arrows to connect key variables. This technique is instrumental in analysing and understanding how variables interrelate, including the positive and negative feedback loops that dictate system behaviour. Causal loop diagrams are pivotal for evaluating the effects of changes and interventions within systems and form the basis for quantitative modelling. They provide a graphical representation of the causal connections between components, facilitating the comprehension of complex systems, their feedback mechanisms, and the influence of various interventions. This mapping technique is especially useful in instances where cause-and-effect relationships are not immediately discernible.

The components of causal loop maps include the following:

1. Variables are represented by phrases linked by arrows marked with plus or minus signs.
2. The depiction of variables should avoid vagueness.
3. A minus sign indicates that a change in one variable leads to an opposite change in another, signifying negative feedback. Conversely, a plus sign denotes that changes in the connected variables move in the same direction, representing positive feedback.
4. While system boundaries can be delineated, they are sometimes omitted to maintain the simplicity of the diagram.

How Can Causal Loop Mapping Be Used for Learning Supported by AI?

The causal loop Map 5.15 shows the impacts of invasive plants on forest size. This model considers variables such as the need for forest-derived products, logging (legal and illegal), and tree planting. Loops illustrate how positive and negative feedback



Map 5.15 Causal cycle map on the effects of deforestation, the online visual paradigm. Okada (2024)

affect these variables and, consequently, the total forest size. Developed by students, this map can be discussed with professionals such as forest engineers, enterprises, and policymakers.

AI can enhance causal loop mapping projects in several ways. It assists in gathering and analysing data to identify key variables and uses pattern recognition to uncover complex relationships within the system. AI-driven simulations enable students to model scenarios and evaluate potential interventions. Collaborative AI tools facilitate real-time teamwork, even across different locations. Additionally, AI can search for educational resources and synthesise qualitative data into quantifiable elements for their diagrams. Discussions with experts about these applications allow students to develop more accurate models and gain deeper insights into system dynamics.

5.16 Strategic Environmental Assessment Mapping

Strategic environmental assessment (SEA) map is also known as a diagram that evaluates the environmental implications of planned policies, programmes, or projects. In the realm of environmental policy, the Welsh Government (Maloney 2019) implemented SEA to assess the risks associated with flood and coastal erosion management. This assessment map proved valuable for identifying and analysing the potential impacts of environmental risks on biodiversity.

What is SEA Mapping?

SEA mapping is a proactive technique used to evaluate the potential environmental effects of proposed actions, such as policies, plans, programmes, and projects, before their implementation. When applied by various levels of government and across sectors such as transportation, energy, and urban development, SEA aims to embed environmental considerations into decision-making, making sustainability and environmental protection fundamental to planning processes.

The genesis of SEA is linked to the growing environmental consciousness of the 1970s, sparked partly by Rachel Carson's influential book 'Silent Spring' in 1962. The subsequent dialogue on the environmental impact of technology paved the way for the development of environmental evaluation methods. While the SEA technique arose in the 1970s, it was not until the 1990s that it was recognised as essential for sustainable planning and environmental governance.

The SEA employs a structured methodology with key steps: defining the assessment's purpose and scope; engaging stakeholders; collecting baseline data; evaluating impacts; examining alternatives; proposing mitigation and enhancement measures; conducting reporting and quality assurance reviews; making decisions; performing monitoring and follow-up; and finally, compiling and writing the report. The SEA map can be useful in various scenarios:

- **Environmental Protection**: It anticipates and prevents adverse environmental impacts.

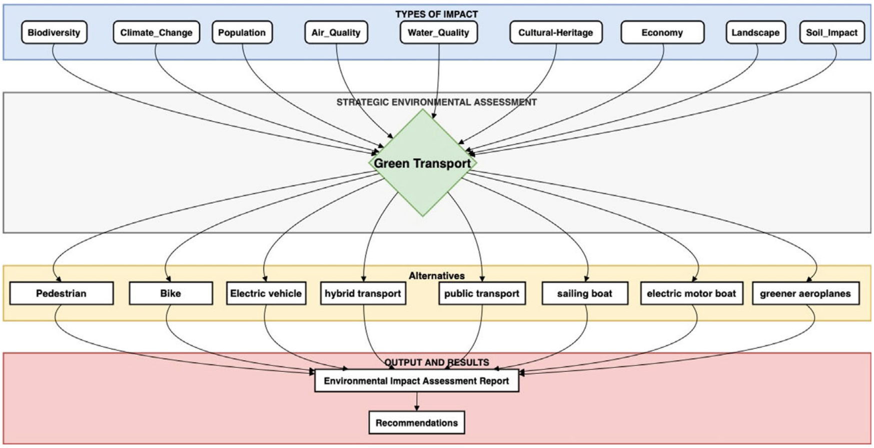
- **Integration**: SEA ensures that environmental considerations are integral to strategic planning and decision-making.
- **Sustainability**: Sustainable development can be supported by balancing environmental, economic, and social factors.
- **Public Participation**: By involving the public, SEA enhances transparency and accountability in planning.
- **Legal Compliance**: SEA has been incorporated into various legal frameworks as a policy requirement.

How Can SEA Mapping Be Used for Learning Supported by AI?

Map 5.16 illustrates the steps involved in performing SEA mapping for green transportation initiatives. The map details various components, starting with an assessment of the potential environmental impacts of different green transport options, such as hybrid and electric vehicles. Students discuss and expand the map with their families and then brainstorm ideas on the environmental implications with educators and researchers, covering areas such as biodiversity and climate change. AI tools can be employed to streamline the SEA map and enhance the clarity of the accompanying report, which outlines key findings and recommendations.

Creating and analysing this SEA map serves as an educational tool for developing research and innovation skills across several contexts:

- Formulating or revising policies, laws, and regulations at local, regional, or national levels.
- Designing infrastructure projects, including urban development, transportation networks, and energy programmes.
- Engaging in international agreements that entail environmental considerations.



Map 5.16 SEA map for green transport, App.diagrams.net. Okada (2024)

- Employing a programmatic approach to tackle complex and interrelated environmental issues.
- Managing significant projects with notable potential environmental impacts.

5.17 Monitoring and Evaluation Mapping

Monitoring and evaluation (M&E) map is a visual representation that combines strategic mapping with rigorous planning and assessment to enhance outcomes and facilitate continuous improvement. In the health sector, the Global Youth Network (GYN) and the World Health Organization (WHO) developed a report for the United Nations in 2016, including IOM (2021). This report outlines a structured M&E map for assessing youth substance abuse prevention programmes. Adopted by the United Nations, this framework has been effective in evaluating health and education initiatives targeting youth.

What is Monitoring and Evaluation Mapping?

M&E mapping is a vital technique for project management and data analysis and is employed to evaluate the performance of proposals, policies, programmes, and organisations. It draws from a variety of approaches that have evolved over time. For instance, the programme evaluation and review technique (PERT) and the critical path method (CPM), both devised in the 1950s, are foundational project management tools that introduce the use of flowcharts and diagrams to oversee project tasks.

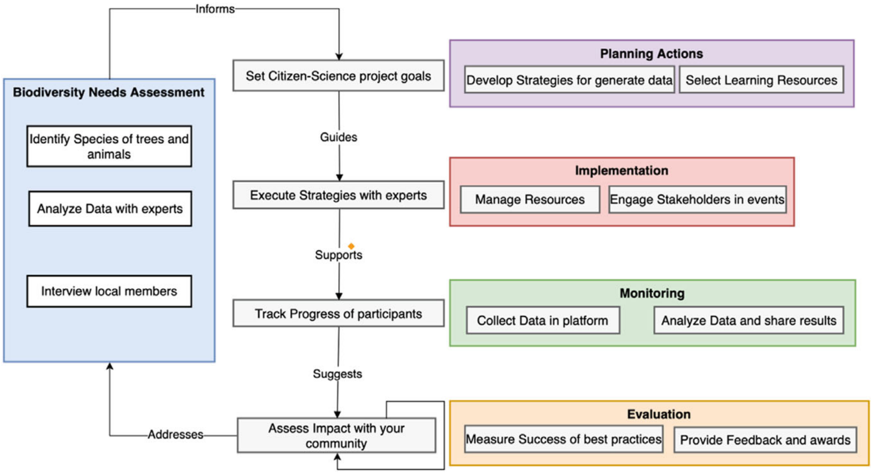
Evaluation focuses on determining whether a project has met its predefined objectives. Thus, establishing clear and relevant objectives is crucial, as it simplifies the assessment process and aids in measuring success. Crafting these objectives is often a complex task, especially in project-based learning or project research management, requiring careful and thoughtful analysis.

The field of M&E is dynamic, with its techniques continually refined by contributions from diverse individuals and organisations. International bodies, such as the United Nations and specialised agencies such as the WHO, the WFP, and the IMF, have been instrumental in progressing M&E methods, particularly within international development and humanitarian work. These organisations have developed unique M&E frameworks suited to their operational needs.

Simultaneously, influential entities such as USAID and the World Bank have significantly influenced M&E practices, especially in international development. They have established stringent methodologies, standards, and best practices that are critical for assessing the impact and effectiveness of development initiatives.

How Can M&E Mapping Be Used for Learning Supported by AI?

Map 5.17 describes monitoring and evaluation (M&E) mapping for a citizen science biodiversity project, encapsulating a cyclical, five-stage process: needs assessment, planning actions, implementation, monitoring, and evaluation. This map was created by a group of educators and researchers.



Map 5.17 M&E map on citizen science, App.diagrams.net. Okada (2024)

Initially, Biodiversity Needs Assessment involved identifying species and analysing data with experts, complemented by local interviews. The insights gathered inform the planning actions, where project goals are set, strategies for data generation are developed, and educational resources are selected. The implementation phase includes resource management and stakeholder engagement. Progress is systematically monitored, participation is tracked, data are collected and analysed, and findings are disseminated.

In the evaluation stage, the project's impact and efficacy are measured, providing feedback and recognising achievements. AI can support students in the evaluation phase by synthesising content and analysing feedback to inform the monitoring process. Ongoing evaluation ensures the project's adaptability and continuous growth.

5.18 System Dynamics Diagram Mapping

System dynamics map, also known as system dynamics diagram, is useful for structuring the components and factors of a system. In agriculture, a research project was developed by Saysel et al. (2002) about environmental sustainability using the system dynamics approach. The authors found that system dynamics maps played a crucial role in problem solving for regional agricultural projects based on water resource development. This approach enabled a holistic analysis of complex systems, policy testing, and identification of strategies for long-term sustainability while also offering the potential for broader applications in similar contexts.

What System Dynamics Diagram Mapping?

System dynamics mapping is a technique for understanding and evaluating complex systems that was developed by Jay W. Forrester in the 1950s and notably applied in the 1972 "Limits to Growth" study by the Club of Rome. The technique involves the following steps:

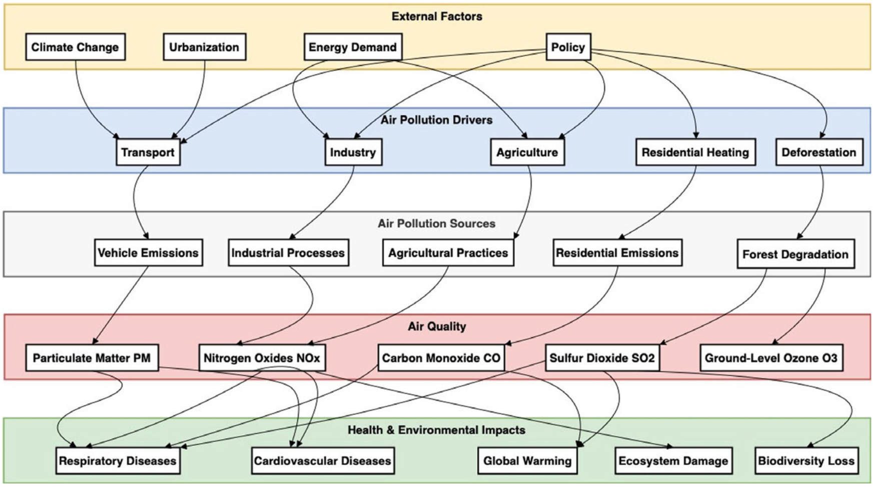
1. **Diagram creation**: Constructing a visual representation of the system, including measurable aspects and influencing factors.
2. **Data Gathering**: Collecting relevant data, using estimations if necessary, and experimenting with different values to observe effects.
3. **Defining Relationships**: Writing equations that describe the interactions between system variables.
4. **Programming**: Implementing system dynamics algorithms in software tools.
5. **Model Runs**: Using the model to produce outputs that track changes over time and space.
6. **Verification and Validation**: Ensuring that the model accurately represents system relationships and comparing outputs with real-world data for reliability.
7. **Option Exploration**: Simulating different decisions with the model to identify optimal strategies.
8. **Monitoring and Revision**: Aligning model predictions with real-world outcomes and revising accordingly

System dynamics maps are used for the following:

- Studying situations that are dynamically complex and involve feedback processes and unforeseen consequences.
- Representing quantifiable situations using numerical variables.
- Diagnosing problems.
- Identifying their underlying causes.
- Uncovering the long-term impacts of decisions and policies.
- Assessing the effectiveness of different solutions.

How Can System Dynamics Mapping Be Used for Learning Supported by AI?

Map 5.18, crafted by educators and researchers with the aid of AI and scientific references, illustrated a system dynamics map of the effects of air pollution. This system dynamics diagram serves as a foundational tool for students, who can localise and enrich it with additional connections to explore air pollution mechanisms specific to their own towns or villages. AI can augment this map by integrating large sets of real-time data, facilitating a deeper analysis. Subsequently, experts can provide feedback to refine the map and recommend strategies that could effectively reduce air pollution, thereby addressing health and environmental concerns.



Map 5.18 System dynamics map of air pollution, app.diagrams.net. Okada (2024)

5.19 System Thinking Mapping

System thinking map is a visual representation for systematically developing reasoning. In urban studies, Rehman et al. (2019) developed a research project on applying systems thinking to flood disaster management for sustainable development and risk reduction. Their system thinking map highlights climate change systems and interventions.

What is System Thinking Mapping?

Systems thinking mapping is an analytical technique that examines how parts of a system interrelate within larger contexts over time. This approach applied in various fields, such as biology, engineering, social science and business explores complex issues by analysing the relationships between system components rather than viewing them in isolation.

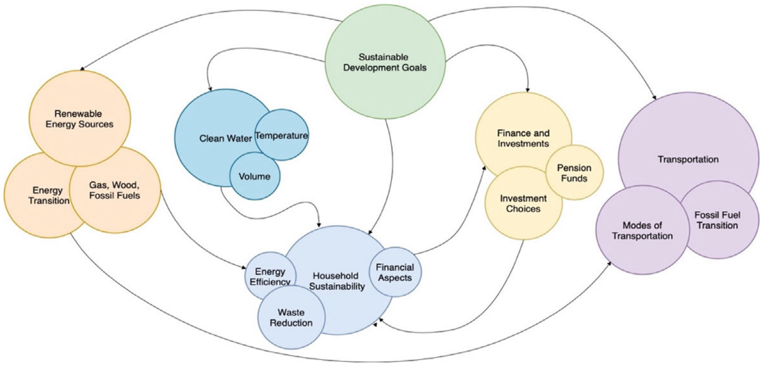
The roots of systems thinking are found in Ludwig von Bertalanffy's General System Theory in the 1930s and further shaped by Norbert Wiener's cybernetics in the mid-twentieth century. The visualisation of complex systems through diagrams gained traction with Jay Wright Forrester's system dynamics work at MIT in the 1950s.

Systems map typically includes the following:

1. Figures: shapes representing elements within the system or environment.
2. Words: labels identifying each system component.
3. Title: a succinct description of the system's map.

Systems maps are valuable for:

- Clarifying the initial analysis, offering a clearer view of complex situations.
- Assisting structural planning for detailed diagrams and comprehensive understanding.



Map 5.19 Systems thinking on sustainability, App.diagrams.net. Okada (2024)

- Experimenting with boundaries to determine the scope of the analysis.
- Focusing on the relevant aspects of the system.
- Communicating complex structures visually and effectively.

How Can System Thinking Mapping Be Used for Learning Supported by AI?

Map 5.19 demonstrates how a systems thinking map can effectively illustrate the complex interactions among various components related to sustainable development goals, such as clean water, energy, household sustainability, finance, and transportation, aligning with Agenda 2030. This map incorporates a wide range of aspects and components and serves as a tool for students to engage in discussions with families, teachers, and scientists. AI can further enhance this tool by expanding its scope with insights, references and strategies, including external factors such as government policies, technological advancements, and public awareness that can support the SDGs. Additionally, citizen consultations can be utilised to refine the map, clarify desired outcomes, and develop a comprehensive action plan.

Reflective Remarks

This chapter examined 19 mapping techniques to support socioscientific skills and considered scenarios for applying these techniques and AI tools in real-world contexts

Action Points: Use the examples provided to select issues, techniques, skills, and AI tools based on your interests

Next chapter will delve into the use of CARE-KNOW-DO resources in open schooling, exploring activities involving a combined set of mapping techniques and AI tools, and participant feedback to assess benefits and challenges

Question: How can mapping techniques and AI Apps be combined to address real-life sustainability issues in open schooling contexts?

