A Living Lab Approach to Geo-data Visualization in Higher Education in the Netherlands

Mór Grommers

“The purpose of visualization is insight, not pictures.”

Ben Shneiderman

Final Thesis Report

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Preface

I would like to express my sincere gratitude to all those who have contributed to my MSc thesis “A Living Lab Approach to Geo-data Visualization in Higher Education in the Netherlands”. I want to thank both my supervisors, Jessica Wreyford and Frida Ruiz Mendoza, for the weekly meetings and their help with all steps of the research. You helped me in the times I was stuck, helping me get through part that were especially difficult for me with valuable feedback and ideas. I also want to thank all stakeholders for their perspectives and insight into the subject, helping me creating engaging and informative results and recommendations. Lastly, I want to thank my friends and family for their support, pushing me to improve and finish my thesis. Special thanks to Yoëlle and Ricardo for ongoing feedback, encouragement, and keeping me on track.

I hope everyone enjoys reading the thesis, and new insights are given, and interest is sparked for innovation in data visualization education.

Abstract

As geo-data visualization is becoming increasingly important in today's society, adequate education in this field is needed to prepare students for their future career. This research attempts to identify key improvement areas and generate valuable recommendations educators can use to enhance geo-data visualization education in higher education in the Netherlands. By employing the process and structure of the living lab methodology, various stakeholder perspectives are integrated in the research process through a co-creation session and interviews. The results of a systematic literature review of nine articles are combined with the co-creation results, which make use of the Visual Literacy Competency Standards for Higher Education. Practical skills, non-technical competencies, focus on fundamentals, and industry relevance emerged as focal points for refining data visualization education. A set of ten recommendations, refined to improve geo-data visualization education, is generated to be used in course design.

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1. Introduction

1.1 Background

"A picture is worth a thousand words." This phrase speaks to the importance of visualizations and their usefulness. Throughout history, visualizations have served as powerful tools for human communication and comprehension. From ancient cave paintings depicting stories to the intricate maps crafted during the Age of Exploration to graphics representing terabytes of data, visual representations have conveyed information in ways that transcend linguistic barriers. As important literacy is to read a book and write a letter, as important visual literacy is for creating and understanding visuals. Visual literacy teaches how to effectively find, interpret, evaluate, use, and create images and visual media (Analytic Alpha, n.d.).

The evolution of data visualization techniques has paralleled the advancements in technology, facilitating the transformation of complex data into comprehensible and impactful visual narratives (L. Y.-H. Lo et al., 2019; Petrone, 2019). Especially in today's data driven world, data visualization is a crucial skill (Asamoah, 2022). Data visualization is not only useful for presenting results or communicating information, but also for data cleaning, exploring data structures, detecting outliers and unusual groups, identifying trends and clusters, spotting local patterns, and evaluating modelling output (Unwin, 2020). Data visualizations reveal features otherwise hidden in models, statistics, or text.

Data visualization is a broad field existing of multiple areas such as scientific visualization, information visualization, visual analytics and other sub-areas like statistical graphics, psychology, and project management (Ryan et al., 2019). It is taught as a skill in a wide range of studies and courses both internationally and in the Netherlands and is a highly appreciated skill for working data-centric companies and jobs (Asamoah, 2022; L. Y. H. Lo et al., 2019; Noble Desktop, 2023; Petrone, 2019; Ryan et al., 2019). A study by Ryan et al. (2019) showed an increase in the number of job postings requiring the skill data visualization and Lo et al. (2019) shows a rapidly increasing demand for data analytics. Study programs often provide a comprehensive understanding of the subject through their courses, preparing students for careers in data analysis, data journalism, business intelligence, and many other related fields (TUDelft, 2023; University of Twente, 2023). For graduates to be competitive in the currently data-driven, they must be introduced to the data visualization field early and often in their studies (Byrd, 2019). Universities of Utrecht (2023), Wageningen (2023), Delft (2023), Twente (2023), Groningen (2023) and Amsterdam (2023) all have study programs involving data visualization. Also, various HBOs have study programs involving data visualization, like HAS Green Academy (2023), Aeres (2023), Hogeschool Utrecht (2023), Hogeschool van Amsterdam (Hogeschool van Amsterdam, 2021) and Hogeschool Leiden (Hogeschool Leiden, 2023).

According to a survey by the Body of Knowledge for the domain of Geographic Information, responded to by students, the knowledge area's cartography and visualization are some of the most relevant for their professional work (Rip et al., 2014). 'Geoscience students need data visualization skills to prepare for careers in government, industry, and research that increasingly require work with big data and communication with diverse collaborators and audiences.' (Bhargava, 2023) A change in teaching method might result in a higher level of base knowledge and skill or an improvement in learning goals, which has a positive impact on the future career of students. A living lab methodology, used in this research, is known for collaborating with actors, users, and audiences and will be used to obtain varying perspectives on geo-data visualization and its aspects.

Living labs are "user-centered, open innovation ecosystems based on a systematic user co-creation approach in public–private–people partnerships, integrating research and innovation processes in real life communities and settings" (Robles et al., 2015). They revolve around stakeholder participation, using their perspectives, knowledge, arguments, experience, and skills to shape an innovative process and collectively find solutions to a problem or product (Steen & van Bueren, 2017b; te Brinke, 2021). This form of research has been used when developing a particular innovation based on a specific problem, mostly at a specified location. Many living labs, for example in Amsterdam, are urban living labs focused on urban sustainability (Steen & van Bueren, 2017b). The living lab approach is considered an innovative method offering testing, validation, development, and co-creation for design and commercialization processes (Compagnucci et al., 2021). No publications have been found in the Scopus database applying the living lab methodology on education or pedagogy. Therefore, its application could bring insights from a different perspective, potentially providing additional information that might otherwise not have been uncovered (Steen & van Bueren, 2017a).