References

Birney A, Kellard B, Reed J (2011) The journey of sustainable schools: developing and embedding sustainability - Inspiring leaders to improve children's lives

Buzan T (1993) The mind map book. BBC worldwide, London

Carr CS (2003) Using computer supported argument visualization to teach legal argumentation. Visualizing argumentation: software tools for collaborative and educational sense-making. Springer, London, London, pp 75–96

Chambers R (1988) Direct matrix ranking (DMR) in Kenya and West Bengal. URL https://opendocs.ids.ac.uk/opendocs/bitstream/handle/20.500.12413/326/rc50.pdf?sequence=1

Checkland P, Poulter J (2020) Soft systems methodology. In: Systems approaches to making change: a practical guide, pp 201–253

De Feo G, Ferrara C, Giordano L, Osseo LS (2023) Assessment of three recycling pathways for waste cooking oil as feedstock in the production of biodiesel, biolubricant, and biosurfactant: a multi-criteria decision analysis approach. https://www.mdpi.com/2313-4321/8/4/64

Dodge M, Kitchin R (2001) Mapping cyberspace. Routledge, London

Edmondson KM (1995) Concept Mapping for the development of medical curricula. J Res Sci Teach 32(7):777–793

Eftekhari M, Sotoudehnama E, Marandi SS (2016) Computer-aided argument mapping in an EFL setting: does technology precede traditional paper and pencil approach in developing critical thinking? Education Tech Research Dev 64:339–357

Eggert S, Nitsch A., Boone WJ, Nückles M, Bögeholz S (2017) Supporting students' learning and socioscientific reasoning about climate change—the effect of computer-based concept mapping scaffolds. Res Sci Educ 47:137–159. https://www.researchgate.net/publication/289694380_Supporting_Students'_Learning_and_Socioscientific_Reasoning_About_Climate_Change-the_Effect_of_Computer-Based_Concept_Mapping_Scaffolds

Ellegård K, Palm J (2011) Visualising energy consumption activities as a tool for making everyday life more sustainable. Appl Energy 88(5):1920–1926

Fish CS, Calvert K (2016) An analysis of interactive solar energy web maps for urban energy sustainability. Cartographic Perspect 85:5–22

Gaertner M, Biggs R, Te Beest M, Hui C, Molofsky J, Richardson DM (2014) Invasive plants as drivers of regime shifts: identifying high-priority invaders that alter feedback relationships. Divers Distrib 20(7):733–744

Giraldo D, Clarkson G, Dorward P, Obando D, Ramirez-Villegas J (2023) The development of a farmer decision-making mind map to inform climate services in Central America. Front Clim 5

Hicks-Moore, Sandee L, Pastirik PJ (2006) Evaluating critical thinking in clinical concept maps: a pilot study. Int J Nurs Educ Scholarship 3(1), Article 27

IOM (2021) IOM monitoring and evaluation guidelines—Chapter 1. Int Org Migr. https://publications.iom.int/system/files/pdf/IOM-Monitoring-and-Evaluation-Guidelines-Chapter-1_1.pdf

Jain DR, Dilkina B, Fujimoto R (2016) An approach to integrate interdependent simulations using HLA with applications to sustainable urban development. In: 2016 winter simulation conference (WSC), Washington, DC, USA, 2016, pp 1218–1229. https://doi.org/10.1109/WSC.2016.7822178

Kepner CH, Tregoe BB (1965) The rational manager: a systemic approach to problem solving and decision making. McGraw-Hill Book Company

Kirschner P, Buckingham Shum S, Carr C (Orgs) (2003) Visualising argumentation: software tools for collaborative and educational sense-making. London Springer-Verlag

Maloney J (2019) Strategic environmental assessment environmental report flood and coastal erosion risk management: development of a national strategy for wales. https://www.gov.wales/sites/default/files/consultations/2019-06/strategic-environmental-assessment-environmental-report.pdf

Mikučionienė R, Martinaitis V, Keras E (2014) Evaluation of energy efficiency measures sustainability by decision tree method. Energy Build 76:64–71. https://www.sciencedirect.com/science/article/abs/pii/S0378778814001625

Novak J (1998) Learning creating and using knowledge: concepts maps as facilitative tools in schools and corporations. Lawrence Erlbaum Associates Mahwah, London

Okada A (2006) Cartografia Investigativa: interfaces epistemologicas comunicacionais para mapear conhecimento em projetos de pesquisa (Investigative Cartography: Epistemological and communicational interfaces to map knowledge in research projects). Pontifícia Universidade Católica de São Paulo. URL https://tede2.pucsp.br/handle/handle/9889

Okada A, Buckingham Shum S, Sherborne T (eds) (2014) Knowledge cartography: software tools and mapping techniques (2nd ed). Advanced Information and Knowledge Processing. London: Springer

Okada A, Okada A, Muller R, Moura R, Castro T, Ferreira L, Oliveira E, Vaz G, Benaian R, Castro S, Almeida J (2023) Open schooling in the amazon for community empowerment: a case study in the TUPÉ sustainable development reserve

Okada, A. (2024). Knowledge Cartography for Young Thinkers: Sustainability Issues, Mapping Techniques, and AI Tools. Figures. The Open University. CCBY. https://doi.org/10.21954/ou.rd.27963327

Pendle M (2013) Estuarine and coastal managed realignment sites in England-A comparison of predictions with monitoring results for selected case studies. https://www.researchgate.net/publication/265048794_Estuarine_and_coastal_managed_realignment_sites_in_the_UK_A_comparison_of_predictions_with_monitoring_results_for_selected_case_studies

Rehman J, Sohaib O, Asif M, Pradhan B (2019) Applying systems thinking to flood disaster management for a sustainable development. Int J Disaster Risk Reduction 36:101101. https://www.sciencedirect.com/science/article/pii/S2212420918309804?casa_token=GlDfYtV_MA8AAAAA:vAOC_7Uzv8Df8AUUA3TBqhnLRf-pPrs3K-272dS68_kS9x5Y-zcjG_pp4p5oALfOXLvfnDO9pmw

Renzi C, Leali F (2017) Decision-making methods in engineering design: a designer-oriented approach. Dirección y Organización, 63:21–49. https://iris.unimore.it/retrieve/e31e124d-3f3e-987f-e053-3705fe0a095a/513-1050-1-SM%20%281%29.pdf

Rider Y, Thomason N (2014) Cognitive and pedagogical benefits of argument mapping: L.A.M.P. Guides the way to better thinking. In: Okada A, Buckingham Shum S, Sherborne T (eds) Knowledge cartography: software tools and mapping technique. Springer, London

Rowe G, Reed C (2008) Argument diagramming: the araucaria project. Knowl Cartograp: Softw Tools Map Tech 164–181

Saysel AK, Barlas Y, Yenigün O (2002) Environmental sustainability in an agricultural development project: a system dynamics approach. J Environ Manage 64(3):247–260

Selman P, Knight M (2006) On the nature of virtuous change in cultural landscapes: exploring sustainability through qualitative models. Landsc Res 31(3):295–307

Sierhuis M, Shum SJB (2014) Human-agent knowledge cartography for e-science: NASA field trials at the Mars Desert Research Station. In: Knowledge cartography: software tools and mapping techniques, pp 381–399

Svenfelt Å, Engström R, Svane Ö (2011) Decreasing energy use in buildings by 50% by 2050—a backcasting study using stakeholder groups. Technol Forecast Soc Change 78(5):785–796. https://www.sciencedirect.com/science/article/abs/pii/S004016251000209X

Van Gelder TJ, Bissett M, Cumming G (2004) Cultivating expertise in informal reasoning. Can J Exp Psychol 58:142–152

Wang Y, Touboulic A, O'Neill M (2018) An exploration of solutions for improving access to affordable fresh food with disadvantaged Welsh communities. Euro J Operation Res 268(3):1021–1039.https://doi.org/10.1016/j.ejor.2017.11.065

Welsh Government (2020) Strategic environmental assessment: environmental report flood and coastal erosion risk management: development of a national strategy for wales https://www.gov.wales/sites/default/files/publications/2020-10/strategic-environmental-assessment-flood-and-coastal-erosion-risk-management-national-strategy-for-wales.pdf

Wolditsadik M (2018) Ethnobotanical study of traditional medicinal plants in Adami Tulu Jido Kombolcha district, Oromia, Ethiopia (Doctoral dissertation, M. Sc. Thesis, Haramaya Univarsity). https://www.researchgate.net/publication/331981089

Zeiliger R, Esnault LE, Ponti M (2005) Constructing knowledge as a system of relations. In: Proceedings of the IRMA international conference, San Diego, May 15–18, 2005, USA

Zhang J, Tao D, "Agency to Transform: How Did a Grade 5 Community Co-Configure Dynamic Knowledge Building Practices in a Yearlong Science Inquiry?" (2021). Educational Theory and Practice Faculty Scholarship. 39. https://scholarsarchive.library.albany.edu/etap_fac_scholar/39

Chapter 6
Case Studies of Knowledge Maps

Abstract The chapter six presents three learning objectives:

1. Understand how mapping techniques can be combined and applied in open schooling contexts, especially in addressing real-life sustainability issues supported by the CARE-KNOW-DO principles.
2. Explore the various activities and mapping techniques, including the use of AI tools and AI assistant apps, utilised by teachers, students, and community members in these case studies.
3. Evaluate feedback from participants to discern the benefits and challenges of these approaches, and discuss how they can transform teaching, research, and learning practices.

Keywords CARE-KNOW-DO · Open schooling · Biodiversity · Energy · Microplastic · Carbon neutral

This chapter presents three case studies (Map 6.1) using 4 scenarios from the CONNECT project that were selected to demonstrate a variety of issues, techniques, and tools within the CARE-KNOW-DO framework in education for sustainability. A new approach in these multiple case studies is to explore “an integrated set” of cartography techniques for students to develop problem-solving skills and become aware of the advantages and limitations of AI in knowledge mapping. School educators have utilised a range of open schooling resources related to sustainable development goals. The resources suggest a variety of participatory methods for problem-solving or decision-making aligned with curriculum objectives and time available from short activities such as family discussions, school debates, and expert interviews to moderate activities such as citizen consultation, school projects, and community deliberation, among others. Some of these resources suggest mapping techniques proposed by the CONNECT team or created by teachers incorporating AI.

A. Okada, *Knowledge Cartography for Young Thinkers*, SpringerBriefs in Advanced Information and Knowledge Processing, https://doi.org/10.1007/978-3-031-54677-8_6

Map 6.1 Case studies: principles, techniques, and applications. Okada (2024)

SDG	Resource (URL)	Video (URL)	Scientists interview	Roles of students
C1: SDG-15 	Life on Land	Rewilding	Dr. Lawrence Ball	Urban forest policymakers
C2: SDG-13 	Climate Action	CO2 neutral	Prof. N. Shah	Green scientists
C2: SDG-07 	Clean energy	Energy savers	Prof. N. Eyre	Energy efficiency marketing experts
C3: SDG-15 	Life below water	Microplastics	Prof. R. Thompson	Micropastics filter entrepreneurs

The examples discussed in this chapter were supported by the author and developed with groups of teachers-educators, teachers-parents, students, and researchers who were interested and available to participate in a pilot study.

We employed qualitative and quantitative evaluation instruments, templates, and protocols approved by the ethics committee of the CONNECT project. Our participatory approach using observation notes, activity descriptions, and semistructured self-report questionnaires allowed participants—learners and formal, non-formal, and informal educators—to document their learning outcomes and challenges as well as their views about their learning gains.

CONNECT participants also discussed the principles of human-centred AI (HCAI) underpinned by CARE-KNOW-DO. CARE emphasises collaborative learning with real-life issues that involve uncertainties and require ethical oversight. KNOW promotes critical discussions on concepts, principles and human values.

DO supports reflection in and on actions enhanced by continuous feedback, including mechanisms to align AI applications with educational goals and ethical standards.

The studies were supported by informed consent adapted to young students, including awareness and discussion of five principles:

- **Ethics**: Defines norms for the responsible use of AI, aiming for fair and moral decisions.
- **Accountability**: Ensures that users and developers are responsible for safe and beneficial actions and outcomes.
- **Transparency**: Promotes clarity on how AI makes decisions, including the disclosure of processes and data.

- **Fairness**: Ensures that AI treats everyone fairly, avoiding biases and discrimination.
- **Respect**: Protects the privacy, rights, and dignity of all individuals.

6.1 Protecting Life on Land: Rewilding

Case Study Information
Participants:

Students: Aged 11–13, year 7 and year 8, lower secondary schools

Teacher: Biology

Expert partners: Science curriculum designer and the author

Activity/action: Students were invited to design a poster for a campaign to be distributed in their national wildlife park

Curriculum topics: Interdependence, food webs, environmental issues, human activities

Mapping techniques: Inquiry map, concept map, argument map, and multi-criteria map

Societal Challenge: What are the potential threats to nature reserves, and what strategies can be implemented to safeguard ecosystems in national parks, forests, and other green landscapes?

References for Case Study 1 Rewilding

Okada, Alexandra; Sherborne, Antony; Young, Gemma (2024). Rewilding Open Schooling Resource related to SDG 15 for teachers, students, scientists and families. The Open University. Media. https://doi.org/10.21954/ou.rd.25765434.v1

Found by Perplexity. AI:

Rewilding Britain. (2022). *Rewilding and Climate Change* https://www.rewildingbritain.org.uk/why-rewild/what-is-rewilding.

As indicated by ChatGPT-4:

Kimbrought, L. (2023) Rewilding animals could be key for climate: Report. Mongabay Blog https://news.mongabay.com/2023/03/rewilding-animals-could-be-key-for-climate-report/

Found by Gemini:

Rewilding Europe (n.d.) Our Story – Making Europe a Wilder Place. https://rewildingeurope.com/our-story/

As mentioned by Claude AI:

Allen, D., Blythe C. (2023) Rewilding Argentina's Ibera Wetlands. https://geographical.co.uk/wildlife/rewilding-argentinas-ibera-wetlands

Okada, A., Sherborne, T., Panselinas, G., & Kolionis, G. (2024, under review). AI in Education: A Cross-National Study of Open Schooling Using the CARE-KNOW-DO Framework for Sustainable Development Goals.

Care (Skill: Problematise)

1. Mind Map

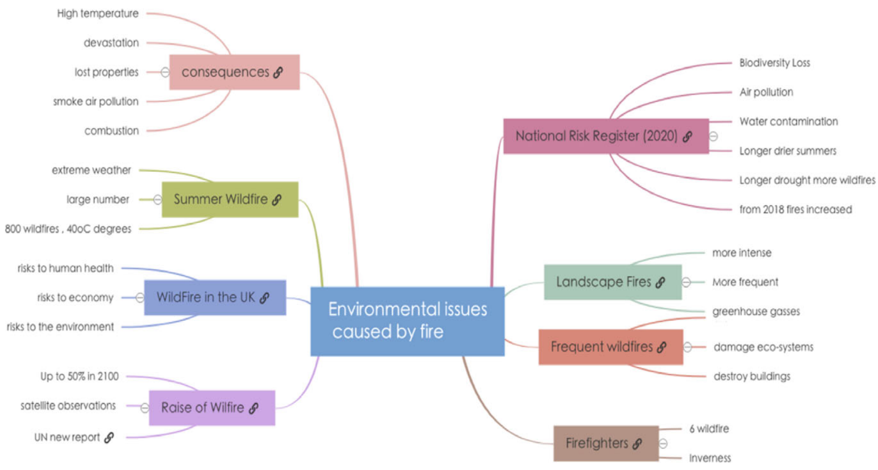
This activity introduced a significant societal challenge for environmental protection. Teachers noted the topic's appeal to young people due to its connection with their personal experiences in green areas, national parks, and wild landscapes, sparking their curiosity and fostering emotional engagement. To further increase their curiosity, students discussed the role of trees in mitigating climate change impacts and reflected on environmental issues such as deforestation and wildfires, which reduce large green areas. The initial task was to contribute to a mind map and brainstorming ideas, including questions and information about forest fires.

How Was the Mind Mapping Developed by Participants?

The class began with the teacher initiating a conversation on the pressing matter of ecosystem destruction. This conversation served to actively engage students and piqued their own interest, indicating readiness to explore the subject more deeply. Participants shared several questions as follows.

- What are the consequences of climate change and temperature fluctuations on flora and fauna?
- How have human activities, such as deforestation, impacted green areas?
- How do wildfires, erosion, floods, and droughts affect national parks?
- What specific environmental issues arise from wildfires?
- What are the national parks near us?

Map 6.2 was initiated with a tittle in the centre and eight subtitles. Each of them linked to an article selected by the teacher found with the support of AI Perplexity, with the aim for students to search for information related to one of their questions. The activity was to explore the links in pairs and expand the map with key information about the source. The eight pairs of students collaboratively expanded the mind map. They summarised the central points into keywords that succinctly articulated the specifics of their respective subthemes. For instance, the pair that focused on 'the rise of wildfires' incorporated projections stating, 'up to 50% increase by 2100', citing 'satellite data' and a 'UN new report' as evidence for their findings. AI was helpful in finding interesting web articles and science-in-the-news online for youth.



Map 6.2 Rewilding case: mind map of challenges, MindonMap. Okada (2024)

The Mind Map: Environmental Issues Caused by Fire

After mapping, students provided their views articulating with what they read by employing newly learned terminology, such as linking forest fires to increased greenhouse gas emissions. One of the students mentioned, *'I know that an increase in greenhouse gases is linked to climate change. This has many negative effects on the planet and our lives'*. Connecting new findings and existing knowledge of the implications of threats for their local environment and local communities enhanced students' understanding, engagement, and care.

These mapping activities demonstrated to the teacher how students can be active participants in learning by choosing what they want to investigate related to their interests and curriculum and being able to have agency over the next steps in their learning. These are key important components of principles related to meaningful learning, mastery learning and inquiry-based learning (Chap. 4).

Skills Gained

Students developed various skills through this inquiry mapping activity:

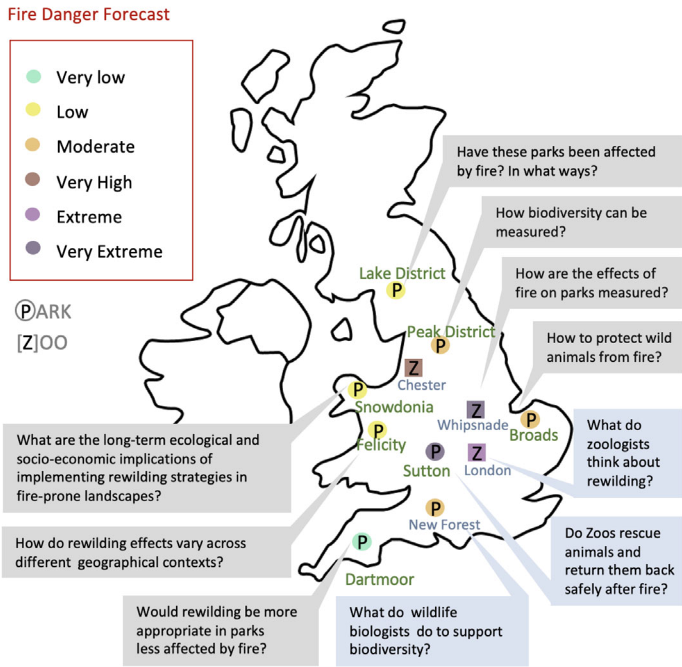
- Engaging with a range of sources and acquiring new vocabulary specific to subjects such as biology, chemistry, and geography (e.g. biodiversity loss, greenhouse gases, damage ecosystem) and general use terms (e.g. devastation, contamination, combustion).
- Selecting and connecting relevant terms in the knowledge map to enhance lexical knowledge and apply terms in context.
- Summarising extensive information into keywords to distinguish essential points from complex material.

- Categorising information within the map improved their conceptual understanding, creating a foundational schema that facilitates the integration of new knowledge.
- Evaluating, synthesising and comparing information from diverse sources cultivated critical thinking, ensuring a discerning approach to information relevance and importance.

The Inquiry Mapping: Rewilding Britain!

The second map (Map 6.3) was created by the research author with students to build knowledge in context. The teacher used the map to connect relevant issues that matter for students (forest fires in Britain) with the curriculum topic (is rewilding a solution to restore ecosystems?).

Students were interested in discovering potential areas affected by fires and identifying which national parks were in danger. The curriculum goal was to explore ecosystems and interdependence. The next mapping activity (Map 6.3) focused on exploring fire danger forecasts, locating parks and zoos and answering questions



Map 6.3 Rewilding case: Inquiry Map, TextoMap and EFFIS EU. Okada (2024). Details: "What are the environmental issues caused by fire? What are the locations of Zoos and national parks? questions chosen by students as issues that matter to them. Fire Danger Forecast (https://effis.jrc.ec.europa.eu/about-effis/technical-background/fire-danger-forecast). Fire Risk Viewer https://effis.jrc.ec.europa.eu/apps/fire.risk.viewer/ (geospatial data and AI science) and the AI tool TextoMap

about rewilding as a strategy to bring back an endangered animal to enhance biodiversity and rebalance the ecosystems in wildlife reserves. Students were asked to consider which national parks may be suitable for rewilding programmes.