The living lab methodology will be implemented in this research and will structure this paper. Therefore, the sections will be divided by the steps of the living lab: Initiation & Plan Development, Co-Creation, Implementation, Evaluation, Refinement & Dissemination. The living lab methodology was chosen for this research, as it can be used to get a good understanding of the various perspectives of different stakeholders influenced by the main problem of the research, due to its usefulness in complex settings (Higgins & Klein, 2011). Research about education of data visualization, its improvement and curriculum design have already been published before (Asamoah, 2022; Cesal & Makulec, 2023; L. Y.-H. Lo et al., 2019; Ryan et al., 2019) which can be seen in another review by F. Capra-Ribeiro (2022). Results from this review show a rise in interest regarding data visualization in higher education. Notably, data visualization courses tend to emphasize hands-on practice over theoretical teachings, initiating the visualization process early on, minimizing time spent on tool familiarization. The systematic literature review in this research is done independently from other reviews done in the past and dives into the existing data visualization education.

Currently, there is a lack of research focusing on the education of geographical data visualization in the context of Dutch higher education institutions. This research gap will be addressed by incorporating perspectives from stakeholders through a co-creation session, novel to this research field. They will use the Association of College & Research Libraries (ACRL) Visual Literacy Standards for Higher Education to guide the cooperation into finding solutions and recommendations for improving geo-data visualization courses in higher education in the Netherlands.

1.2 Problem statement

Data visualization is a complex topic because it is a broad field connected to a wide variety of industries and applications (TUDelft, 2023; University of Twente, 2023), its dependance on the development of other fields and its long history (Friendly & Denis, 2023). Even though the importance of data visualization is clear, courses that incorporate data visualization into the teaching materials can be taught in many ways. There is limited research on what is needed to teach and learn data visualization (Mahmud et al., 2022) and no findable research specifically studying Dutch institutes or education for geo-data visualization.

As previously stated, the world of data visualization is changing rapidly. Because of this rapid change, requirements for the working field also change (Chua, 2021; Talentguard, 2023). Camm et al. stated ‘Clearly, there is a gap between the talent profile sought by industry and the talent profile provided by business higher education in the analytics and data science space’ (Camm et al., 2023), which is confirmed by the researcher’s first-hand experience with data visualization education and personal connections with alumni and students. This leads to an educational gap, where education sometimes misrepresents the skills and aspects of data visualization needed for future job requirements. Ryan et al. (2019) tries to bridge this gap between academia and the labor market by investigating stakeholder perspectives from educators, students, visualization experts, pedagogy experts, companies, and alumni.

In summary, data visualization is a broad and interconnected field, spanning numerous industries and having a rich history. Its educational aspects involve various stakeholders, each contributing diverse perspectives to its teaching methodologies. Despite its evident importance, there's limited research on effective teaching approaches for data visualization, particularly within Dutch institutions and in the geo-data field. Different teaching methods could significantly impact students' knowledge and career prospects, given the rapidly evolving nature of the field. This mismatch between educational practices and industry demands highlights an educational gap, potentially leaving students unequipped with essential skills needed in the data visualization industry.

1.3 Research objective

This research aims to apply the living lab methodology to investigate how Dutch higher-education institutes currently educate people on the topic of geo-data visualization. By exploring stakeholder's insights and perspectives, this research intends to collectively explore viable solutions to the identified research gap to ultimately offer recommendations for educators, equipping them with effective strategies to enhance the current educational methodologies in geo-data visualization courses. The focus extends beyond the present, considering the career prospects of students within the changing landscape of the geo-data visualization industry.

Based on the research objective, the following research questions have been formulated. The sub-research questions are structured using the framework of the Living Lab methodology and are used to guide the research stages of this thesis.

> *"What areas of improvement and recommendations for educators can be identified within the field of geo-data visualization education for the Netherlands using the living lab methodology?"*

1. *Initiation and plan development:* What is the current state of research on the topic of data visualization in higher education in the Netherlands?
2. *Co-creation:* What geo-data visualization aspects are taught, used, and identified as important by relevant stakeholders?
3. *Implementation:* What aspects of geo-data visualization are seen as relevant and can be recommended to be integrated?
4. *Evaluation:* What is the suitability and representativeness of the information gathered from the co-creation of the living lab methodology to determine the state of geo-data visualization in higher education in the Netherlands and be able to give recommendations for improvements?
5. *Refinement and dissemination:* What recommendations for improvement can be made for existing and new courses covering geo-data visualization in higher education in the Netherlands?

1.4 Research scope

The extent of this thesis will be limited to spatial- or geographical information, or geo-data visualization courses taught in person at higher education institutions in the Netherlands. Massive Open Online Courses (MOOCs) and other online courses will not be considered in this research, as there are large pedagogical differences, Additionally, the dynamic, quality and level can differ a lot, which makes their inclusion too broad for this research. By excluding MOOCs and online courses from the research scope, more focus can be put on the traditional higher education environment in the Netherlands. As there is lack of research specifically about geo-data visualization in education in the Netherlands, the systematic literature review incorporates data-visualization in education in general.

The discussion about data visualization being a skill or a discipline will not be touched upon. Even though this debate is still ongoing (Ryan et al., 2019), the differentiation has no immediate impact on the research and is, in addition to the time restraints on the research, out of the research scope. Data visualization will be seen as a skill used in various professional and educational fields. Additionally, only general standards and requirements for geo-data visualization careers and studies will be researched. This omits any specific technical visualization aspects, applications, tools, or cases.

The basis of the co-creation session is created solely based on the ACRL's Visual Literacy Standards for Higher Education (ACRL, 2011). Thus, other standards or frameworks for visualization education are not considered. Moreover, the living lab methodology is based only on the theory created by the Amsterdam Institute for Advanced Metropolitan Solutions (AMS). For the research, no other Living Lab methods, theories or frameworks are considered.

2 Theoretical Framework

This chapter is divided into two sections. First, an overview of the living lab methodology and each of its components as applied in this research will be presented (section 2.1). Second, an overview of the visual literacy concept and standards within both higher-education and the field will be provided (section 2.2).

2.1 Living lab

The living lab methodology used in this research will follow the guidelines and definitions as described by Steen & van Bueren (2017b) and as implemented at the AMS Institute. The term living lab has been given multiple definitions in different published works, all gradually building towards a stabilized conception of living labs with roughly similar characteristics (Steen & van Bueren, 2017a). Through a literature review on common denominators of living lab projects, Steen & van Bueren (2017a, 2017b) captured nine defining characteristics of living labs (including one specific for urban living labs) in four dimensions: aims or goal, activities, participants, and context. According to them, they present a 'full (urban) living lab definition'. These aspects and characteristics are explained, after which the stages of the living lab are clarified, and the recommendations made by Steen & van Bueren (2017b) are touched upon. The stages of this research based on the living lab stages are represented in their affiliated sections.

The first aspect, aims, is defined by the characteristics; innovation, formal learning, and urban sustainability, last of which specifically for urban living labs. Living labs aim to blend research and innovation processes, emphasizing learning, and experimentation. Innovation involves developing new products or solutions while learning focuses on sharing and generating knowledge among participants. Living labs distinguish themselves by emphasizing formal learning and dissemination, setting them apart from other policy experiments and innovation hubs. Urban living labs, specifically, prioritize local sustainable solutions for global issues like climate change and energy transition, often using cities as testbeds, aligning with the current focus on cities for economic and sustainable development, and responding to calls for citizen empowerment.

The second aspect, activities, is defined by the characteristics; development, co-creation, and iteration. Living labs encompass various activities, emphasizing the development of a wide array of products or artifacts, including process innovations, rather than solely focusing on testing or implementation. Co-creation plays a central role, promoting collaboration with users throughout the developmental stages. What sets living labs apart from others is their emphasis on seeking solutions collaboratively with users, involving them not just in testing but in decision-making across the developmental phases. These labs operate iteratively, continually using prototypes or products, gathering stakeholder feedback, and refining based on collected insights.

The third aspect, participants, is defined by the stakeholders; users, private actors, public actors and knowledge institutes, and the characteristic of decision power. The living lab model operates as a systematic innovation approach where all stakeholders, including users, actively participate in both the product's development and the process leading to its creation. These stakeholders typically encompass users (often end-users or citizens of the final product), private actors (businesses, firms), public actors (governments, institutions), and knowledge institutes. Importantly, these actors not only participate but also wield the authority to influence the developmental process. This empowerment transforms them from passive consumers into engaged contributors in research and development activities.

The last aspect is context, with the characteristic real-life use context. The complexity and multi-contextuality of real-life environments are seen as a challenge of living labs. This can be both physical and virtual, however a physical environment is seen more frequently in projects using the living lab methodology.

In a report, Steen & van Bueren (2017b) present a simple methodology for setting up urban living labs, which will be the basis of this research. The process is formed by the following stages: Initiation, Plan Development, Co-Creation, Implementation, Evaluation, Refinement, Dissemination (Figure 2-2). The last stage, replication, is out of the scope of this research. An important aspect of the living lab method is that at each stage, it is possible to return to a precious stage, making it an iterative process. For this thesis, the stages are separated into five components, each represented by one of the five sub-research questions (Figure 2-1)(section 1.3).

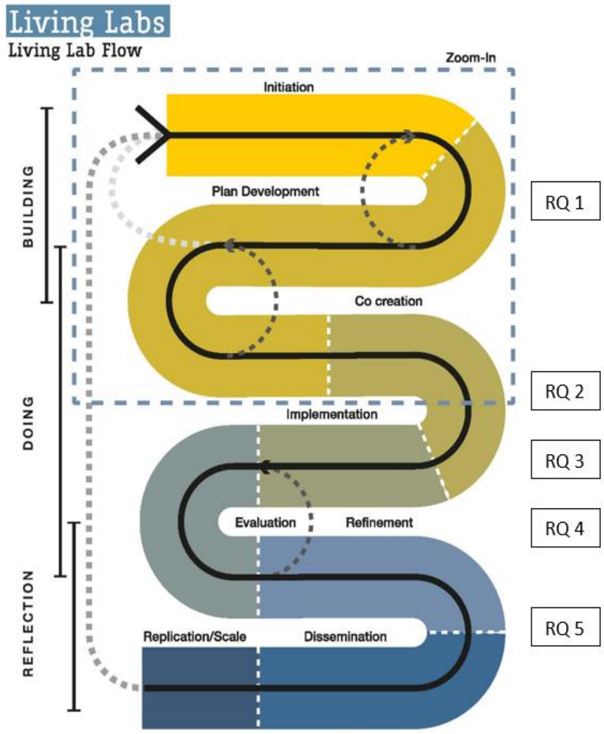

Figure 2-1: This research follows the iterative living lab process. The five components are represented by the sub-research questions. (AMS Institute, 2020)

2.1.1 Initiation & Plan development

The first stage of this research project is the initiation and plan development. A living lab can be initiated in two ways. An idea can serve as a starting point, being relevant to a problem, or a problem can be the starting point, where a solution is being sought for. In this research, the second option is applicable. Based on this idea or problem, contact can be set up with stakeholders that have possible interest in the living lab project. The initiator tries to find partners in the project and persuades them to collaborate with them. This is done through stakeholder mapping. To be able to persuade stakeholders to associate with the project and take a leap, a clearly limited scope needs to be defined, limiting risks. The last part of the initiation is translating the idea into a concrete project and finalizing the setup. Typically, a living lab needs a specific location, which is not relevant to the problem at hand. In this research, the location would be the classes of geo-data visualization or its working environment.