Map 6.3 integrates three distinct UK datasets: the locations of zoos, the locations of national parks, and the risk levels of forest fires. This visual composite allowed students to discern patterns and relationships, facilitating the formulation of innovative hypotheses that furthered their research inquiries and aided in crafting questions for subject matter experts. For example, two students observed that Dartmoor National Park was situated in a low-fire risk zone, leading them to hypothesise that rewilding could effectively enhance biodiversity in such low-risk areas. Conversely, another student noted that a different national park was categorised as having a high risk for fires, prompting them to question the potential adverse impacts on biodiversity if a forest fire were to occur there.

In CONNECT, UK learners also became aware of the Greek Students project (Okada et al. 2024), who used drones and learning machine code using Scratch and photos database to develop a system detector for fires in forests capable of classifying images trained and providing recommendations. British learners were also informed of Brazilian schools facing the largest fires in wetlands and rainforests. Ideas for cross-country projects emerged and engaged young people.

Following their engagement with inquiry maps to restore landscapes affected by climate change and unbalanced ecosystems, students composed microblog posts to express their insights. Here, is an illustrative example from one student:

> Climate change is causing longer dry periods, increased temperatures, stronger winds, and deforestation, all of which are destroying the environment. I am wondering what rewilding means and how it can help the landscapes affected by fires.

Students expressed curiosity about rewilding, areas with low biodiversity in their country, and potential species for reintroduction to national parks. They also increased their empathy and awareness of biodiversity issues, as demonstrated by the following student comments:

> We learned about animals that are at risk and for the animals that have disappeared, animals in danger…

> Science is not just about doing experiments in the lab; it helps us think about how to help the world.

Teachers observed an increase in students' motivation and knowledge after watching a YouTube video on wolves' reintroduction to Yellowstone Park (https://www.youtube.com/watch?v=W88Sact1kws). This video also prompted family discussions at home. Following this, students engaged in dialogues about various species suitable for rewilding and contemplated appropriate locations with curiosity about which animals were chosen by the Greeks and the Brazilians who were engaged in the same project.

A teacher reported a quote that shows that students were learning in a meaningful way and shows Ausbel's advanced organisers theory (Chap. 4) in practice: students were connecting what they were learning in the classroom with real-life issues, which they were able to discuss with different people outside of the classroom:

> Students were involved in this activity. They were asked to discuss the topic with their families. It was possible to confirm discussions with their family from 50% of the class. The information provided by scientists from the videos and from parents' discussions was mapped during a whole class conversation, enabling all students to visualise interesting issues from the experts and from families; even those who did not have the opportunity to discuss with their relatives were engaged in discussions with peers and school staff.

Skills Gained

This activity provided many additional skills that promoted scientific literacy:

- Identifying a range of key questions, sources, and ideas, and establishing relationships between different sets of data.
- Formulating hypotheses based on real data and posing questions to experts to embed the issue in the real world, thereby increasing interest and care about the issue.
- Spotting and prioritising gaps to carry out additional research with families, scientists, and AI tools.

Know (Skills: Research)

In past classroom settings, students were prompted to research new knowledge by engaging in independent research, often online. Students readily found lengthy passages of information but faced difficulties in transforming it into meaningful learning. To aid in this process, concept maps were employed to assist students in organising keywords and establishing connections that made sense of them. The organisation and connections in concept maps aided students in several ways: (1) investigating concepts across various sources; (2) interpreting and mapping content with a focus on keywords and relationships; (3) formulating propositions; and (4) developing critical thinking skills by identifying gaps in their understanding.

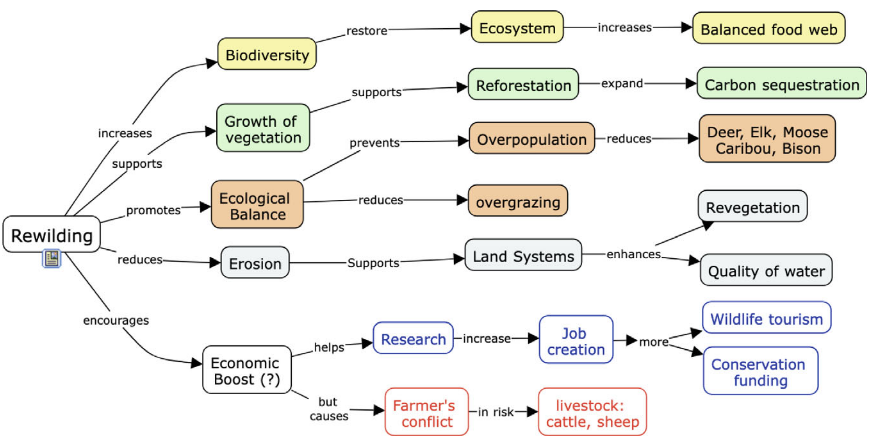
How Concept Mapping Was Used in the Classroom

- Students were asked to select an animal to bring back to the environment. To involve their community in a campaign, students contributed to the school reality TV show "Rewild Britain! (which was readapted into various reality shows "Rewild Brazil, Rewild Romania, Rewild Greece…etc.).
- Students were also taught some science concepts and introduced to food webs and interdependence.
- To prepare a poster for their campaign, students had to expand their understanding of what rewilding means and why rewilding "wolves" could be good for their country.

- These were the starting points of their concept map using Mymap. Ai, which automatically generates answers related to their prompt questions.
- To increase their understanding of the concepts, students should reduce the amount of text generated by the Mymap. AI App into concepts (keywords) linked to verbs forming propositions.
- Although AI has presented good examples of rewilding considering Europe and the USA (wolves, bison, beavers, bears) it has shown very limited examples in South America and Africa.
- Articulating responsibility, ethics, and critical awareness by questioning sources and recognising data and systems biases in AI. Data Bias: This includes biases related to the data used for training AI models, such as lack of representativeness regarding people, culture, gender, language, and socioeconomic status, etc. Systems bias: encompasses limitations within the system, including systemic, algorithmic, technical, and temporal aspects, among others.
- Students selected information read from AI and condensed it into keywords or short sentences, enabling them to create meaningful and effective concept maps.
- Students were allowed to work at their own pace.

The concept map (Map 6.4) identifies multiple advantages of rewilding wolves, which are organised into key effects such as biodiversity enhancement, erosion control, and economic stimulation. The teacher mentioned that the students were able to articulate these benefits in structured sentences, practicing the elaboration of well-founded explanations.

The teacher and the researcher recognised that the map also addressed potential challenges, such as conflicts with farming, which was an opportunity for encouraging students to deliberate on possible resolutions. The student maps also indicated that the reintroduction of wolves led to an increase in biodiversity and a subsequent decline in deer, elk, and moose populations. However, they missed incorporating certain



Map 6.4 Rewilding case: concept map, Mymap.Ai and CMap. Okada (2024)

key concepts related to the curriculum, such as food chains, producers, herbivores, and predators. These concepts were not employed by the AI tool or by the students themselves to explicitly explain the scientific rationale for the importance of wolves in Britain.

This approach presented a pivotal opportunity for teachers to assist students in recalling and connecting what they had learned while also enhancing their critical thinking skills, which are grounded in their understanding of the curriculum. In response to inquiries such as *"How do wolves contribute to the reduction of herbivore populations?"* and *"What ecological benefits result from these changes*? "—supplemented by AI-generated content as well as curriculum knowledge—proved to be essential gaps in helping students relate and understand information from various sources, while appreciating the value of their education in the classroom and progressing with more advanced mapping skills.

In creating a concept map, students made their learning visible to themselves, which enabled them to assimilate their knowledge and their teacher to assess their understanding to inform them of the next stage of learning. Being able to work at their own pace meant that some students completed more extensive maps than others did, but all students gained meaningful learning from the experience.

Skills Gained

- Interpreting key concepts and describing them with keywords.
- Understanding concepts to connect new information with existing knowledge.
- Investigating information from diverse sources and datasets to improve conceptual understanding.
- Evaluating, synthesising, and comparing information from diverse sources and datasets.
- Considering relationships between variables, causes and effects, and benefits and drawbacks—all fundamental scientific thinking skills.
- Selecting, reflecting on, and discussing AI-generated information in pairs, along with editing visual representations, to enhance visual thinking.
- Constructing sentences to help with explanations (e.g. 'rewilding wolves reduce erosion, which improves land systems').

3. Argument Map

Developing a persuasive argument grounded in scientific knowledge is a complex skill for students, requiring socioscientific reasoning. The use of argument maps is recommended to aid students in understanding the logical sequence of an argument's components, incorporating evidence and reasoning, and addressing counter arguments using knowledge from diverse sources, including the curriculum.

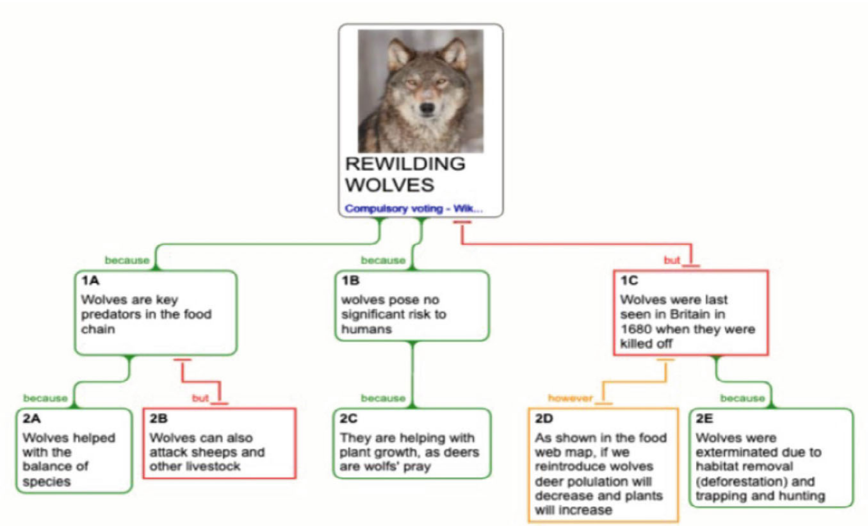
How the Map Was Used in the Classroom

- The students used the online tool Rationale to create their maps. They were first asked to input arguments for (linked with 'because' and counterarguments ('but').

- The next step was to further analyse these arguments by adding further boxes that include evidence to support the argument gained from research and reasoning for the arguments and counterarguments; i.e. this argument is valid because…
- The argument maps were generated in multiple ways:
  - To help students organise their arguments through their own research as well as through the concepts taught to them to construct persuasive campaigns.
  - To highlight any gaps that may prevent them from creating a logical argument to carry out more research.
- To help students peer review the campaign of another student and to help teachers check that arguments are backed by evidence and solid reasoning, constructive feedback is provided.
- For example, even though the map states that "Wolves are helping plant growth since deer are the prey of wolves" does not clearly explain how the decrease in the number of deer increases plant growth. The student did not include a vital piece of evidence in the map: that an overpopulation of primary consumers (deer) will reduce a large area of producers (plants) (Map 6.5).

Students used risk/consequence analysis 'what are the impacts of rewilding wolves?'.

The teacher mentioned that students found using argument maps easier than using textual narratives for identifying missing information that could be used as evidence and for analysing the knowledge acquired based on the number and quality of arguments. The argument mapping approach built on prior science lessons helped students



Map 6.5 Rewilding case: argumentative map—wolves, rationale. Okada (2024)

craft claims and evaluate evidence for robust argumentation. The argumentative mapping facilitated and reinforced the skills learned.

Feedback from a student showed how the mapping helped them build a deeper understanding by transferring their knowledge of food webs to a new context: *I learned how to organise and expand knowledge visually; discussed evidence, the food web, ecosystems, and I learned how to create arguments. I discussed opinions and facts.*

Skills Gained

- Organising arguments, gained through their own research as well as concepts learned.
- Identifying gaps in arguments using evidence-based thinking to enhance argumentation.
- Validating evidence, reasoning, and argumentation through discussion in-an-outside school.

Do (Skills: Decide/Solve)

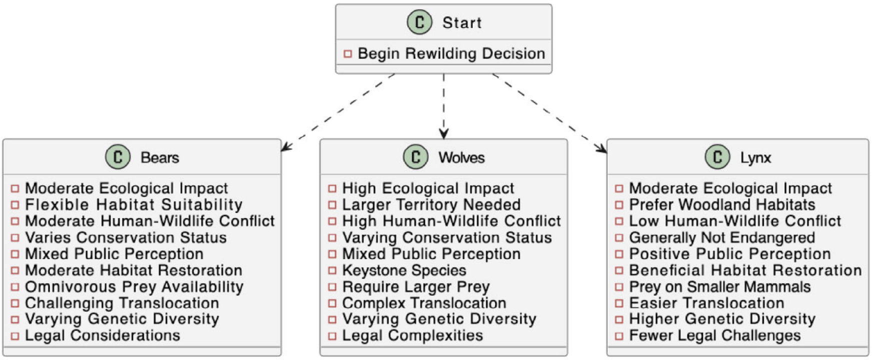
4. Multicriteria Analysis (MCA)

Making decisions supported by visualisation was another challenge for students. Participants had to decide which animal should be selected for their campaign. There were three possible mapping techniques to help them: (1) ranking, (2) decision tree and (3) multiple criteria analysis. Considering that the group had examined different animals in the previous lessons, the research author suggested to the teacher a "multicriteria analysis technique" supported by AI for a public campaign.

How Multicriteria Analysis Mapping Was Used by Participants

- Students were asked to brainstorm on some criteria to select the best animal for the campaign "rewild Britain!". Some suggestions included how dangerous the animal was to humans, how positive its impact on the environment would be, and whether there was suitable habitat for them.
- Students were asked to validate their initial suggestions by watching a video interview with a scientist at Rewilding.
- The teacher then asked the students whether an AI tool, e.g. the OpenChat GPT, could help them by suggesting additional criteria.
- Through OpenAi ChatGPT, they used the following prompt, which was created by themselves with the teachers' guidance:

  Please use multi criteria analysis to compare three animals to rewild in the UK: lynx, wolves and bears".
- Students, along with the researcher and teacher, also asked the AI to create a PlantUML code for three animals using the prompt "Please create a Plantuml



Map 6.6 Rewilding case: multicriteria map—bear, wolf, or Lynx; App.diagrams.net. Okada (2024)

diagram decision tree for rewilding using 3 rectangles for three animals and attach another rectangle of information about them".

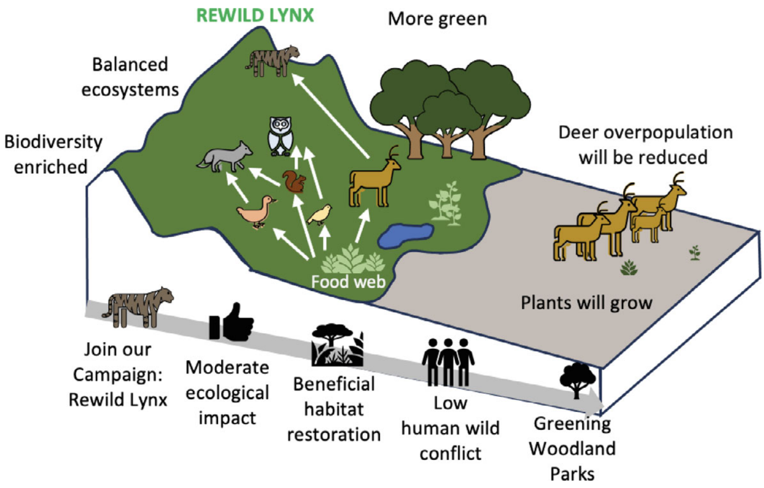
- The students used the resulting MCA (Map 6.6) in groups to choose which animal they thought was the best candidate for rewilding.

Both the students and the teacher found it useful to use the multicriteria analysis. A group of three 14-year-old students used Map 6.6 to decide which animal (bear, wolf, or lynx) they would choose to rewild. After an initial group discussion, the students decided their approach would be to go through each criterion and choose which animal fulfilled it the best by assigning it a 'tick'. The teacher needed to explain the terms 'keystone species' and 'translocation', as these were unfamiliar terms. Moreover, genetic diversity is an important factor to consider. During their discussion, students used their knowledge about various scientific concepts, such as how an omnivorous diet allows organisms to live in a wide variety of habitats. After completing this exercise, the students found that the lynx had the most 'ticks', followed by the wolf and then the bear. One student was then asked the following question: *"what if some of the criteria are more important?"*.

This prompted the students to come up with a ranking system in which they assigned each criterion a number. The teacher reported that *"their discussions about the ranking led to further insightful use of their science knowledge as well as using their argumentative skills as they decided between them the rankings by presenting their opinions and reasoning."*

The group decided that the most important criteria were 'high ecological impact' and 'habitat restoration', as these were the reasons for rewilding. They determined that the least important were 'translocation' and 'varying genetic diversity'. After completing the ranking, the group assigned a score of 21 to wolves and 22 to lynx wolves. This showed that their choice was still the lynx, but with the ranking included, it was much more relevant, proving the importance of including the ranking activity.

Students were tasked with creating persuasive posters through a rich picture map (Map 6.7) using argumentation skills grounded in data and facts. The teacher reported that:



Map 6.7 Rewilding case: rich picture map on ecosystem, Canva. Okada (2024)

> Students enthusiastically embraced the activity, relishing the opportunity to present diverse viewpoints supported by evidence and fostering a space for dialogue enriched by information, ultimately leading to informed decision-making. Students eagerly engaged in discussions to substantiate their claims.

The information presented in the argument maps empowered students to craft compelling narratives and articulate their viewpoints effectively through both written text and oral presentations. Their sense of pride, enthusiasm and accomplishment was evident throughout the various stages and steps of this process, resulting in persuasive and convincing campaigns (see Map 6.7).

A student commented:

> I discussed evidence, the food web, ecosystems, and I learned how to create arguments. I enjoyed making my decision, creating a map, a food web, and a poster for a campaign. I learned how to work collaboratively to produce our work. I learned how to use arguments and check sources with the scientist; with my family, I discussed opinions and facts. I would like to be a forest engineer, environmental journalist, or an ecologist. The rewilding activity was cool.

Skills Gained

- Drawing upon relevant criteria after weighing their importance with a ranking system to make decisions.
- Participating in collaborative discussion and developing social emotional skills.
- Validating evidence and arguments through discussion at school and externally.
- Acting upon feedback using enhanced written and oral communication skills.

6.2 Clean Energy and Climate Action: Energy Savers

Case Information
Participants:

Students: Aged 13–14, year 8 and year 9, lower secondary schools

Teachers: Chemistry, geography, physics

Experts: Educational researchers, Renewable technologies engineer

Communities: Parents, relatives, and local policy makers

Activity/action: Students were invited to provide advice to a café for reducing their carbon emission and develop a fund-raising page for promoting an energy-saving device

Curriculum topics: Climate change, energy resources, energy transfer, energy efficiency

Mapping techniques: Mind map, backcasting, activity map, rich picture and decision tree

Societal Challenge: Some individuals, businesses, and governments are taking steps to lower emissions and lessen. Climate change effects. How can we engage more members of society to help achieve net zero carbon emissions by 2050? Are there any saving energy devices that can help citizens contribute to net zero?

References for Case Study 2 Reducing CO_2

Okada, Alexandra. (2024). Carbon Neutral Open Schooling Resource related to SDG 13 for teachers, students, scientists and families. The Open University. https://doi.org/10.21954/ou.rd.27964578

Okada, Alexandra. (2024). Energy Savers Open Schooling Resource related to SDG 7 for teachers, students, scientists and families. The Open University. https://doi.org/10.21954/ou.rd.27964587

Found by Perplexity.AI:
Woodland Trust. (2022). Climate Change. Woodland Trust. https://www.woodlandtrust.org.uk/trees-woods-and-wildlife/british-trees/how-trees-fight-climate-change/

As indicated by ChatGPT-4:
Berwyn, B. (2023). New Research Makes it Harder to Kick The Climate Can Down the Road from COP28 https://insideclimatenews.org/news/17112023/harder-to-kick-climate-can-from-cop28/

Found by Gemini:
Nasa (n.d.) Climate Change for Kids https://climatekids.nasa.gov/

Mentioned by Claude:
GCP. (2021). The Global Carbon Project https://globalcarbonbudget.org/

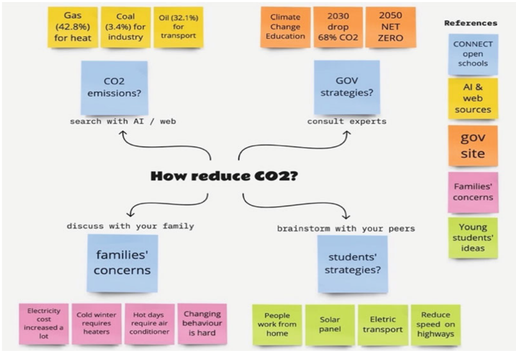
1. Mind Mapping

Brainstorming ideas using mind mapping to develop imagination and creativity engaged students in learning about climate change, CO_2 reduction and energy-saving strategies. Several of them, concerned about the planet's future, were eager to participate in related activities. However, what encouraged their participation was that they were consultants. Most students showed interest in understanding how they could positively influence the future as experts in green energy. This mapping activity was designed to put students in the role of active learners by encouraging them to build knowledge as future professionals.

How Mind Mapping Was Used by Participants

- The teacher initiated a conversation about the strategies used to reduce CO_2.
- The teacher and researcher used questions to prompt the students to elicit ideas from the students:
  - What are the causes of CO_2 emissions, and which is the most significant?
  - Is energy consumption related to CO_2 emissions and climate change?
  - What are the concerns of families related to CO_2 emissions and energy consumption?
  - What are the goals of the UK government, and what do NetZero and carbon reduction mean?
  - What do we need to know to provide advice to cafés on CO_2 reduction?
  - What are the ways to save energy?
- The brainstorming activity started with an exploration of the causes of CO_2 emissions and their significance, followed by an examination of the relationship between energy consumption and CO_2 emissions. It then delved into the concerns of families and the government's goals in addressing these issues. Finally, practical advice on reducing CO_2 emissions and saving energy was investigated.
- The conversation helped students map their ideas onto posts in small groups.
- Collective maps were developed supported by the postits by students in small groups (See Map 6.8).

The application of a mind map to address a complex query proved effective in visualising participant contributions. The students utilised their mobile devices and ChatGPT to enhance the discussion with relevant questions and innovative ideas. The teacher mentioned that the map helped students recognise the importance of identifying the primary sources of carbon dioxide emissions, such as heating, transport, and electricity/industry. This understanding then facilitated a focused discussion on the usage patterns of these sources and potential strategies to reduce emissions in these sectors.



ClaudeAI: Overall, this map provides a well-rounded framework for addressing CO2 reduction, balancing various factors and stakeholder inputs.

Strengths:

- Holistic approach considering technical, social, and educational aspects
- Clear goals and timeline
- Diverse stakeholder involvement
- Recognition of challenges

Areas for Improvement:

- Could include more specific strategies for industry emissions reduction
- Might benefit from more detailed connections between identified sources and proposed solutions
- Could expand on government strategies and policies

Map 6.8 CO_2 and energy case: mind map of strategies, Miro, ChatGPT. Okada (2024)

Teachers played an important role by breaking down the overarching question of identifying strategies into subquestions for students to bring their ideas and suggestions by the government and by their families; additionally, they helped students check AI-generated content with distinct websites.

The AI-generated content using Perplexity.Ai to find references was also checked against distinct websites.

One student commented on the activities they carried out to gather information for their map:

> We did different things; we researched how much energy each home consumes and put the results on an app on our mobile device; heard from a specialist for energy; and what we can do in our city, and we created a map with all the information.

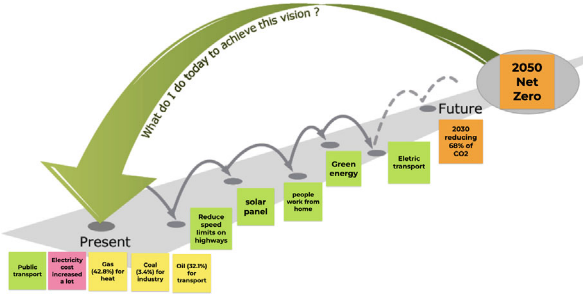
Skills Gained

- Predicting issues by considering the perspectives of various agents and sources.
- Conceiving key challenges and making priorities based on relevance and evidence.
- Envisioning solutions and justifying ideas with supported descriptions.

2. Backcasting Mapping

The teacher introduced the UK's net zero target and asked the students to envisage a future where the UK would achieve the target by 2050. They utilised insights from the mind map and home discussions to think about what changes will need to be made and constructed a backcasting diagram with help from the teacher. This process involved placing identified changes on a timeline, outlining a strategic plan for the UK to reach its target.

How Backcasting Mapping Was Used by Participants



Areas for Improvement: provide more detail on strategies for industry and heating, which are major current emissions sources; policy or regulatory milestones; "green energy" step to specify types (wind, hydro, etc.)

In sum: this is an effective visual representation of a path to net zero emissions. It simplifies a complex process into understandable steps, though it could benefit from some additional details in certain areas

ClaudeAI: This image presents a backcasting map for achieving net zero emissions by 2050.

Vision and Goal: Clearly defines the end goal as "2050 Net Zero", providing a specific target and timeframe.

Present Situation: Identifies current major sources of CO2 emissions

Pathway to Future: Illustrates a step-by-step progression towards the goal, which is effective for visualizing the journey.

Key Milestones: Outlines specific steps in chronological order

Visual Representation: Uses an upward curving arrow to symbolize progress and improvement over time.

Strengths: Clear visualization of the progression from present to future;

Identifies both current challenges and future solutions with a mix of technological, behavioral, and policy changes.

Sets an intermediate goal (68% reduction by 2030) en route to 2050 net zero.

Map 6.9 CO_2 and energy case: backcasting map of actions, Google Jamboard. Okada (2024)

- The teacher presented and explained the backcasting template for students to select the goal to be achieved in the future (e.g. in 2050 and/or 2030) and identify actions or strategies to be implemented towards this desirable vision.
- The students worked in pairs to complete the template, initially by reusing the postit from the mind mapping and then sequencing from the easiest to the most complex alternatives. This approach could be implemented with families (Map 6.9).
- They discussed certain initiatives that could be adopted by all families and others that would require more incentives and financial support.

Backcasting served as an effective pedagogical tool that was easy to implement at this stage in learning, as students were more confident, had more background knowledge and were more familiar with the topic.

Map 6.9 exemplifies the collective backcasting diagram facilitated by the teacher with students postits. The plan started with the vision of what should happen in 2050 and how to achieve this goal considering the timeline.

After completing the map, the students discussed how to present it to their family or at the school assembly. They found ChatGPT4 useful to assist and evaluate the map description. Student feedback from the CARE activities indicated increased awareness about climate change issues:

> We have identified a problem related to the nonrenewable energy sources that create climate change.

> With my family, we listed how not to waste energy, and we studied it. I responded to a questionnaire to determine the energy footprint of my family. I created a table describing the energy consumption of home for 3 days.

We created a questionnaire on climate change and then conducted research on the same subject, meeting with a scientist to inform us about climate change.

Skills Gained

- Developing logical thinking to construct well-reasoned explanations and arguments.
- Thinking backwards to reorganise current and potential future challenges for net zero by 2050.
- Working collaboratively to enhance problem-solving abilities and commitment to addressing environmental challenges.
- Considering the real-world impacts of science and technology, preparing for meaningful discussions on climate change mitigation strategies.
- Use AI to get evaluation and feedback to discuss how to improve the map with teachers.

Know (Skills: Synthetise)

3. Activity Mapping

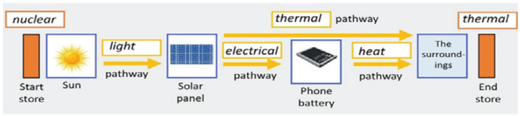
Activity mapping was the technique selected for students to explain abstract processes such as energy conversion using components, images, arrows and labels. The objective of this exercise was to expand the understanding of solar panels by representing the process of transferring energy from the Sun to a phone charger via a solar panel. Energy transfer diagrams are concepts that many students find challenging because of their abstract nature; therefore, this activity was designed to provide a scaffold to support this journey to understanding based on Bruner's research (Chap. 4). After using solar panels in the classroom and experiencing a concrete experience, students reflected on what they had experienced (experiential learning based on Kolb's research) and were provided with a template, which they used as a scaffold to complete an energy transfer diagram.

How Activity Mapping Was Used by Participants

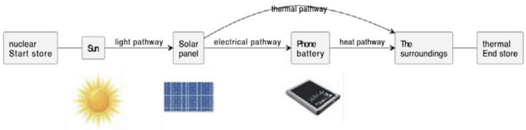
- Students engaged in exploring how renewable energy devices could address climate change and energy crisis issues.
- They had the opportunity to learn about solar and wind technologies through hands-on experiments with renewable technology. This involved the use of solar panels and wind turbines to investigate energy input and output, including quantitative measurements of these values.
- Upon completing these experiments, the students were guided to discuss and explain how energy flows from the sun through solar panels, phone batteries and their surroundings change from one store to another along pathways.
- To scaffold this process, students were given a template to complete by adding the correct terms (Map 6.10).

```
@startuml
skinparam rectangle {
  RoundedCorner 15
}
rectangle "nuclear\nStart store" as StartStore
rectangle "Sun" as Sun
rectangle "Solar\npanel" as SolarPanel
rectangle "Phone\nbattery" as PhoneBattery
rectangle "The\nsurroundings" as Surroundings
rectangle "thermal\nEnd store" as EndStore
StartStore -right- Sun : ""
Sun -right-> SolarPanel : "light pathway"
SolarPanel -right-> PhoneBattery : "electrical pathway"
PhoneBattery -right-> Surroundings : "heat pathway"
SolarPanel   -right-> Surroundings : "thermal pathway"
Surroundings -right- EndStore : ""

@enduml
```



activity diagram map presented by teacher



activity diagram map presented by students with app.diagram.net

Map 6.10 CO_2 and energy case: activity map of solar energy, Canva. Okada (2024)

- They then used AI ChatGPT to recreate a PlantUML code, readapt and reedit in app.diagram.net

Students were asked to use an activity map (Map 6.10) to explain how solar energy could be used to charge a mobile phone.

The teacher reported that “*the activity map helped students describe their explanations about how solar energy could be used as a panel-powered phone charger*”.

The teacher also provided an example from a student: “*It depicts energy stores as boxes, with the initial input store labelled ‘nuclear’ and the final output store labelled ‘thermal’. Pathways between each store demonstrate the energy transfer process”*.

By completing this map, the student was able to explain how a solar panel could be used to charge a phone.

> Energy starts off in the nuclear store of the sun and travels to the solar panel on Earth along the light pathway. Inside the solar panel, the energy in the light pathway moves onto an electrical pathway, which charges the phone battery. The phone battery feels hot as it charges because some of the energy is transferred along the heat pathway to the thermal energy stored in the surroundings.

Students also used AI to determine if their explanations were concise. Claude.Ai (*energy from the sun is converted into electrical energy to charge a phone battery)*, Copilot (*some of the energy is converted into thermal energy*), ChatGPT(energy from the sun is converted into electrical energy*),* Perplexity (*The solar panel converts the energy from the electromagnetic radiation (light) into electrical energy*); Gemini (*A solar panel converts sunlight into electricity).*

All these AI conversational agents used the inaccurate term ‘energy conversion’ instead of ‘energy transfer’.

According to BBC (2024) “Energy can be described as being in different ‘stores’. It cannot be created or destroyed but it can be transferred, dissipated or stored in different ways.”. Science has moved away from the term ‘energy conversion’ to emphasise a more accurate and comprehensive understanding of energy. Instead of thinking of energy as being converted from one form to another, it is more accurate to consider energy as being transferred and stored in different ways.

Skills Gained

- Elaborating easy-to-understand components to simplify complex content.
- Understanding the energy pathway between 'stores' using visual representation.
- Verifying AI outputs by cross-checking with multiple reliable sources and consulting knowledgeable experts, acknowledging that AI can be inaccurate.
- Integrating components to create a clear visual summary.
- Creating illustrations to explain energy dynamics with activity diagram maps.
- Elaborating a prompt for AI to produce UML code for an activity diagram map, then testing and re-editing it in app.diagram.net.
- Recognising the limitations of AI with the support of teachers and experts.
- Constructing explanations and recommendations with experts.

4. Rich Picture Map

To grasp the functioning of solar panels, the students completed an exercise from 'Engagingscience.net called Solar Roadways' (Map 6.1). This resource helps students create a rich picture that explains how solar panels work.

How Rich Picture Mapping Was Used by Participants

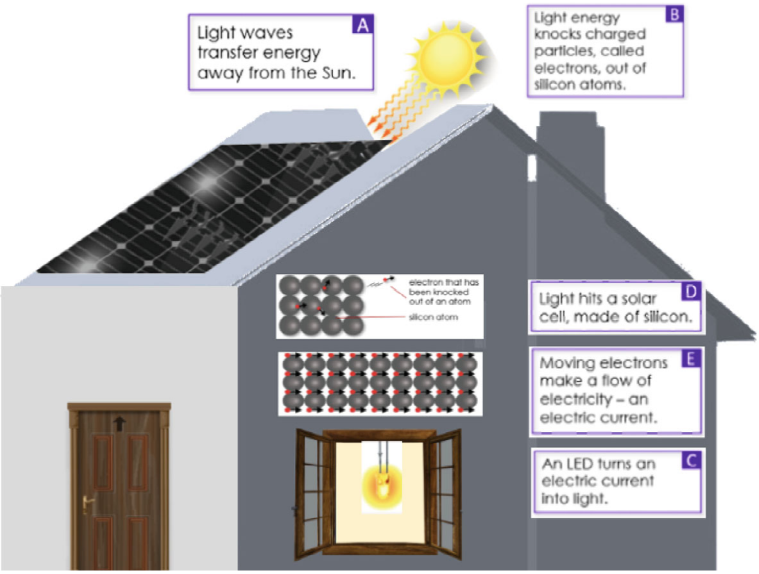
Students cut out the images and descriptions and sequentially arranged them to form a comprehensive illustration that elucidated how solar panels operate. Following this, the students were encouraged to create their own detailed illustrations supported by Canva AI using a clipart open licence to illustrate another form of renewable energy. They then used ChatGTP to help them write descriptions of how the technology works, which they added to their illustrations to create their own rich picture. Creating rich pictures helped students simplify complicated technology using images, symbols, and diagrams. This scaffolded activity enabled all the students to access knowledge, an important component of mastery learning (Chap. 4).

After completing this activity, the students met an engineer who talked to them about the renewable energy devices he was working on, which effectively ignited their curiosity, and their enthusiastic participation was evident as students asked insightful questions.

A rich picture map (Map 6.11) was developed by students using the Canva AI and Engage templates. Students had the opportunity to present their rich picture to a solar panel engineer. During this meeting, the students reported that they were engaged with the activities and that the maps were useful for explanations and solutions. *"We mapped ways to reduce our energy footprint. We conducted research on the energy performance of our home appliances using Excel for graphs and MindMeister for mapping solutions."*

Skills Gained

- Thinking critically about system components, their interactions, and their significance.
- Enhancing the comprehension and retention of information.
- Visualising, organising, and using AI tools such as Canva to develop rich picture maps.



Map 6.11 CO_2 and energy case: rich picture map of solar panel, Canva. Okada (2024)

Do (Skills: Innovate)

5. Decision Tree Mapping

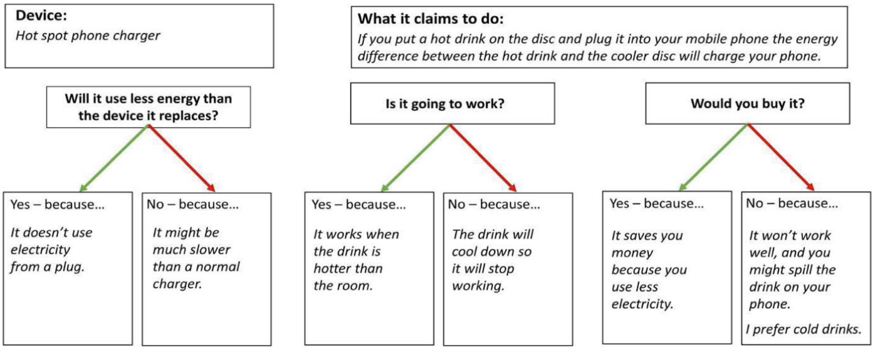
Through their discussions, students started thinking about the possibility of using devices at home that did not rely on the main source of electricity to reduce an individual's carbon footprint and save energy.

They were given information about new energy-saving inventions found by the researcher on crowd-funded websites.

Examples included solar and wind-powered devices, a solar oven, a phone charger that works when a hot drink is placed on it, a portable river turbine and a skipping rope light. A discussion was initiated on whether students would choose to help fund-raise for the devices—what questions would they need to answer to decide? Decision tree mapping was introduced as a tool that can be used to make decisions. Two different types of decision tree mapping were used.

How Decision Tree Mapping Was Used by Participants

- Through discussion with the teacher, the students chose three questions they wanted to consider when making their decision: 'Will it use less energy than the device it replaces?', 'Is it going to work?' and 'Would you buy it?'.
- The students discussed what the device does to save energy and how manufacturers claim it works.



Map 6.12 CO_2 and energy case: decision tree map on devices, Canva. Okada (2024)

- The students added the questions to a template designed by the teacher and subsequently answered them based on the information they had received, their science knowledge and their personal opinions.
- The researcher used Canva AI to create another decision tree (Map 6.12) based on the criteria identified by the students.
- The students used this tree to make decisions about the different energy-saving devices through a series of prompts.