In the plan development, goals and ambitions are defined and the stakeholder interests are embedded into the project plan. When working together with stakeholders in the plan development, agreements need to be made and a division of roles and expertise is sought. In current research, the stakeholder participation and input start at stage 2; co-creation. In the plan process of this research, a systematic literature review is set up to delve into existing publishments about education in data visualization. Also, some semi-structured initial interviews with stakeholders are held as preparation for the co-creation and to get a first grip on stakeholder perspectives. This stage ends with planning the co-creation session.

2.1.2 Co-creation

Stage two is the co-creation stage, or the co-creative design. In a co-creation session, prototyping of the product takes place and the design based on the concept is elaborated upon by the initiator and stakeholders. The stakeholders actively participate and listen to each other. This process minimizes hierarchical dominances in typical development processes and focusses on assembling the varying perspectives, knowledge, arguments, experience, and skills to find an integrated solution. It is important for all stakeholders to not fall back on traditional patterns and keep an open and transparent attitude. Informal, low-threshold meetings establish greater participation and decision-making. Simplified discussions, tangible results, and a focus on celebrating achievements keep the momentum alive, driving the innovation process forward. Developing trust among stakeholders and accepting uncertainty are key mindsets.

The co-creation session will be planned, and invitations will be sent to the stakeholders. After hosting the session, the results will be processed. A set of seven visual literacy standards lays the basis of the session. From there on, the session will lead by the discussion and ideas of the participants. A suitable infrastructure for communicating and sharing will guide the participants to create useful output. The visual literacy theory and standards are explained in section 2.2.

In addition to the visual literacy standards, the stakeholders will use a Venn diagram in the session. 'A Venn diagram is a simple illustration that uses ovals to picture the universe of data that an analysis begins with and the subsetting, unions, and intersections that one can make within that data.' (Hughes, 2016). In the session, the Venn diagram is used to clearly visualize the aspects of data visualization that the stakeholders have been taught in their studies, that they use in their working environment and the ones that are both taught and used, represented in the overlapping area of the ovals.

To supplement the data of the co-creation session, additional interviews are conducted with stakeholder types missing in the co-creation session. The interviews are again semi-structured like the initial interviews in the initiation & plan development.

2.1.3 Implementation

Implementation is stage three of this research project. What has been discussed and found out in the co-creation session will now be implemented. The steps taken in this research differ from the theory by Steen & van Bueren, as the goal of this research was not an innovation, but rather recommendations for education. This stage focusses on the analysis and results of the co-creation session and interviews. As a result, an initial list of recommendations to be used in the educational system of higher education in the Netherlands is created. These recommendations will be generated by combining the input from the stakeholders as well as the results from the literature analysis done in the plan development and the interviews done. The recommendations will be simple and to the point and focused on the long term.

2.1.4 Evaluation

Having gone through the theory and results, the evaluation stage will be next. Dependent on the results of this evaluation, adjustment can be made to the research or way of representation of results. Important in this stage is to evaluate both the data suitability and data representativeness of the results of the research project. Evaluation, both by the initiator and the stakeholders, is a crucial stage in the living lab method as it is partly aimed at learning for future research. Lessons learned during the process will be drawn and documented as a step towards the discussion.

2.1.5 Refinement & Dissemination

The last stage of this research is Refinement and Dissemination. The recommendations generated in the implementation step are reviewed and adapted to specifically fit geographical data visualization in higher education in the Netherlands.

Throughout the entire project, the results and process are subject to change. If needed, the process will reiterate to a previous stage or stages. This research will not have a co-creation step in the refinement & dissemination step.

2.2 Visual literacy

A person processes images 60.000 times faster than text. Of the information processed by the brain, 90% is visual (Weissman, 2022). Visuals are the simplest and most effective way to make sure that the information gets stored as a long-term memory (Jandhyala, 2017). These are just a small part of proven statistics and facts about visuals, supporting the statement that visualizations and visual literacy are extremely important for humans and sharing information. Visual literacy has emerged as a critical skill in today's information-rich environment (Bleed, 2005; Huilcapi-Collantes et al., 2023). As the volume and complexity of data continues to expand, the role of visual literacy becomes paramount, particularly in the field of data visualization (Moraes Bueno Rodrigues et al., 2021).

The Association of College & Research Libraries (ACRL) defined the concept of visual literacy as (ACRL, 2013):

> *"… a set of abilities that enables an individual to effectively find, interpret, evaluate, use, and create images and visual media. Visual literacy skills equip a learner to understand and analyze the contextual, cultural, ethical, aesthetic, intellectual, and technical components involved in the production and use of visual materials. A visually literate individual is both a critical consumer of visual media and a competent contributor to a body of shared knowledge and culture."*

This section explores the intrinsic relationship between (data) visual literacy and higher education while delving into the standards outlined by the ACRL regarding visual literacy.