Students used a decision tree to decide whether they would buy the 'power charger'. This device is a small portable charger that works by placing a hot drink on top of it. The inventor claims that the charger works because of the difference in heat energy between the hot drink and the surroundings. The students added facts and opinions to the decision tree to help organise their thoughts. Using their knowledge of energy transfer, they correctly identified a flaw in the device: *'it works when the drink is hotter than the room, the drink will cool down so it will stop working'*. Because of this, they decided that they would not buy the device.

The following AI prompt was used: A code mermaid was created for a decision tree diagram to evaluate a power charger using three criteria: c1. save energy (yes, no electricity from a plug/no, uses electricity from a plug), c2. works properly (yes, the science is correct)/no, the science is flawed), and c3 saves money (yes saves money/ no, does not save money); if the answer is "no, the science is flawed", the connection goes to "Don't buy the device".

Maps 6.13 and 6.14 shows the illustration to make a decision about the 'power charger'.

Students were tasked with completing a fund-raising page to raise money to mass produce one invention. Map 6.14 is a model for designing a rich image map that contains an activity map, which is part of the CONNECT feature. The map was designed by a group of students who supported cell phones recharged by a solar-powered cap. The group chose the best solar panels to use in the cap, calculating the efficiency of different panels and selecting the most efficient ones. The students also explained the significance of this discovery.

Students were asked to persuade people to fund the invention, and they showed their command of the scientific concepts by correct terminology: *'is a sustainable energy source, does not emit carbon'*. They have used persuasive text highlighting the benefits of the cap: *'saves money and saves the environment', 'this amazing, fun cap…* They even gave the cap a catchy name, an eye-catching design, 'the Sunny Side up', showing creativity.

One student outlined what they did: *"We designed a fundraising page for an energy-saving device, including a description of how it works as well as convincing customers to invest in this invention."*

Teacher feedback about the activities included *"Meaningful discussions about energy savers and research skills developed" and "Students were very involved with the activity, and I would have liked to have had more time. It worked well for sowing the seeds of curiosity; they were very engaged."*

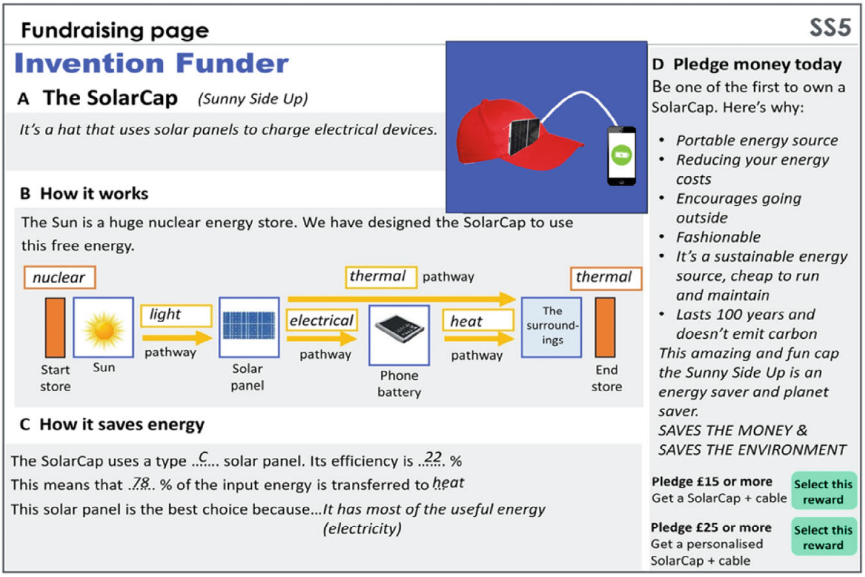
Skills Gained

- Developing logical thinking and evidence-based decision-making supported by decision tree mapping.
- Practicing gathering, interpreting, and synthesising information from various sources, including crowd-funded websites, for assessing new technologies.
- Applying theoretical concepts to practical situations, such as evaluating the thermodynamic principles behind the power charger.
- Presenting and defending ideas based on scientific reasoning.
- Visualising, organising, and coding information using AI tools like Canva and App Diagrams.net, facilitating decision-making and communication.


```
graph TD
A[Save Energy?] -->|Yes| B[Yes, no electricity from a plug]
A -->|No| C[No, it uses electricity from a plug]
B --> D[Works Properly?]
D -->|Yes| E[Yes, the science is correct]
D -->|No| F[No, the science is flawed]
E --> G[Saves money]
C --> G[Saves money]
G -->|Yes| H[Yes, it saves money]
G -->|No| I[No, it does not save money]
H --> J[Buy Device]
I --> K[Don't Buy Device]
F--> K[Don't Buy Device]


style H fill:#e0f7fa,stroke:#333,stroke-width:2px
style I fill:#ffebee,stroke:#333,stroke-width:2px
style J fill:#bbdefb,stroke:#333,stroke-width:2px
style K fill:#ffccbc,stroke:#333,stroke-width:2px
```

Map 6.13 CO_2 and energy case: decision tree map for energy savers, App.diagrams.net. Okada (2024)



Map 6.14 CO_2 and energy case: rich picture map of solar energy device, Canva. Okada (2024)

Skills Gained

- Elaborating pertinent questions needed for decision-making.
- Learning how to make decisions based on valuing scientific evidence, not just opinion.
- Refining results with theoretical concepts by gathering, interpreting, and synthesising information from various sources.
- Cocreating evidence-based decisions, solutions, or project outputs with maps.
- Expanding results collaboratively by presenting and defending ideas based on scientific reasoning.
- Collaboratively designing a fund-raising campaign using interpersonal and intrapersonal skills.

6.3 Conserving Life Below Water: Microplastics

Case Information

Students: Aged 11–13, year 7 and year 8, lower secondary schools

Teachers: From chemistry, geography

Experts: Educational researchers, Marine biologist, Pollution chemist

Communities: Parents, relatives, and local policy makers

Activity/action: To design an invention to help solve the problem of microplastics in the environment

Curriculum topics: Polymers, pollution, and separation techniques

Mapping techniques: System map, mind map, causal loop map, strategic environmental assessment, rich pictures

Societal Challenge: Reducing the impacts of plastic pollution

Real-world issue: Can we combat the proliferation of microplastics that pose risks to wildlife and human health?

References about Case Study 3 Microplastic

Okada, Alexandra (2024). Microplastic Open Schooling Resource related to SDG 14 for teachers, students, scientists and families. The Open University. Presentation. https://doi.org/10.21954/ou.rd.27964557.v1

Found by Perplexity.AI.

IUCN. (2021). Issues Brief: Marine Plastics. https://www.iucn.org/resources/issues-briefs/marine-plastics

National Geographic. (2019). Microplastics. https://www.nationalgeographic.com/environment/article/microplastics

As indicated by ChatGPT-4:

Thompson, R, (2024). Everywhere we looked we found evidence: the godfather of microplastics on 20 years of pollution research and the fight for global action https://theconversation.com/uk/topics/microplastics-17592

Found with Gemini:

https://www.gov.scot/publications/strategic-environmental-assessment-proposed-ban-manufacture-supply-sale-wet-wipes-containing-plastic-environmental-report/pages/4/

National Geographic Kids (n.d.) Pollution. https://kids.nationalgeographic.com/nature/kids-vs-plastic/article/pollution-1

Mentioned by Claude:

Aves, A. R., & McDonald, A. J. (2022). This paper provides the first evidence of microplastics in Antarctic snow. The Cryosphere, 16(6)

Care (Skills: Design)

1. System Thinking Map

Plastic pollution was a topic that students were familiar with, but the term microplastics was new for them and attracted their curiosity. That curiosity about playing the role of a scientist to find "a solution to microplastic" emerged in a whole class discussion. Students were invited to discover what microplastic means and explore a solution to reducing microplastics. This became more concrete after participating in an outside classroom activity, a citizen science project: "The Great Big Litter Hunt" Students were involved in collecting plastics after lunch inside and around the school (e.g. the park nearby) and quickly realised how large the issue was. The students enthusiastically participated in volunteer and environmental clean-up activities, obtaining first-hand observations of biodegradation stages and developing a deeper connection with nature. The knowledge maps were useful for visualising and reflecting on the knowledge built. The involvement of these individuals contributed to environmental protection and improved quality of life. This real-life experience helped students connect the problem of plastic waste to aspects of their lives, lending it personal relevance and helping to make learning more meaningful.

Feedback from the activity showed that students learned about the issues surrounding plastic waste and were encouraged to have agency and make a change:

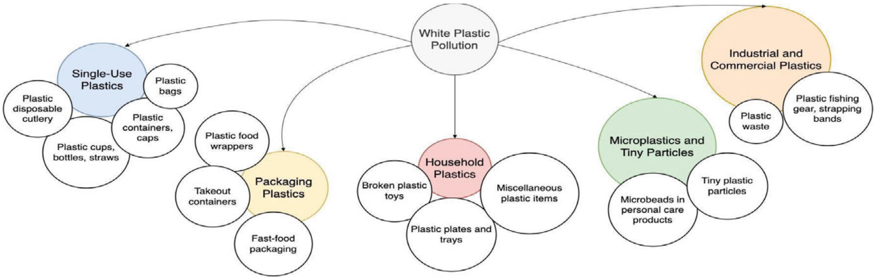
> I learned that if each of us did our part by collecting waste and putting it in the recycling bin to be recycled, it would help a lot, and we can also see that plastic is not only affecting our environment but also our health.
>
> We decided to perform a project to remove trash from the streets.

Students also categorised and quantified the objects found to experience the scientist Richard Thompson's experiment, which led him to create the term microplastic. Students saw Prof. Thompson's first interview and were deeply involved in the topic. System maps were then introduced as a technique to help them classify types of plastics found with clear examples quantified to support the design of a solution.

How System Thinking Mapping Was Used by Participants

System thinking mapping was chosen to categorise the waste that the students found (Map 6.15).

- Students used the system map to sort the litter and then showed the results in terms of their choice. For example, many chose to use a results table to show how much of each type of plastic they found, and some also included its location. The students also used the data to create bar charts.
- This activity motivated the students to raise awareness about the proper disposal of plastics by launching a campaign at their school, using their results as evidence.
- At home students shared their findings with their families and completed an activity where they thought about what single-use plastic items they used and thought of ways of reducing this use, e.g. using non-plastic alternatives, further expanding possible ideas for reducing plastic waste.



Map 6.15 Microplastics case: systems thinking map of pollution, App.diagram.net. Okada (2024)

The map was used by students first at school, where they found that the most common items were packaging plastics. At the park near the school, the key issue was single-use plastic from picnics. The participants were not able to identify microplastics due to their size, but they found objects left outside that they classified as commercial plastics.

Skills Gained

- Connecting questions that are critical for evaluating potential solutions to problems.
- Revising solutions and decisions systematically and collaboratively.
- Iterating ideas in group discussions through active listening, reviewing AI analysis, and synthesis.
- Categorising plastics based on careful observation and data collection.
- Collaborating in group discussion to discuss issues.
- Using system thinking maps to ensure consistency in classification.

Know (Skills: Analyse)

2. Mind Mapping

The students participated in video interviews with marine biologists and chemists. They discussed how plastic litter on land eventually degrades into microplastics and how washing clothes releases microplastics into the water supply. The authors also explained the impact of microplastics on the planet. Listening to scientists who research microplastics provided a sense of realism and urgency to the issue. Students also carried out their own research on microplastics.

They used practical activities: the teacher used a simulation involving the students to demonstrate bioaccumulation and how plastics accumulate as they pass through the food chain, which provided links to the curriculum and increased engagement and provided a tangible angle for students to link to. The teacher commented:

> This experiential learning was key for students to feel truly involved and use concrete experiences to enrich their visual thinking.

Student feedback highlighted how the practical tasks helped engage the students as well as teaching scientific concepts in a novel context.

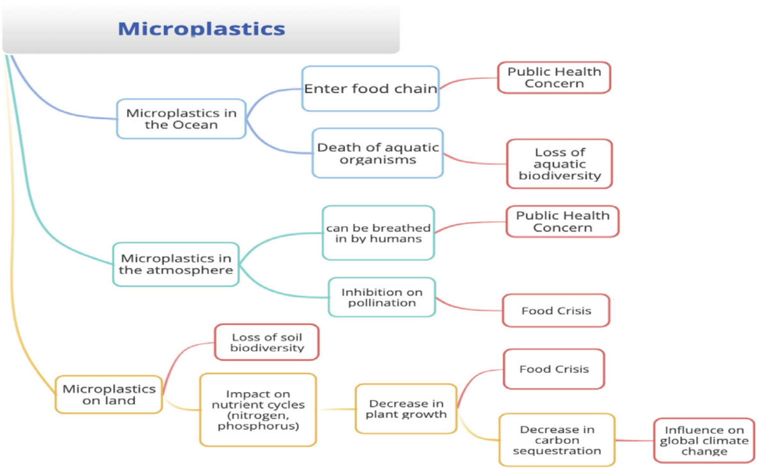
> I enjoyed coming up with new ideas and things to solve problems.
>
> We learned how to use a microscope to look at objects closely and conduct the experiment.
>
> It was different from normal. I found it fun when we got to do experiments. Then, seeing the result is fun, as it looks amazing. I liked practicals or coming up with ideas and working with others.

Following these activities, students accumulated a large body of knowledge about microplastics, but this information was disjointed and often poorly understood. Mind mapping was used to highlight the most important information, to establish links between the microplastics and to help students develop a clear understanding of their impacts, further motivating them to find a solution.

How Mind Mapping Was Used by Participants

Using what they learned from scientists, in addition to their own research carried out at home, groups worked together to construct a map (Map 6.16) to show the impacts of microplastics.

- The teacher provided them with the first three boxes (microplastics in the ocean, in the atmosphere and on land).
- Students then completed the mind map to show the impacts on the environment, wildlife and humans.



Map 6.16 Microplastics case: mind map of consequences, Ayoa. Okada (2024)

- Students used their maps to write a paragraph about why we needed to reduce microplastic pollution. This provided motivation to find a solution.

Students working in groups each chose one of three themes to discuss the impacts of microplastics. One group highlighted how microplastics enter the food chain, affecting both sea life and humans. They then integrated these ideas into a map, linking issues such as biodiversity loss to specific causes and using visual elements such as red boxes to denote concerns. This activity allowed students to see the broader implications of microplastic pollution for various aspects of food production. The exercise not only boosted their confidence in science but also fostered in-depth discussions and research skills development. Teachers observed that the activity effectively connected real-world problems to the students' everyday lives, sparking extensive dialogue on potential solutions to microplastic pollution.

> There was some real-life context to things that they were using like glitter pens, and it is all microplastics." "It is linked to a news article about plastics being found in human blood and the gut, and we talked about what might be the effects on this.

Skills Gained

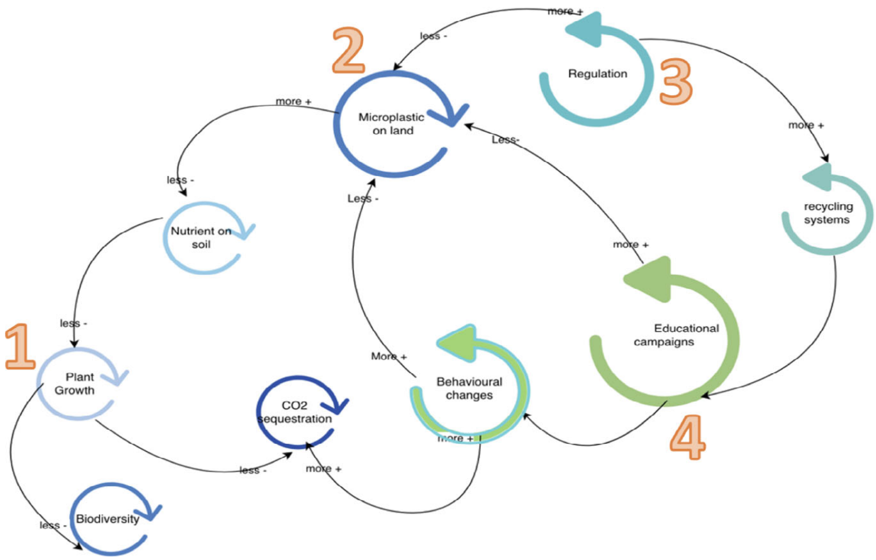
- Compiling the mind map to visualise the issues caused by microplastics worldwide.
- Thinking critically about which pieces of information to include and how to link them to create a comprehensive understanding.
- Writing paragraphs using the knowledge map to connect sources of information through the most important points.
- Establishing relationships between various aspects of microplastics, such as water pollution affecting ecosystems, food production impacting the economy, and biodiversity in oceans influencing ecological balance.
- Collecting and organising data supported by categories and schemas around the issue.
- Practising comprehension skills and analysing data to explain results.
- Understanding how to make decisions supported by evidence.

3. Causal Loop Diagram Map

A causal loop diagram Map 6.17 was created by the researcher with the teacher to help students explain how microplastics affect life on land. This was chosen because even though the mind mapping activity helped students to *describe* the negative effects of microplastic pollution, it did not help them to *explain* how they caused these issues.

How a Causal Loop Diagram Map Was Used by Participants

- The teacher explained what a causal loop diagram map is by showing the students an example created with the support of a researcher and an AI tool.
- The teacher then introduced the first group of connections by introducing the following question: 'What would it happen if there was less plant growth (1)?'



Map 6.17 Microplastics case: causal cycle map of strategies, online.visual-paradigm. Okada (2024)

and prompted students to answer 'more biodiversity or less biodiversity?' 'How about CO_2 sequestration (less or more?)'. Students were able to use the map to answer these questions.

- The teacher then asked 'what would cause less plant growth based on the map?' Students noted 'fewer nutrients in soil'. Another student asked 'what would cause this?', which led a student to reply 'More plastic on land' (2).
- Finally, the teacher introduced other variables on the map, (3) regulations to control plastic and (4) educational campaigns, and asked students to add labels to the arrows, including effects with increasing or decreasing these variables to " + plus" or "− minus".

After the exercise, the students were asked about the meaning and purpose of the causal loop diagram maps (Map 6.17). Students described that a map contains variables and relationships of causes and consequences; it can be used to explain what happens to one variable when another increases.

Students were asked to write about the diagram and use it to approximately compile cause and effect explanations: (1) what affects the amount of microplastics on land and (2) how this affects the environment.

The teacher reported that "*the causal loop diagram was useful to further explore the initial ideas from the mind map and helped students to understand how the variables they researched were linked*".

Finally, the researcher presented how the map was created using OpenAI ChatGPT and app.diagram.net (Map 6.17).

The following AI prompts were used:

> Create a causal loop diagram on mermaid about microplastics using these words: microplastic on land, impact on nutrients, loss of soil biodiversity, decrease in plant growth, decrease in carbon sequestration, more recycling systems, effective regulation, educational campaigns, behavioural change.

Students were able to present their explanations—both written and verbally—using the causal loop diagram to construct simple cause and effect sentences; e.g. *'more educational campaigns about microplastics will result in less microplastic on land because people are more aware of the problems they cause',* and *'more microplastic on land will result in less nutrients in the soil, which leads to less plant growth because plants need nutrients to grow.'*

Skills Gained

- Explaining causal loop diagrams including cause and effect, particularly useful in science and geography.
- Examining the links between variables to predict how a single change may result in multiple outcomes.
- Structuring a prompt for AI to produce code for a causal loop diagram map, then refined with support from experts.

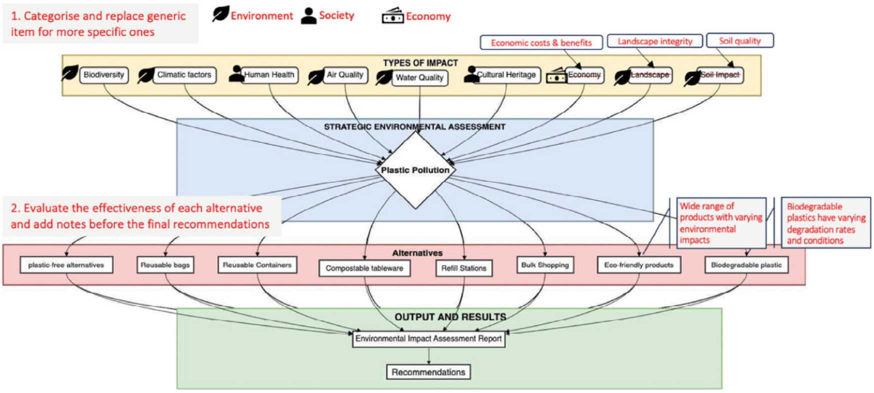
Do (Skills: Evaluate)

4. Strategic Environmental Assessment (Sea)

Students were tasked with designing their own solution to microplastic pollution. The design of this activity was initiated by a researcher, the author and teachers. First, we investigated issues and solutions, including SEA reports. SEAs are policy reports that provide data and recommendations but are long documents and difficult for students to use as references. Thus, the researcher created Map 6.18, a simplified version of SEAs using sources assisted by AI where SEA was used to assess the output of strategies to reduce microplastic pollution (such as https://www.gov.scot/publications/strategic-environmental-assessment-proposed-ban-manufacture-supply-sale-wet-wipes-containing-plastic-environmental-report/pages/4/). Or European level Microplastics—European Commission—Environment https://environment.ec.europa.eu/topics/plastics/microplastics_en

How Strategic Environmental Assessment (SEA) Was Used by Participants

A simplified SEA was created by the author, and OpenAI ChatGPT was used to support the refinement, simulation and debugging of the UML code. After obtaining a simple version, the code was used by the students to construct App.diagrams.net (Map 6.18), which was revised with their ideas and discussion with the teacher. The teacher explained to the students how SEAs are used in real life to develop possible solutions to environmental problems and evaluated them by considering the possible outcomes.



Map 6.18 Microplastics case: SEA map of pollution, App.diagrams.net and Miro. Okada (2024)

Students were asked to analyse the SEA in groups and explain how each suggested alternative can help the problem of microplastic pollution. They discussed which solutions they thought would be the most effective and why.

Students were then asked if there were any other actions they would like to add to the SEA that would also help reduce microplastic pollution. Suggestions included removing plastic pollution that is already in existence, e.g. by using booms in the ocean to stop larger pieces of plastics from breaking down into microplastics and educating people about using less single-use plastic.

Using the SEA map (Map 6.18), students built upon their previous studies. The teacher guided them through the impacts on biodiversity and human health, integrating these impacts into the SEA to generate alternative strategies for reducing microplastic pollution. Discussions extended to examples of reusable items beyond bags and containers, including batteries and clothes, highlighting the role of reusability in reducing landfill waste and microplastic generation. The conversation also covered the benefits of natural fibres and alternatives to microbeads in cosmetics. The activity culminated in students engaging in group discussions and problem-solving, devising creative solutions to mitigate microplastic pollution, although it was noted that additional context might be needed for full relevance, particularly for younger students: *"It would have been nice to have in our map a link to a video about how plastics are collected in the sea, as there are some great examples of the boon being used"*.

They also mentioned the interesting reflections and facts students had about our impact on the Earth and how we might mitigate this: *"They all had a go at designing something and had various different ideas, some better developed than others. We discussed the pros and cons of their ideas"*.

AI conversational models, such as Chat-GPT4, were used to bring insights to critique the maps and evaluate inconsistencies. The students' discussion enabled them to select the most relevant comments from Chat-GPT4 and add notes (in red) to the Map 6.17 for improvements. This collective annotation supported by AI was integrated using Miro.

Skills Gained

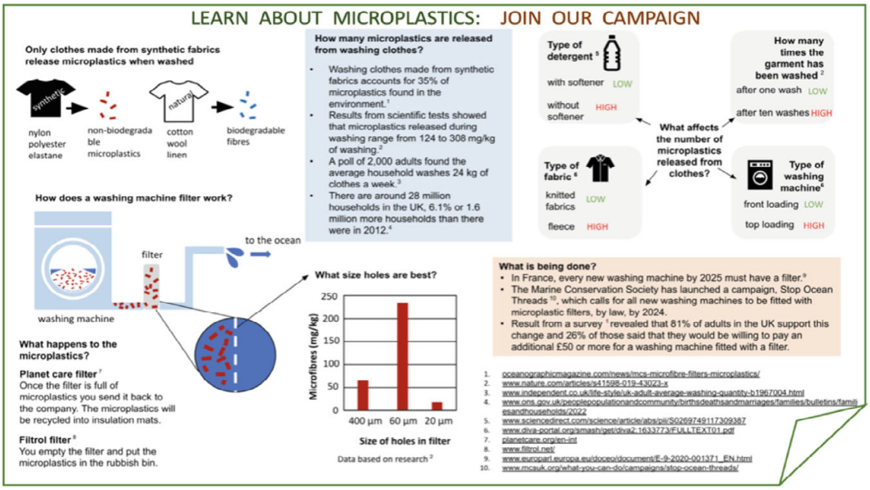
- Assessing and refining strategies for protecting the environment.
- Identify inconsistencies and discuss solutions considering possible outcomes supported by AI.
- Revising the map structure and content to produce new ideas, prompts and AI-generated code to enhance maps and develop computational thinking skills.

5. Rich Pictures

One solution already being used to reduce microplastic pollution in water is the use of a washing machine filter. On introducing the idea, the students discussed important questions that they wanted to ask, such as 'what is it?', 'how does it work?', 'will it truly reduce microplastic pollution?' and 'should all new washing machines be fitted with a filter?' To facilitate students to find answers to these questions themselves, the mapping technique-rich pictures were used in two ways. The first rich picture, designed by the teacher, contained the sources of information students needed to search the answer to their questions. The second was a template created as part of the CONNECT project that students used to create their own rich picture explaining the filter.

The First Rich Picture: Should We Use Washing Machine Filters?

The teacher designed a rich picture (Map 6.19) containing information and various online sources to help students evaluate their use.



Map 6.19 Microplastics case: rich picture map for Campaign, Canva. Okada (2024)

How Rich Pictures Were Used by Participants?

- Students were asked to use the rich picture to determine more about washing machine filters and to develop their own opinions on whether they should be used.
- The teacher scaffolded the task so that each student was challenged by a suitable amount of material by using questions as prompts to access the information based on their level of understanding:

  - *The mass of microplastics produced in the UK was estimated every week.*
  - *Do you think this will change in the future? Why?*
  - *Explain how a washing machine filter works using ideas about filtration.*
  - *What size holes are best for the filter? Why?*
  - *What happens to the microplastics that are removed from the washing machine?*
  - *Is this better than what happens in a washing machine with no filter? Why?*
  - *People could reduce the amount of microplastics they produce.*

The rich picture includes various forms of information, including data, infographics, diagrams and text. The tool was carefully designed to enable all students to access information from reliable sources. This approach was particularly useful for students with lower literacy levels or who do not yet have enough experience carrying out their own research.

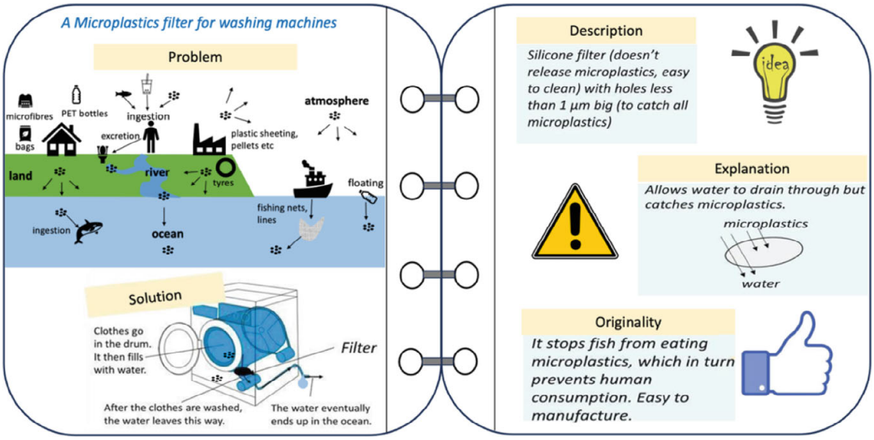
This activity utilised the theory of critical pedagogy, as it enabled students to critically evaluate the use of washing machine filters, equipping them with the knowledge to campaign for their use, or find alternative ideas.

Feedback from students showed how microplastic activities helped develop their knowledge and engagement:

> It was useful to perform practical and learning about filtering, for example, mixing chemicals to determine what happened. Doing this work opened my eyes to how research is important for my life, not just for school assignments.
>
> Learning about it was fun and the microscope. I like projects and creating things in science, coming up with ideas to dissolve microplastic.

Skills Gained

- Identifying key questions critical for evaluating potential solutions to problems.
- Practicing comprehension skills for effectively answering questions using information.
- Reading and writing descriptions of diagram maps to understand complex interactions and explain cause and effect.
- Observing and assessing links between variables to predict outcomes.
- Analysing data, calculating estimates, critically evaluating designs, and explaining results using concepts.
- Revising prompts and AI-generated code to identify inconsistencies and develop computational thinking skills.



Map 6.20 Microplastics case: rich picture map for filter Production, Canva. Okada (2024)

The Second Rich Picture Template Map: How Do We Design a Washing Machine Filter?

Students were asked to use a template to create their own rich picture to design their own washing machine filter. This template was created as part of the CONNECT materials. Map 6.20 is an example filled in by a 14-year-old student.

The students described their invention by using the mathematical concepts of size and scale to choose a size for the holes in the filter paper that is smaller than the smallest microplastic. There is evidence that they have carefully considered what to make the filter from, using what they have learned about microplastic pollution: *'Silicon filter (does not release more microplastics, easy to clean)'*. The group used the scientific concept of separating mixtures to explain filtration justifying how filtration works through a diagram that shows that large microplastic particles cannot pass through small holes in a filter but can pass through water.

Finally, they used what they learned about the dangers of microplastics to human health to explain why their invention should win the competition. *'It stops fish from eating microplastics, which in turn prevents human consumption'*.

The next stage was to assess the first draft (by a peer, teacher or researcher), who can provide feedback to improve the design. The filter was placed inside the machine, leading to difficulties in removing it to dispose of the trapped microplastics. The students were also asked to rethink the size of the holes; the smaller the holes were, the quicker the holes were to clog, reducing the efficiency of the filter. A teacher described how well the resources were linked to the curriculum: *"They link nicely into the materials chemistry curriculum, which we happened to be teaching at the time"*.

The skills gained were justifying their ideas to explain why they choose a certain material or why their design will work and applying scientific knowledge, e.g. through the use of the concept of filtering to explain how inventions will work.

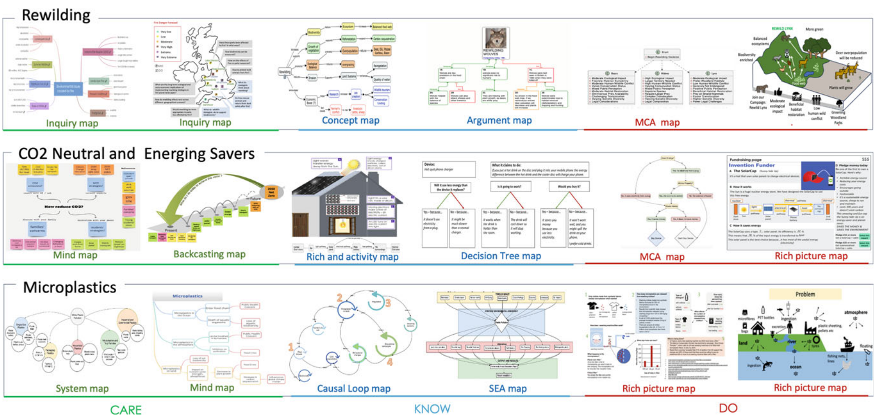
Final discussion was how AI could be useful to develop a microplastic filter for washing machines:

1. **Material Selection**: Use AI to analyse and select optimal materials for capturing microplastics.
2. **Design Optimisation**: Utilise AI-driven generative design software to create and optimise the filter structure.
3. **Simulation and Testing**: Implement AI simulations to predict filtration performance and refine designs.
4. **Prototyping**: Employ AI-optimised 3D printing for rapid prototyping of filter designs.
5. **Real-World Testing**: Use AI to monitor filter performance in real-world conditions and analyse data
6. **User Feedback Analysis**: Apply AI to analyse user feedback for insights on filter effectiveness and usability.
7. **Predictive Maintenance**: Utilise AI to predict when filters need cleaning or replacement based on usage data.

6.4 Overview

In summary, this chapter presented three case studies using knowledge mapping. Map 6.21 summarises various knowledge mapping techniques that were employed for problem-solving across different subject areas based on three themes:

The first theme, "Rewilding," incorporated several types of knowledge maps—such as inquiry maps, concept maps, argument maps, multicriteria analysis (MCA) maps, and rich picture maps. These techniques were utilised to delve into and articulate the arguments, perspectives, and intricacies of the ecosystems that are integral to rewilding initiatives.



Map 6.21 General summary map of knowledge maps. Okada (2024)

The second theme, "CO_2 Neutral and Energy Savers," focused on climate change. Here, the problem-solving process integrated mind maps for ideation and structuring thoughts, backcasting maps for envisioning and planning from a future goal backwards to the present, and decision tree maps that delineate diverging paths and potential outcomes.

The third theme, "Microplastics," centred on the key issue of microplastic pollution. System maps, mind maps, causal loop maps, strategic environmental assessment (SEA) maps, and rich picture maps were used to map the complexities of microplastic pollution, its environmental impact, and potential countermeasures.

These thematic maps were further aligned with the stages of CARE, KNOW, and DO, forming a structured, process-oriented approach to problem-solving. As mentioned in Chap. 4, "CARE" involves the initial grasp and engagement with the issue, considering associated values, concerns, and overarching societal and environmental repercussions. "KNOW" represents a deepening understanding of the problem through thorough analysis and synthesis of information. "DO" is the phase where accrued insights translate into practical action, encompassing strategic planning, decision-making, and execution of solutions.

These mapping techniques are instrumental in fostering a holistic approach to problem-solving (Vuorikari et al., 2022), integrating various data points, stakeholder insights, anticipated effects, and potential strategies.

Reflective Remarks

This chapter provided three case studies combining sets of various mapping with CARE-KNOW-DO principles in open schooling contexts to address real-life sustainability issues

Action Points: After examining various activities and mapping techniques, including AI tools used by teachers, students, and researchers, identify the benefits and challenges of these approaches. Using your notes from previous chapters, outline strategies to transform teaching, research, and learning practices

Next chapter will reflect on the results from the case studies and discusses AI-enhanced maps within communities

Question: How can mapping tools and AI resources be further integrated to enhance educational outcomes?

Reference

Vuorikari, R., Kluzer, S., Punie, Y., DigComp 2.2. (2022). The digital competence framework for citizens—with new examples of knowledge, skills and attitudes, EUR 31006 EN, Publications Office of the European Union

References

Okada, A. (2024). Knowledge Cartography for Young Thinkers: Sustainability Issues, Mapping Techniques, and AI Tools. Figures. The Open University. CCBY. https://doi.org/10.21954/ou.rd.27963327

Vuorikari, R., Kluzer, S. and Punie, Y. (2022). DigComp 2.2: The Digital Competence Framework for Citizens – With new examples of knowledge, skills and attitudes, EUR 31006 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-48883-5, https://doi.org/10.2760/490274, JRC128415

Chapter 7
Afterwords

Abstract This final chapter indicates three learning objectives:

1. Reflect on the findings from the case studies, particularly the opportunities and limitations of knowledge cartography.
2. Understand the benefits of mapping, such as visual thinking, insights, problem-solving, and decision-making.
3. Consider mapping techniques within communities of practice, using the CARE-KNOW-DO framework to foster shared knowledge creation across research, teaching, and learning.

Keywords Knowledge mapping originality · Impact · Relevance · Multiliteracies

7.1 Originality and Impact

An original feature of this book is its combined use of diverse mapping techniques, an approach not yet found in other knowledge cartography literature. By integrating different types of knowledge mapping, students can develop a wide range of skills to enhance problem-solving, decision-making, and project work. With guidance from teachers, peers, and experts, students create detailed maps that help them connect new information in meaningful ways. For instance, concept mapping helps clarify important ideas, aiding in understanding complex topics. This conceptual clarity becomes crucial when students use argument mapping to weigh pros and cons during decision-making. Argumentative thinking supported by evidence and research questions is also useful in inquiry mapping for problem-solving. The solutions and key messages culminate in rich picture mapping, where students visually present their project methodologies and outcomes. This process assists learners in identifying knowledge gaps and bridging them with new questions, concepts, facts, and data, thereby deepening their understanding (Novak 2011; Okada et al. 2014).

The application of the CARE-KNOW-DO model illustrates how students engage with knowledge mapping to address sustainability challenges. For example, in addressing local wildlife concerns, students mapped risks and rewilding solutions to

A. Okada, *Knowledge Cartography for Young Thinkers*, SpringerBriefs in Advanced Information and Knowledge Processing, https://doi.org/10.1007/978-3-031-54677-8_7

enhance biodiversity. These maps enabled them to build a deeper understanding of ecosystems and interdependencies. As part of their climate action initiatives, students focused on CO_2 reduction and energy savings, using mapping to develop renewable energy solutions for a fundraising campaign. Another real-world challenge involved microplastics, where students applied their curriculum knowledge on polymers, pollution, and separation techniques to design a filter for use in washing machines. These examples highlight how students employ critical, systemic, and creative thinking skills, including perception, imagination, abstraction, and pattern recognition (Chen 2003; De Luca Picone and Freda 2022). Mapping techniques facilitated their ability to envision, structure, and interpret both linear and multilinear connections. This process supports learners acquiring, building, and creating knowledge, demonstrating the benefits of mapping in learning (Ausubel 2000; Novak 2011).