2.2.1 Visual literacy in Education

With the invention of new applications and technologies, most people can create and share visual media, however the ability to critically review, use and produce visual content is not a general skill and thus have to be developed and learned (ACRL, 2011; Hattwig et al., 2013). Visual literacy and developing visual literacy skills is essential for graduate students and learners in the 21st century higher education(Hattwig et al., 2013; Huilcapi-Collantes et al., 2023). Visual literacy 'encourages careful observation, awareness of aesthetics and their effect on meaning, visualization of concepts and data, contextualized visual interpretation, and experimentation with tools and technologies to design and create new media' (ACRL, 2013). With more academic practice in these skills, the visual literacy competencies of students will grow and develop. Even though visual literacy is an upcoming topic in higher education, a gap exists on the way these concepts and skills are taught (Cao, 2023; Guglietti, 2023).

2.2.2 ACRL Standards

The ACRL, an influential American body in the realm of academic libraries and higher education, provides a framework for understanding visual literacy called 'Visual Literacy Competency Standards for Higher Education' (ACRL, 2011). The framework defines seven standards with over one hundred learning goals tailored to visual materials, providing guidance to education in visual literacy in a wide range of academic fields (ACRL, 2011, 2013; Hattwig et al., 2013). Together with other concepts in information literacy, the standards can be used to incorporate image-based critical thinking and visual communication in education.

The visual literacy standards developed by the Visual Literacy Standards Task Force (VLTF) based on, and to complement the information literacy standards. Depending on the curriculum and learning goals, the standards can be used as a whole or in part. The usage of the standards can vary per discipline depending on their usage, and do not have to be handled in order.

According to the ACRL Visual Literacy Competency Standards for Higher Education, visual literacy encompasses seven key standards (ACRL, 2011), also seen in Figure 2-2:

1. **Define need**: Determine the nature and extent of the visual materials needed.
2. **Find**: Find and access needed images and visual media effectively and efficiently.
3. **Interpret & analyze**: Interpret and analyze the meanings of images and visual media.
4. **Evaluate**: Evaluate images and their sources.
5. **Use effectively**: Use images and visual media effectively.
6. **Create**: Design and create meaningful images and visual media.
7. **Use ethically & cite**: Understand many of the ethical, legal, social, and economic issues surrounding the creation and use of images and visual media, and access and use visual materials ethically.

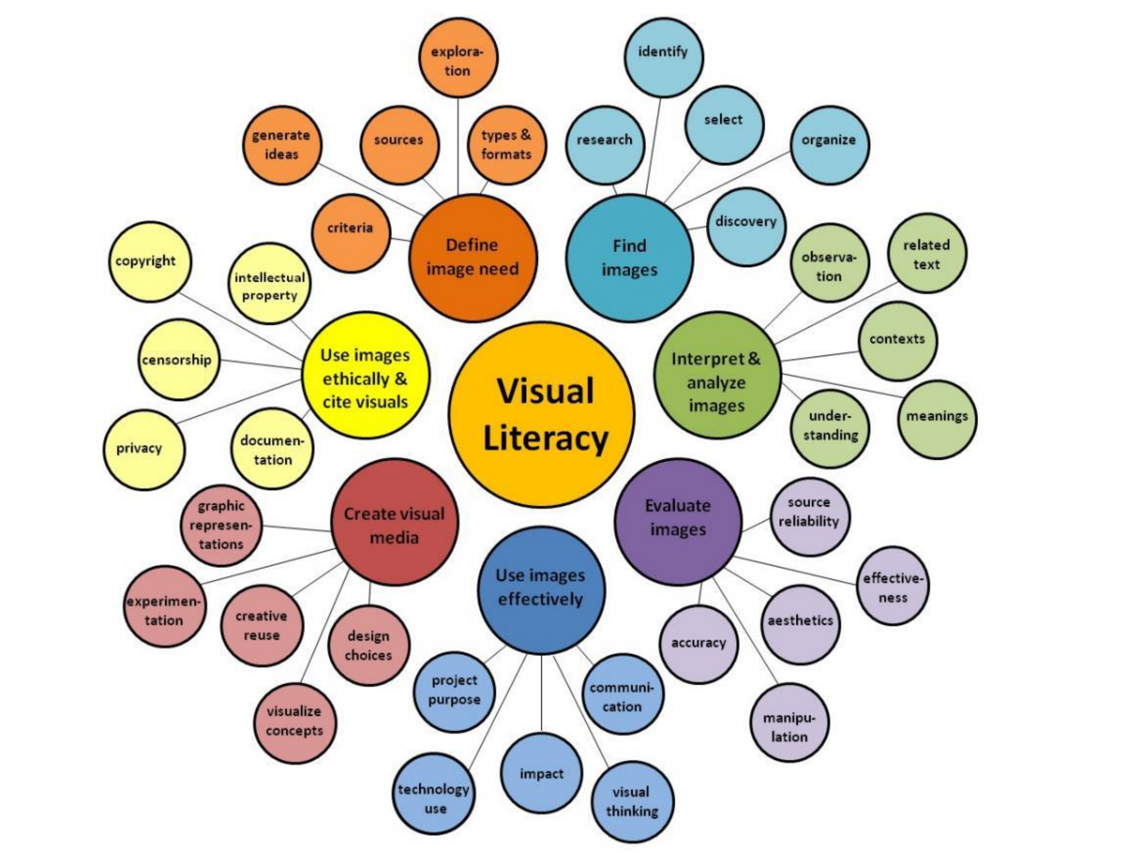

Figure 2-2: The Visual Literacy Array is representing the seven ACRL's Visual Literacy Standards with learning outcomes (Hattwig et al., 2013).

The fusion of visual literacy with data visualization is integral to the effective communication and comprehension of data-driven information (Mahmud et al., 2022). ACRL's standards for visual literacy provide a guiding framework that focusses on the development and application of skills essential for fields such as data visualization in academic and professional circles. Understanding and applying the principles of visual literacy enriches the process of creating, interpreting, and disseminating data through visual means, contributing to a more informed and visually literate society (Cao, 2023; Huilcapi-Collantes et al., 2023).

The ACRL Visual Literacy Competency Standards for Higher Education will be used as a starting point for the co-creation session (section 2.1.2).

3 Methodology

In this chapter, the methodology of the implementation of the living lab stages in this thesis are described.

3.1 Initiation & Plan development

The initiation and plan development stage consists of five sections. In the first section a systematic literature review analyzing nine published works between 2016 and 2023 on data visualization in higher education is done. In the second section, the stakeholders are represented through stakeholder mapping. In the third section, two initial interviews are described as preparation for the co-creation stage. In the fourth section, the setting for the co-creation session is explained.

3.1.1 (Systematic) Literature Review: Data visualization

Because of the lack of research in geo-data visualization in education, the literature review deals with data visualization in general. To delve into the existing body of knowledge surrounding the area of data visualization in higher education, this critical literature review focuses on exploring relevant research articles retrieved from the Scopus and Web of Science databases. A conference paper by F. Capra-Ribeiro called 'Visualization Research: Scoping review on data visualization courses' (Capra-Ribeiro, 2022) is comparable with this this literature review. This review is done independently from the conference paper.

3.1.1.1 Systematic article search

For this systematic literature review, an independent search is conducted in Scopus and Web of Science. The first criterium of the articles used in the literature review is to be of quality and integrity. Scopus states international experts review the content using quantitative and qualitative measures (Elsevier, 2023). Web of Science has independent editorial experts evaluating and selecting content (Clarivate, 2023). In both databases, the following search query was used to find relevant articles and papers:

> ALL "teach* data visualization" OR "data visualization course*" AND "education*" AND "data visualization*" AND PUBYEAR > 2004 AND PUBYEAR < 2024 AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (PUBSTAGE , "final"))

Initially there were 91 results of the search. After removing the irrelevant results according to the title, 26 were left. After analyzing the keywords and abstract, 11 papers were deemed relevant for the current study. Further text screening resulting in the removal of another two articles, coming to a final of 9 papers, as shown in the process for paper selection in Table 3-1.

Table 3-1: The steps in the process for paper selection are described with the number of papers left at each step.

Step	Description	Nr. of papers	
		Scopus	Web of Science
1	Search terms: "teach* data visualization" OR "data visualization course*" AND "education*" AND "data visualization*" AND PUBYEAR > 2004 AND PUBYEAR < 2024 AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (PUBSTAGE , "final"))	90	5
2	Merge and removal of duplicates	91	
3	Title screening	26	
4	Abstract and keyword screening	11	
5	Document located	11	
6	Text screening	9	
	Final number of reviewed papers	9	

The search is centered around the terms 'data visualization' and 'education', as they represent the core of this research. To combine these subjects and prevent the search from being too general, two other terms are added: 'teach* data visualization' and 'data visualization course*'. These last two terms cause the search engine to only include search results directly linking education and data visualization. Only results in the English language are included in the search, as another language is not readable for the reviewer. Also, only items in the final publishing stage are included to prevent non-finished work from becoming part of the review. In addition to this, only results from 2005 onwards are selected so the very outdated results are omitted.

The search is not limited any more, as specifying for example education in the Netherlands and geographical data visualization yields too few results. 21 of the 91 initial results originate within Europe and only one from the Netherlands. Three of these are specifically about data-visualization in education. When looked at the 9 chosen articles dealing with data-visualization education, none mentioned the geographical field, showing that the perspectives upon specifically geo-data visualization haven't been researched much and need further investigation. The 9 papers and articles included in the systematic literature review are listed in Table 3-2.

Table 3-2: The nine articles and papers included in the systematic literature review are described with the authors, year of publication and the document type.

Title	Authors	Year	Doc. Type
More than just charts and graphs: What to teach in a data visualization course	Camm J.D.; McCray G.E.; Roehm M.L.	2023	Article
Undergraduates' Perceptions on Data Visualization Consumption versus Production: It's Communication, but Is It 'Writing'?	Gunning S.K.	2022	Conference paper
Reflections and Considerations on Running Creative Visualization Learning Activities	Roberts J.C.; Bach B.; Boucher M.; Chevalier F.; Diehl A.; Hinrichs U.; Huron S.; Kirk A.; Knudsen S.; Meirelles I.; Noonan R.; Pelchmann L.; Rajabiyazdi F.; Stoiber C.	2022	Conference paper
Innovative Pedagogy for Teaching and Learning Data Visualization	Byrd V.L.	2021	Conference paper
A Didactic Framework for Analyzing Learning Activities to Design InfoVis Courses	Keck M.; Stoll E.; Kammer D.	2021	Article
Design Study "lite" Methodology: Expediting Design Studies and Enabling the Synergy of Visualization Pedagogy and Social Good	Syeda U.H.; Murali P.; Roe L.; Berkey B.; Borkin M.A.	2020	Conference paper
Facilitating Deep Learning Through Vertical Integration Between Data Visualization Courses Within an Undergraduate Data Visualization Curriculum	Byrd V.L.	2019	Conference paper
Learning Vis Tools: Teaching Data Visualization Tutorials	Lo L.Y.-H.; Ming Y.; Qu H.	2019	Conference paper
Teaching Data Visualization as a Skill	Ryan L.; Silver D.; Laramee R.S.; Ebert D.	2019	Article

3.1.2 Stakeholder mapping

For this project a range of stakeholders are identified and contacted to participate in the project process, including the co-creation session and interviews. A total of seven stakeholder groups are identified through a brainstorming session, each having an impact on the project and/or are impacted by the project. In this section, the internal and external stakeholders are identified.