The case studies in this book illustrate how artificial intelligence (AI) can support learning by providing insights and feedback, encouraging students to explore diverse sources. This enables them to explore a variety of viewpoints, expand connections and maintain a focus on their needs and interests. In rewilding projects, students are supported by AI map socioscientific issues, questioning sources, becoming aware of biases, and enhancing their vocabulary and criteria for multiple analyses. In CO_2/Energy projects, students use AI supported by teachers for coding, testing and debugging diagram mapping to explain energy transfer. The AI was also used to assist in the evaluation of their explanations, helping them make their descriptions more concise, and they also became more aware of the importance of checking accuracy. Students plan, revise, and optimise AI-driven solutions to develop a prototype to filter microplastics.

The mapping process—visualising, interpreting, and iteratively refining maps—is recursive; the map shapes the thought, and the thought reshapes the map. With the aid of AI and input from expert reviewers such as teachers, community members, and researchers, this interaction becomes more dynamic and insightful. This allows learners to develop a deeper understanding from multiple sources, perspectives, and insights.

In group settings, when visualisation techniques are paired with AI, they become a powerful means to generate new insights. This effectiveness is rooted in four types of vision (Okada 2006):

Insight: Gaining a deep understanding through reflective practices such as mind and concept maps.

Foresight: Anticipating future events through strategic thinking and proactive planning facilitated by backcasting map.

Hindsight: Learning from past experiences to shape current decisions, typically through monitoring and evaluation map.

Oversight: Maintaining a broad view to integrate various elements and their interconnections, which is essential for coordination efforts, as demonstrated in multicriteria map.

By weaving these visions—insight, foresight, hindsight, and oversight—learners develop a 'multisight' perspective that transcends mere factual knowledge. This comprehensive approach not only boosts resilience and adaptability but also equips learners to envision future possibilities, reinterpret past experiences, and oversee complex scenarios. These capabilities for sustainability in the digital age are vital for learners adapting and innovating in a changing world.

From Information Literacy to AI Literacy

In the digital age, the challenge of multiliteracies is exacerbated by digital distraction, information overload and disinformation (Karnouskous 2020; Osborne and Pimentel 2023). These issues highlight the critical role of knowledge cartography. Misinformation underscores the need for robust information literacy to map more accurate and reliable content. Digital distractions, driven by constant notifications and the lure of social media, impair focus, underscoring the value of knowledge mapping for deep engagement with learning materials. Furthermore, the overwhelming volume of digital resources challenges students in identifying relevant and credible sources, demonstrating the importance of mapping strategies for effective inquiry, navigation, and construction of knowledge that is not only more comprehensive, but also deeper.

With the aim of exploring multiliteracies challenges, a study of the WESPOT project workflow for enquiring with social personal and open technologies (Corrêa et al. 2014) revealed that secondary school students, despite recognising the need to compare web sources, lack strong information literacy skills. They often rely on the first search engine results and prefer simpler content over more complex, authoritative sources. Expert feedback and pedagogical support in learning communities are key for students to use critical thinking, build inquiry maps and discuss relevant information.

Further research through the ENGAGE project—equipping the next generation with responsible research and innovation skills (Rocha et al. 2018)—investigated whether evidence-based dialogue maps engaging students, scientists and communities could assist participants in mapping evidence and evaluating its reliability. The findings indicated that the rubric system facilitates students' critical thinking, helping them revise their maps, including questions, claims, arguments, and evidence. Knowledge mapping is more necessary when critical thinking is more difficult. However, these peer-reviewed maps with rubrics require careful planning and can be time-consuming.

Recent studies from the CONNECT project—open schooling for engaging and future-oriented science (Okada et al. 2024; Okada et al. 2023)—have examined secondary students using AI with machine learning, image databases, and drones to develop intelligent systems to detect fires and protect forests. Students are also using AI for coding and diagram mapping. With the rise of user-friendly AI conversational systems, students can now use AI-generated content in real time to answer their questions and refine illustrations, videos, coding, and maps with examples presented in this book. AI has evolved into systems that mimic human reasoning and adaptability (McCarthy 2007), performing tasks such as learning and problem-solving through machine learning, natural language processing, and neural networks (Zawacki-Richter et al. 2019).

In today's rapidly evolving technological landscape, AI literacy—defined as the critical ability to understand, evaluate, use, and create artificial intelligence applications—is essential for students (Casal-Otero et al. 2023; Ng et al. 2021). It equips them with the skills to recognise AI's benefits, limitations, and problems, such as hallucinations, deep fakes, and biases. By teaching AI literacy in schools (Shneiderman 2022; Sperling et al. 2024), we prepare students and teachers to critically evaluate AI-generated content, thereby mitigating misinformation and disinformation. This foundational skill, which is as crucial as reading, writing, and math, ensures that students can effectively engage with AI technologies in their personal and professional lives. With a solid foundation in AI literacy, students supported by their learning community need to be prepared to address real-world problems, as indicated by the case studies of Chap. 6.

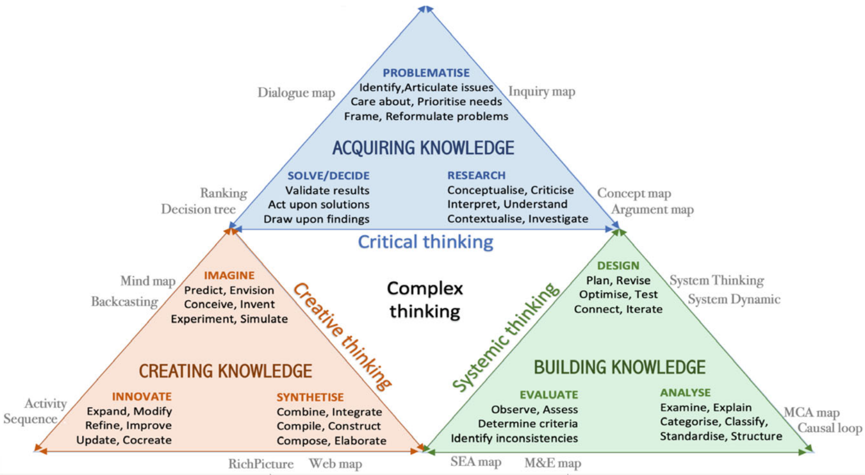
However, students' low level of critical thinking and lack of reliable prior knowledge present challenges, particularly in evaluating the integrity, accuracy, and truthfulness of AI-generated content in education. Students who copy and paste ideas from AI without their own interpretation and critical thinking will not effectively achieve their learning outcomes or develop self-efficacy. As Buckingham Shum (2024) noted, AI can increase the productivity of professionals in the short term by improving information synthesis, creativity, and insightful reasoning. However, in education, productivity gains should focus on cognitive engagement and skill development rather than automating processes to increase speed. Addressing these challenges requires not only awareness but also a commitment to equity in AI education.

There is growing concern about increased inequalities due to the skill gap between those who can take advantage of AI and those who are unprepared for it. Ethical and inclusive AI practices are essential. Human-centred AI systems (Wei et al. 2023; Yang 2021; Yang et al. 2021) can enhance sustainable development by providing advanced analytics (How and Hung 2019), predictive insights (Druga et al. 2019), and personalised feedback (Cavalcanti et al. 2023). The case studies presented in this book show students using AI to navigate new topics effectively, asking questions to resolve doubts and enhancing discussions within their groups. This approach fosters time for reflection, verification, discussion, and social activism (Hodson 2011), thereby making learning more productive and meaningful. Supported by educators and peers, learners engage more critically and creatively, shifting away from mere information replication to authentic, contextual learning that integrates real-life challenges with collaborative mapping practices. Building on these practical implementations, it becomes key to formalise authentic education with AI literacy (Rigley et al. 2024; UNESCO, 2024a; UNESCO 2024b).

7.2 Knowledge Cartography Multiliteracies Competencies

Knowledge mapping supporting sustainable development enhanced by AI literacy offers students opportunities to develop essential competencies for lifelong learning and future professional roles. Map 7.1 expands Map 1.5 by presenting these competencies rooted in three components, CARE-KNOW-DO.

The "Knowledge Cartography Competencies for Young Thinkers" map offers a summary of competencies based on the case studies presented in Chap. 6. These factors, underpinned by the CARE-KNOW-DO model, include values, knowledge,



Critical mapping (Problematise)	*Critical mapping (Research)*	*Critical mapping (Solve/decide)*
A1. Identifying a range of key questions, sources, and ideas.	A4. Interpreting key concepts and describing them with keywords.	A7. Drawing upon key criteria with a ranking system to make decisions.
A2. Formulating hypotheses based on real-life issues and experts' feedback.	A5. Understanding concepts to connect new information with existing knowledge.	A8. Validating evidence and arguments through discussion at school and externally.
A3. Prioritising gaps to conduct research with families and scientists.	A6. Investigating information from diverse sources and datasets.	A9. Acting upon feedback using enhanced written and oral communication skills.
Systemic Mapping (Design)	*Systemic Mapping (Analyse)*	*Systemic Mapping (Evaluate)*
B1. Connecting questions that are critical for problem-solving.	B4. Collecting and organising data supported by categories and schemas.	B7. Assessing and refining strategies for problem-solving.
B2. Revising solutions and decisions systematically and collaboratively.	B5. Practicing comprehension skills and analysing data to explain results.	B8. Identifying inconsistencies and discussing solutions considering outcomes.
B3. Iterating ideas through discussions with active listening and participation.	B6. Examining the links between variables to predict changes and outcomes.	B9. Revising the map structure and content to produce new ideas.
Creative Mapping *(Imagine)*	*Creative Mapping (Synthetise)*	*Creative Mapping (Innovate)*
C1. Predicting issues by considering various perspectives and sources.	C4. Elaborating easy-to-understand components to simplify complex content.	C7. Cocreating decisions, solutions, and project outputs based on evidence.
C2. Conceiving key challenges and solutions by thinking backwards.	C5. Integrating components to create a clear visual summary.	C8. Refining the map, including actionable knowledge with a practical description.
C3. Envisioning alternatives supported by informed views.	C6. Constructing new explanations and recommendations with experts.	C9. Expanding the use of the map with new ideas collaboratively.
AI literacy for CARE	AI literacy for KNOW	AI literacy for DO.
Building knowledge maps prioritising problems with ethics and critical awareness of AI.	Systematising knowledge maps in context evaluating sources and recognizing biases in AI data.	Creating actionable knowledge maps with AI and people's feedback to critically enhance accuracy and trust.

Map 7.1 Knowledge cartography competencies map. Okada (2024)

skills and attitudes enhanced by mapping techniques with AI tools for exploring and addressing sustainability issues. The CARE component includes problematisation, design, and imagine issues that students care about. Critical mapping involves identifying key questions and formulating hypotheses based on real-world feedback. This lays the groundwork for systematic mapping, where essential questions are connected, solutions are collaboratively revised, and discussions are enriched through active participation. In the realm of creative mapping under CARE, learners predict potential issues by considering a wide array of perspectives, conceive solutions by reverse thinking, and envision alternative solutions informed by robust data.

With respect to the KNOW component, the emphasis shifted to research, analysis and synthesis. Critical mapping here includes interpreting and connecting key concepts and probing diverse data sources, enhancing learners' ability to link new information with what they already know. Systemic mapping strengthens this by organising data into meaningful categories and schemas, which aids in comprehending complex content and analysing it to predict potential outcomes. The creative mapping aspect of the KNOW facilitates the integration of different components into a coherent visual summary, further solidified by constructing expert-backed explanations and recommendations.

Finally, the DO component applies these insights to practical, real-world applications, engaging students in solving/deciding and evaluating and innovating. In critical mapping, learners utilise specific criteria to make informed decisions and validate their ideas through rigorous discussions both inside and outside the classroom. Systemic mapping here focuses on refining strategies for effective problem-solving and identifying any inconsistencies within proposed solutions. Creative mapping encourages learners to cocreate decisions and refine their maps, ensuring that the knowledge they create is not only practical but also actionable.

Additionally, AI literacy across these components enhances the mapping process. CARE involves prioritising ethical considerations and understanding the limitations of AI in mapping. KNOW supports the systematisation of knowledge within a contextual framework, critically evaluating sources and recognising biases in AI data. For DO, AI literacy enables the creation of dynamic knowledge maps that incorporate extensive feedback from both AI systems and human input, thus improving the accuracy and trustworthiness of the maps, including their practical use.

By delineating these competencies, Map 6.21 not only extends but also deepens the insights from Map 1.5, providing a seamless continuation of the framework. This approach ensures that learners can engage with AI technologies through critical, creative, and systematic practices, fostering comprehensive competencies that are tailored for the future.

7.3 Knowledge Cartography Limitations

Knowledge mapping is an educational approach with two noted limitations, including difficulties in interpreting multiple connections (Feng and Law 2021) and the potential for underrepresenting complex ideas including challenges (Balaid et al. 2013). Knowledge maps typically simplify complex issues using keywords or brief texts linked by multiple relationships. However, translating these connections into a clear, linear narrative can be challenging, as complex subjects often contain nuances and interdependencies that are difficult to fully capture in a simplified diagram. Additionally, focusing primarily on multiple relationships can complicate understanding.

Given these limitations, it is advisable to use knowledge mapping cautiously and to supplement it with other analytical methods to ensure a more comprehensive understanding of complex topics. Effective supplementary approaches might include narratives, animations, video clips, podcasts, and blog posts. Integrating these methods with knowledge maps can provide clearer and more detailed insights into complex subjects.

7.4 Knowledge Cartography Recommendations

From the case studies, ten recommendations were developed to harness the educational benefits of mapping and AI:

1. **Foster Collaborative Learning and Belonging**: Encourage students to work in pairs or groups to analyse and discuss AI-generated information, identify real-life issues they care about, and enhance collective knowledge and critical thinking skills.
2. **Encourage Original Thought**: Before consulting AI conversational tools, students should bring their own ideas, questions, and information to foster original thinking and personal engagement with the content.
3. **Promote Critical Evaluation**: Teach students to critically evaluate AI-generated content by asking key questions:
   - Does the information sound familiar or align with their prior knowledge?
   - Is the content clear and understandable? Are references or sources provided?
   - What other questions could be explored based on the AI's response?
   - Was the AI-generated content verified with trusted sources or through discussion with peers and educators?
4. **Reflect on Ethical Considerations**: Encourage reflective practices where students explore how AI content has influenced their understanding and consider alternative viewpoints. Educate them on the ethical use of AI to recognise potential biases in AI-generated content and to understand the importance of authorship and integrity.

5. **Support Analysis**: Teach students to identify and select meaningful keywords, breakdown information into key concepts, and examine how different pieces of information relate to each other.
6. **Practice Synthesis**: Students should be guided in connecting these keywords and concepts to create a coherent knowledge map, integrating insights from various sources, and complex information in an organised manner.
7. **Focus on Relationships and Causality**: Encourage students to reflect on their choice of verbs and connections in their maps to gain a deeper understanding of relationships within the content, including cause and effect, part-whole, comparative, hierarchical, and correlational. Doing so provides opportunities for collaborative voting to engage students in discussions that solidify these relationships, thereby enhancing the connections, format, and technique.
8. **Transform Maps into Writing**: Encourage students to turn their maps into written analyses, starting with AI-driven preliminary evaluations and followed by feedback from teachers and experts. This process aids in refining their interpretations and enhancing their ability to communicate complex information clearly.
9. **Enhance Knowledge Mapping with Academic Integrity**: Engage students in collaboratively evaluating their AI-supported maps and narratives. Ensure that both images and descriptions are comprehensive yet concise, informative, and insightful, as well as clear and reliable. Additionally, promote integrity by clearly attributing authorship, acknowledging, and citing all sources and tools used.
10. **Use Mapping for Sustainability and Open Education**: Empower students to critically interpret and evaluate AI-designed maps and guide them in developing recommendations for sustainability. Advocate for the use of knowledge maps in activities such as presenting solutions, communicating results, and fostering engagement. Promote the value of open licences, open content, and open science to enrich these endeavours.

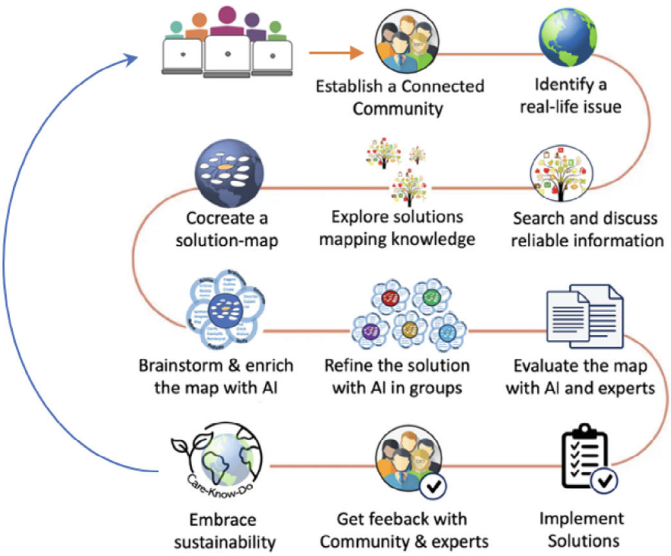
7.5 Knowledge Cartography Implications for Young Thinkers

Knowledge cartography helps individuals and communities explore complex situations to develop actionable knowledge. This enables more informed decision-making and can contribute to addressing sustainability issues that are important to the community. The implications of employing knowledge cartography with CARE-KNOW-DO principles (Okada 2024; Okada and Sherborne 2018) to support sustainable development goals include the following:

1. **Enhanced Environmental Stewardship**: Promoting effective conservation strategies and environmental protection through critical-creative mapping.

2. **Improved Social Equity and Inclusivity**: Fostering inclusion, improving access to resources, and enhancing socioaffective engagement through collaborative mapping.
3. **Sustainable Economic Growth**: Supporting efforts to minimise environmental impacts and monitor sustainable practices with systemic mapping.
4. **Innovation in Sustainable Solutions**: Aiding in the development of technologies and approaches that balance human needs with environmental preservation through creative knowledge mapping.
5. **Responsible Consumption and Production**: Encouraging sustainable lifestyles and reducing waste with critical knowledge mapping.
6. **Supported Policy Development and Implementation**: Enhancing advocacy for policies that address sustainability challenges through complex knowledge mapping.

To operationalise these implications and further develop a knowledge mapping community, Map 7.2 outlines a comprehensive framework designed for collaboratively fostering real-world problem-solving skills through partnerships between schools, universities, professionals and families.



Map 7.2 Knowledge cartography community map for sustainability supported by AI. Okada (2024)

This collaborative learning map leverages AI and expert insights to enhance students' actionable knowledge towards sustainable solutions. Students, educators, citizens, researchers, and policymakers engage in discussions about relevant life issues, reliable resources, and scientific solutions. The integration of community and expert feedback further enriches learning outcomes, promoting education for sustainability.