As a result, two stakeholder maps are made to identify the key stakeholders and understand their interest and influence on the project and topics (section 4.1.2). The first stakeholder map shows the relative knowledge of the stakeholders of data visualization and of education. The second stakeholder map shows a Mendelow's matrix (Mendelow, 1981) used to analyze stakeholder groups based on their influence on the research and their interest in the research. As a result, the stakeholder groups are shown in four quadrants, representing the stakeholders manage closely, keep informed, keep satisfied and monitor. The outcomes are used in the implementation stage of this research to prioritize the statements made by the stakeholders and to analyze the results of the co-creation session and interviews.

3.1.2.1 Internal stakeholders

Internal stakeholders are entities with influence and impact through a direct relation in the research (Fernando, 2023). In this project, students, educators, and education institutes associated with geo-data visualization courses or studies are internal stakeholders. Both the students and educators are seen as end-users of the final product, recommendations for improving geo-data visualization courses.

Students of geo-data visualization courses and studies are impacted greatly by a change in course design and learning outcomes. They have knowledge about the current way the courses are set up and have views on what they want to learn. Changes made to the course have an impact on students' learning environment and their future career possibilities.

Educators of geo-data visualization courses are the stakeholders who have most knowledge about how the courses are created and have the biggest hand in altering the course goals, activities, and learning outcomes. A main goal of teachers is quality learning, which encompasses supporting students and educate them in the best way possible for them to have the best future and be able to contribute to society (Djoub, 2022).

Higher education institutions that provide geo-data visualization courses and studies are important stakeholders for this research, as they are responsible for the quality assurance of the education (Kettunen, 2015). One of the four main perspectives of higher education institutions is organizational learning: "This perspective describes the stakeholders that help the institution's personnel develop their capabilities to achieve high quality in the processes."(Kettunen, 2015). The main goal of this research fits that perspective perfectly. In addition, by increasing the effectiveness of their education, institutions will be able to attract more students and improve their image.

3.1.2.2 External stakeholders

External stakeholders are entities that participate in collaboration in research and development, support services and education (Kettunen, 2015). The external stakeholders in this research have specific expertise on a subject. Some of them are indirectly influenced by the research outcomes.

Organizations and institutions engaging in geo-data visualization require their employees to be able to address the specific needs and requirements of the company or institution. They have certain requirements that new employees must meet, sometimes expecting graduates to have mastered them in their studies. Their knowledge can help set a better view on what students need to learn to best start their future careers in the geo-data visualization field.

Alumni of geo-data visualization courses have intimate knowledge about the courses and can compare what they have learned to what is needed in their current working environment. They are the best bridge between education and the geo-data visualization industry.

Data visualization experts have intimate knowledge about visualization methods and have proficiency with data visualization software and tools. They can provide insight into tools and skills needed to become a data visualization professional and share their experiences of the best ways to learn. They can provide case studies illustrating how data visualization is applied in various domains.

Pedagogy experts have expertise in the educational system and teaching methods. They can introduce innovative teaching methods tailored to geo-data visualization, ensuring diverse learning styles are accommodated. By understanding how students learn best, pedagogy experts can contribute to structuring the curriculum to optimize learning outcomes and coherence.

3.1.3 Initial interviews

As preparation for the co-creation session and a first look into the stakeholder's perspective on the topic, two initial semi-structured interviews are done. In these interviews, the background of the participants is asked, and their perspectives of the research objectives are explored. The questions that lead the interview can be found in Appendix I: Questions interview. Both interviews are held in Dutch.

3.1.4 Co-creation plan development

The co-creation plan development will provide the setting of the co-creation session. Different stakeholders are invited to the session through personal contact, email, or reference.

The co-creation session takes place at the Amsterdam Metropolitan Solutions (AMS) Institute. When the participants arrive, they are welcomed in the reserved room with something to eat and drink.

3.2 Co-creation

This section presents the plan and agenda of the co-creation session and the additional interviews conducted.

3.2.1 Plan and agenda

The agenda created for the co-creation session in Amsterdam can be seen in Table 3-3. As it is a tight schedule, it is crucial that the participants stick to the planning.

Table 3-3: A schedule is made to fit all parts of the co-creation session in 1.5 hours, showing the start and end time, task, and formation.

Start	End	Task	Formation
10.00	10.10	Reception, explanation living lab, agenda, and goals, and introduction workshop and participants.	All
10.10	10:15	Break out in 2 groups, individually write down as many aspects of data visualization and put them on the whiteboards in the sections of the visual literacy standards they belong to.	Individual
10.15	10.25	Discuss within the groups whether they are in the right place and group together the similar aspects.	2 groups
10.25	10.30	Put stickers on the aspects you find most important.	Individual
10.30	10.35	Preparing small pitch with summary.	2 groups
10.35	10.40	Both groups present their findings in 2 minutes.	All
10.40	10.50	Break.	All
10.50	11.05	Take all aspects from the visual literacy standards and place them in the Venn diagram.	2 groups
11.05	11.15	Discuss in the two groups what the key takeaways are.	2 groups
11.15	11.30	Come together to finalize thoughts and discuss the outcomes. Share the final thoughts and wrap-up.	All

The session begins with an introduction about the research. The research topic and goal are explained and the plan for the co-creation session is shared. The concept of visual literacy and the standards by the ACRL are clarified, as they are the basis of the co-creation session. Also, the scope of the research is made clear, so that the participants will keep their input and discussions within this scope. The introduction takes a short time so that there is enough time left for the stakeholders to work together and co-create. At the end of the introduction, the stakeholders have time to introduce themselves and explain the relevance of this topic for them specifically. At any time, questions can be asked.