Reflective Remarks

This chapter discussed findings from CONNECT project case studies (see Appendix), examining the opportunities and limitations. It highlighted the value of AI literacy and its impact on critical and creative thinking, collaboration, and engagement. The chapter also explored how mapping techniques within cooperative communities using the CARE-KNOW-DO framework can foster shared knowledge creation in research, teaching, and learning

Action Points

- Integrate these innovative strategies into your practices
- Consider how they can illuminate your path and empower the young minds you guide
- Identify specific strategies that resonate with you and adapt them to fit your community's challenges

Join our network at (https://www.open.ac.uk/blogs/rrimap) to continue the conversation and enrich practices

References

Ausubel DP (2000) The acquisition and retention of knowledge: a cognitive view. Kluwer Academic Publishers

Balaid ASS, Zibarzani M, Rozan MZA (2013) A comprehensive review of knowledge mapping techniques. J Inf Syst Res Innov (JISRI) 3(1):61–66

Buckingham Shum S (2024) Generative AI for critical analysis: practical tools, cognitive offloading and human agency LAK

Casal-Otero L, Catala A, Fernández-Morante C, Taboada M, Cebreiro B, Barro S (2023) AI literacy in K-12: a systematic literature review. Int J STEM Educ 10(1):29

Cavalcanti AP, Mello RF, Gašević D, Freitas F (2023) Towards explainable prediction feedback messages using BERT. Int J Artif Intell Educ 1–26

Chen C (2003) Mapping scientific frontiers: the quest for knowledge visualisation. Springer, London

Corrêa AL, Rabello CRL, Okada A (2014) Reliability of web-based information in inquiry projects. In: Open learning and teaching in educational communities. Springer International Publishing, pp 385–390

De Luca Picione R, Freda MF (2022) The otherness in the constitution of the psyche: arguments from psychoanalysis and cultural psychology. New perspectives on inner speech. Springer International Publishing, Cham, pp 23–40
Druga S, Vu ST, Likhith E, Qiu T (2019) Inclusive AI literacy for kids around the world. In: Proceedings of FabLearn 2019, pp 104–111
Feng S, Law N (2021) Mapping artificial intelligence in education research: a network-based keyword analysis. Int J Artif Intell Educ 31(2):277–303
Hodson D (2011) Looking to the future: building a curriculum for social activism. Sense Publishers
How ML, Hung WLD (2019) Educing AI-thinking in science, technology, engineering, arts, and mathematics (STEAM) education. Educ Sci 9(3):184
Karnouskos S (2020) Artificial intelligence in digital media: the era of deepfakes. IEEE Trans Technol Soc 1(3):138–147. https://doi.org/10.1109/TTS.2020.3001312
McCarthy J (2007) From here to human-level AI. Artif Intell 171(18):1174–1182
Ng DTK, Leung JKL, Chu SKW, Qiao MS (2021) Conceptualizing AI literacy: an exploratory review. Comput Educ Artif Intell 2:100041
Novak JD (2011) A theory of education: meaningful learning underlies the constructive integration of thinking, feeling, acting leading to empowerment for commitment and responsibility. Mean Learn Rev 1(2):1–14
Okada A (2006) Cartografia Investigativa: interfaces epistemologicas comunicacionais para mapear conhecimento em projetos de pesquisa [Investigative cartography: epistemological and communicational interfaces to map knowledge in research projects]. Pontifícia Universidade Católica de São Paulo. https://oro.open.ac.uk/66364/
Okada A (ed) (2023) Inclusive open schooling with engaging and future-oriented science: evidence-based practices, principle and tools. The Open University, Milton Keynes, UK
Okada A (2024) A self-reported instrument to measure and foster students' science connection to life with the CARE-KNOW-DO model and open schooling for sustainability. J Res Sci Teach
Okada A, Sherborne T (2018) Equipping the next generation for responsible research and innovation with open educational resources, open courses, open communities and open schooling: an impact case study in Brazil. J Interact Media Educ 1(18):1–15
Okada A, Buckingham Shum S, Sherborne T (2014) Knowledge cartography: software tools and mapping techniques. Springer, London
Okada, A. (2024). Knowledge Cartography for Young Thinkers: Sustainability Issues, Mapping Techniques, and AI Tools. Figures. The Open University. CCBY. https://doi.org/10.21954/ou.rd.27963327
Okada A, Sherborne T, Panselinas G, Kolionis G (2024, under review) Fostering transversal skills through open schooling supported by the CARE-KNOW-DO pedagogical model and the UNESCO AI competencies framework
Osborne J, Pimentel D (2023) Science education in an age of misinformation. Sci Educ 107(3):553–571
Rigley E, Bentley C, Krook J, Ramchurn SD (2024) Evaluating international AI skills policy: a systematic review of AI skills policy in seven countries. Global Pol 15(1):204–217
Rocha AKLT, Rocha ABL, Okada A (2018) Rubric to assess evidence-based dialogue of socio-scientific issues with LiteMap. In: Technology enhanced assessment: 20th international conference, TEA 2017, Barcelona, Spain, October 5–6, 2017, revised selected papers, vol 20. Springer International Publishing, pp 137–149
Shneiderman B (2022) Human-centered AI. Oxford University Press
Sperling K, Stenberg CJ, McGrath C, Åkerfeldt A, Heintz F, Stenliden L (2024) In search of artificial intelligence (AI) literacy in teacher education: a scoping review. Comput Educ Open 100169
UNESCO (2024a) AI competency framework for students. https://unesdoc.unesco.org/ark:/48223/pf0000391105
UNESCO (2024b) AI competency framework for Teachers. https://www.unesco.org/en/articles/aicompetency-framework-teachers

Wei X, Dainoff MJ, Ge L, Gao Z (2023) Transitioning to human interaction with AI systems: new challenges and opportunities for HCI professionals to enable human-centered AI. Int J Human-Comput Interact 39(3):494–518. https://doi.org/10.1080/10447318.2022.2041900

Yang S (2021) Precision education-a new challenge for AI in education. J Educ Technol Soc 24(1)

Yang SJ, Ogata H, Matsui T, Chen NS (2021) Human-centered artificial intelligence in education: seeing the invisible through the visible. Comput Educ: Artif Intell 2:100008

Zawacki-Richter O, Marín VI, Bond M, Gouverneur F (2019) Systematic review of research on artificial intelligence applications in higher education–where are the educators? Int J Educ Technol High Educ 16(1):1–27

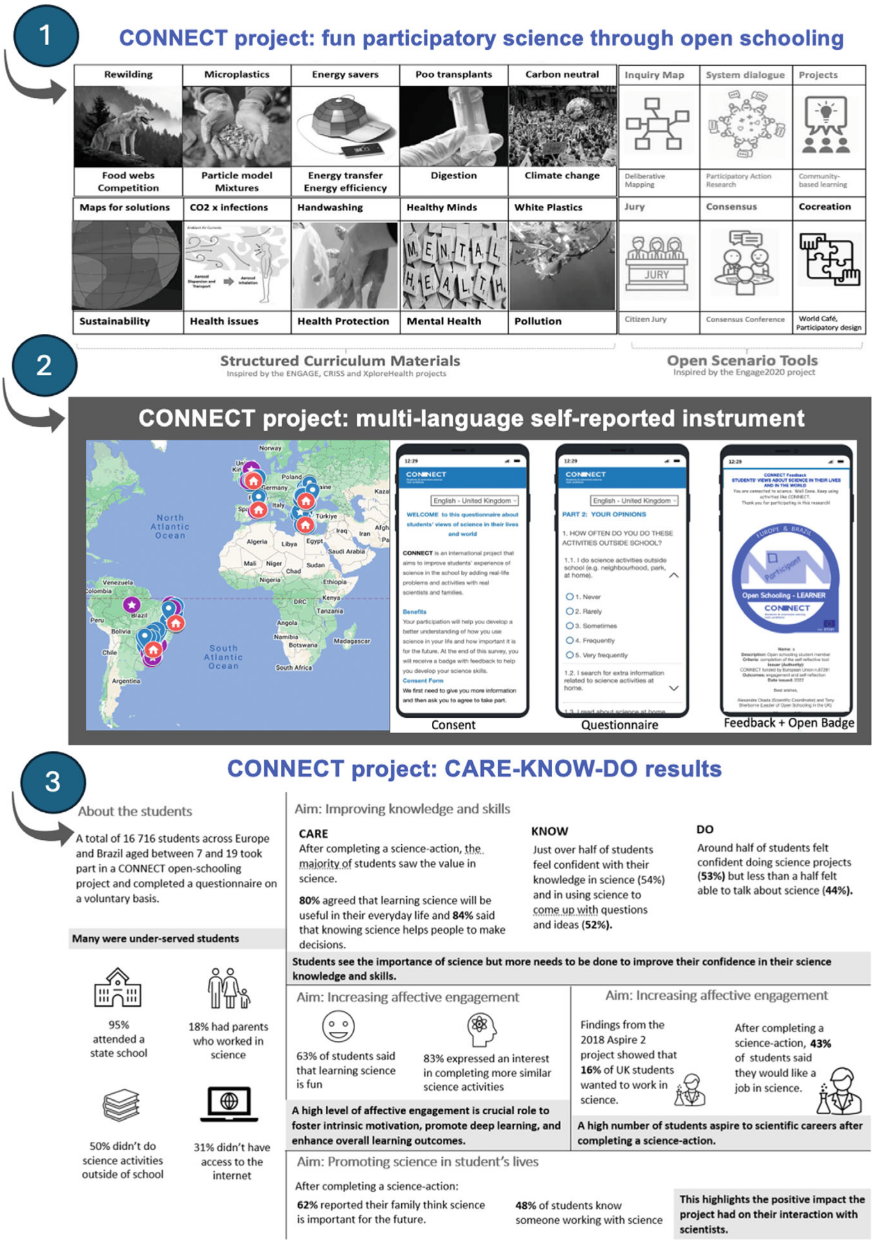
Appendix
The CONNECT Project

This appendix provides an overview of the CONNECT project related to sustainable development goals. The project developed open educational resources to promote participatory science in schools, incorporating curriculum materials and a variety of approaches, including knowledge mapping and AI tools. While the project utilised a broad range of educational approaches, inquiry maps were employed as a smaller component within some resources and identified as needing further development for scalability.

CONNECT engaged 51,488 students from 1,283 schools, utilising the CARE-KNOW-DO framework. Among these, 16,716 students, supported by 1,451 teachers and 183 Early Career Researchers (ECRs) in STEAM, completed a self-reported instrument designed to foster and measure their science connection and transversal skills. Various studies involving students using AI resources have been conducted as part of the CONNECT project (grant no. 872814) and led by ECRs of the METEOR project (grant no. 101178320). Overall, the results highlight the positive impact of CARE-KNOW-DO principles across various approaches, including case studies in knowledge mapping, as presented in this book. We seek partnerships to extend these results and our network using knowledge cartography and AI tools towards achieving Agenda 2030.

References: CONNECT participatory science resources, self-reported instruments and results (https://www.connect-science.net/)

A. Okada, *Knowledge Cartography for Young Thinkers*, SpringerBriefs in Advanced Information and Knowledge Processing, https://doi.org/10.1007/978-3-031-54677-8


1
CONNECT project: fun participatory science through open schooling
Rewilding
Food webs Competition
Microplastics
Particle model Mixtures
Energy savers
Energy transfer Energy efficiency
Poo transplants
Digestion
Carbon neutral
Climate change
Inquiry Map
Deliberative Mapping
System dialogue
Participatory Action Research
Projects
Community-based learning
Maps for solutions
Sustainability
CO2 x infections
Health issues
Handwashing
Health Protection
Healthy Minds
Mental Health
White Plastics
Pollution
Jury
JURY
Citizen Jury
Consensus
Consensus Conference
Cocreation
World Café, Participatory design
Structured Curriculum Materials
Inspired by the ENGAGE, CRISS and XploreHealth projects
Open Scenario Tools
Inspired by the Engage2020 project
2
CONNECT project: multi-language self-reported instrument
North Atlantic Ocean
South Atlantic Ocean
Consent
Questionnaire
Feedback + Open Badge
3
CONNECT project: CARE-KNOW-DO results
About the students
A total of 16 716 students across Europe and Brazil aged between 7 and 19 took part in a CONNECT open-schooling project and completed a questionnaire on a voluntary basis.
Many were under-served students
95% attended a state school
18% had parents who worked in science
50% didn't do science activities outside of school
31% didn't have access to the internet
Aim: Improving knowledge and skills
CARE
After completing a science-action, the majority of students saw the value in science.
80% agreed that learning science will be useful in their everyday life and 84% said that knowing science helps people to make decisions.
KNOW
Just over half of students feel confident with their knowledge in science (54%) and in using science to come up with questions and ideas (52%).
DO
Around half of students felt confident doing science projects (53%) but less than a half felt able to talk about science (44%).
Students see the importance of science but more needs to be done to improve their confidence in their science knowledge and skills.
Aim: Increasing affective engagement
63% of students said that learning science is fun
83% expressed an interest in completing more similar science activities
A high level of affective engagement is crucial role to foster intrinsic motivation, promote deep learning, and enhance overall learning outcomes.
Aim: Increasing affective engagement
Findings from the 2018 Aspire 2 project showed that 16% of UK students wanted to work in science.
After completing a science-action, 43% of students said they would like a job in science.
A high number of students aspire to scientific careers after completing a science-action.
Aim: Promoting science in student's lives
After completing a science-action:
62% reported their family think science is important for the future.
48% of students know someone working with science
This highlights the positive impact the project had on their interaction with scientists.

Glossary

AI: Bias refers to the tendency of artificial intelligence systems to produce outcomes that favour certain groups or characteristics to the detriment of others. This bias can occur due to the data used to train the AI.

AI: Data Security and Privacy The protection of data from unauthorised access, disclosure, alteration, or destruction; ensuring that individuals' privacy is maintained.

AI: Deep Fake Synthetic media created using deep learning algorithms where a person's likeness in an image or video is replaced to produce realistic but fake content; highly convincing yet false visuals.

AI: Disinformation Deliberately false or misleading information using AI, created and spread to deceive people. This often involves exaggerated claims, fabricated research, or manipulated data that exploit AI's ability to generate believable but unverified content, influencing public perception or policy.

AI: Misinformation False or inaccurate information from AI that, despite not being intended to deceive, stems from AI-generated content from uncertain sources, leading to the spread of incorrect data, misreported outcomes, or flawed understanding of AI processes.

AI: Fallacies Incorrect assumptions or misconceptions about the behaviour, performance, or security of AI systems and networks. These fallacies often reflect human misconceptions, such as overestimating AI's abilities or misinterpreting its purpose. For example, believing that AI can replace human judgement in all scenarios without error is a fallacy.

AI: Hallucinations Inaccuracies or false information generated by the AI itself, resulting in outputs that do not match reality. For instance, an AI system creating a detailed but entirely fictional news article about an event that never happened is an example of an AI hallucination.

AI: Human-Centred AI (HCAI) AI systems that are designed, guided, supervised, and enhanced by human input to ensure alignment with human values, needs, and ethical standards.

A. Okada, *Knowledge Cartography for Young Thinkers*, SpringerBriefs in Advanced Information and Knowledge Processing, https://doi.org/10.1007/978-3-031-54677-8

AI: Integrity, Reliability, and Accuracy Refers to the critical assessment to ensure that the content generated by AI is ethical, consistent, accurate, unbiased, and aligned with the expected standards of truthfulness.

AI: Tools/apps Software applications or systems that utilise artificial intelligence to perform tasks, generate content, analyse information, or solve problems.

Learning: Ability The current state of being able to execute tasks, handle situations in different contexts, or complete an activity effectively.

Learning: Aptitude The inherent potential or natural talent for learning or excelling in a specific subject or skill. Aptitude is often seen as an innate quality rather than a learned quality.

Learning: Capability The quality of being able to perform a specific job or task under given conditions. It often implies a measure of potential or suitability for specific roles or challenges in learning.

Learning: Capacity The general ability to perform a set of activities or responsibilities, often in formal or informal learning related to work or life.

Learning: Competencies The set of skills, knowledge, and attitudes that students or employees are expected to develop or demonstrate. It is more complex to assess because it requires the integration of a set of knowledge and skills, including their application in real-world scenarios.

Learning: Skill The specific ability acquired through learning, mastery of techniques, or practical experience. It is often more focused and easier to measure with standardised objective tests and practical evaluations.

CARE-KNOW-DO Framework A pedagogical approach emphasising care (emotional engagement), know (cognitive understanding), and do (practical application).

Content Analysis This research technique is used to interpret text data by systematically categorising and coding the content of the text or illustration.

Critical Socioconstructivism A theoretical framework that combines the principles of critical pedagogy, which emphasises the role of education in challenging societal inequalities, with constructivism, which posits that learners construct knowledge through experiences and interactions.

Decision-making The cognitive process of selecting a course of action from multiple alternatives. In educational and scientific contexts, decision-making typically involves critical thinking and problem-solving, and it is essential for navigating research questions, pedagogical approaches, and administrative strategies.

Emerging Technologies New and rapidly evolving technological innovations that have the potential to significantly impact society, the economy, and culture. In the context of education and science communication, emerging technologies, such as AI apps, offer new tools and methods for learning, teaching, and conducting research.

Experiential Learning Learning through direct experience, reflecting on those experiences and applying them to real-world contexts, often characterised by hands-on or interactive activities.

Inquiry-Based Learning An active learning approach where students pose questions, problems, or scenarios and then investigate solutions through a process of observing, questioning, and assessing.

Knowledge Cartography The process of creating visual representations (maps) of complex relationships and knowledge in various fields or topics.

Knowledge Construction The process of building knowledge and understanding. This can include synthesising information from various sources, conducting original research, or developing new interpretations or applications of existing knowledge. It is a fundamental aspect of educational and scientific endeavours.

Knowledge Mapping Techniques Methods used to visually organise and represent knowledge, often highlighting the relationships between different concepts or datasets.

Mastery Learning This is an educational strategy premised on the understanding that students must achieve a level of mastery in prerequisite knowledge before moving forward to learn subsequent information.

Meaningful Learning A learning process where new information is connected to prior knowledge, thus becoming significant to the individual and enhancing understanding and retention.

Multidimensional Vision The concept of viewing or approaching a problem from multiple perspectives, including ecological, economic, social, and cultural dimensions.

Multimodal Qualitative Data Analysis The examination and interpretation of multiple types of data that come in multiple forms or modes. This approach to qualitative research may include the analysis of text, images, maps, audio, video, and social interactions, among others, to understand concepts, opinions, or experiences.

Open Schooling This is an educational approach where schools collaborate with professionals and the community to offer meaningful learning experiences, both inside and outside the school. These experiences address real-world problems through practical activities focused on sustainability and the application of science in personal and professional life.

Participatory Research Practice This is a methodological approach in which researchers and participants collaboratively engage in the research process.

Real-World Problems challenges that are present in the real world and affect people's lives locally and globally.

Science Connection the integration of science's meaning and purpose into personal, social, and global actions informed by socioscientific thinking.

Sensemaking The process of constructing a coherent understanding from complex or ambiguous information. Education and communication involve interpreting and making sense of data, experiences, or new information, often in a collaborative context.

Social-Emotional Learning The process through which individuals acquire and apply the skills necessary to manage emotions, set and achieve goals, show empathy for others, establish positive relationships, and make responsible decisions.

Socioscientific Thinking The mental process of critically evaluating complex problems at the nexus of science and society, involving ethical and decision-making considerations.

Sustainability Issues Complex challenges arise at the intersection of environmental, economic, and social factors, requiring informed decision-making to ensure the longevity and health of both human societies and ecological systems.