The participants are split up into two groups. All participants take a pile of post-its on which they write down as many aspects of data-visualization as they can in 5 minutes, after which they stick them on the whiteboard at the corresponding visual literacy standard, shown in Figure 3-1. The next step is to, within two separate groups, discuss whether they are put in the right place, and to combine the post-its that are similar. When they agree upon the status of the board, the participants receive five stickers in a color representing their stakeholder group, which they put on any of the aspects they find most important in data visualization. Students get green stickers, educators yellow, experts blue and alumni purple. The last part before the break is to prepare and give a small pitch about what your group found and talk about the things that stand out.

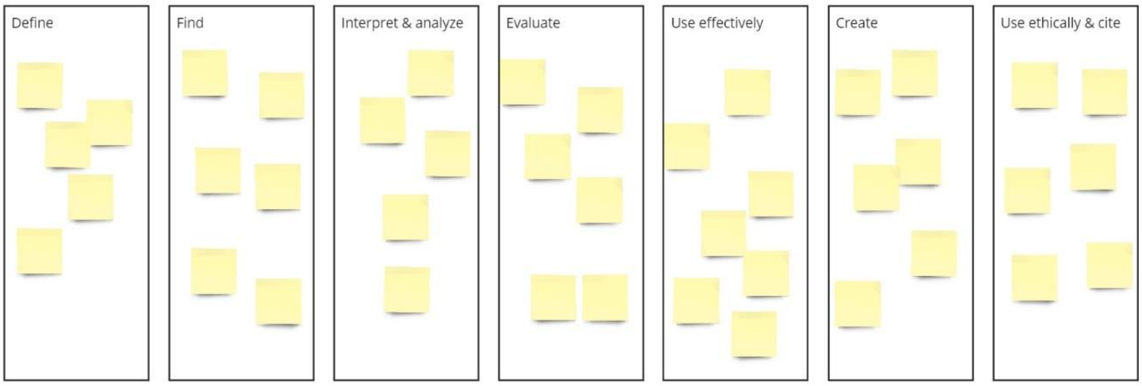

Figure 3-1: The seven components for the standards simulate the whiteboard used in the first part of the co-creation.

After the break, the groups are mixed so that other perspectives might be generated from discussions and dialogue. The two groups take all the aspects that they put on the whiteboards and place them on the other side of the whiteboards in a Venn diagram containing two ovals and an overlap between them, shown in Figure 3-2. One oval represents aspects that the participants have been taught in their studies, and the other oval represents the aspects that the participants have used in their working environment. The aspects that are both taught and used are put in the overlapping part. During and after this step, discussing the placement of the post-its and the takeaways of this representation of data visualization is encouraged.

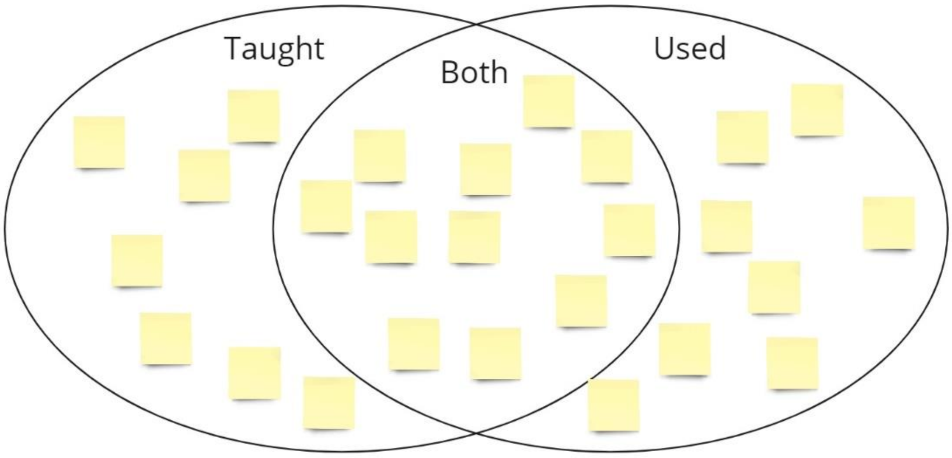

Figure 3-2: The Venn diagram with three categories simulate the whiteboard used in the second part of the co-creation.

Writing down discussion points, results, questions, and other input for the research is also encouraged. The process discussed above is open to adaptions depending on what the situation brings. At the end of the co-creation session, all participants work together to sum up the conclusions and share final thoughts of the session and the groupwork.

3.2.2 Additional interviews

Two additional interviews are held to complement the data gathered in the co-creation session. The structure and questions are the same as the two initial interviews done before the co-creation session. The main difference between the initial and additional interviews is the knowledge of the discussion points and points of attention of the co-creation session, which resulted in the ability of the interviewer to touch upon these points and be able to gather the views of the interviewed stakeholders. One of these points is that is further clarified in the additional interviews is the difference between what is needed for doing their job versus what was taught to them in their data visualization education. All four interviews are analyzed independently of the co-creation data. The main views and points of attention of the interviewees are analyzed, compared, and ultimately used to make recommendations for data visualization education in the Netherlands.

3.3 Implementation

3.3.1 Analysis co-creation data

During the co-creation session, photographs are taken of the resulting output of the stakeholders on the whiteboards at different times, so that the data is saved and can be worked with. Also, discussion points are written down so that they are remembered and included in the analysis.

The data gathered is pre-processed and put into an Excel worksheet. The rows represent different aspects and have information about to what standard it belongs to, what category of the Venn diagram it was in, the number of importance stickers and what stakeholder found it important, and the number of similar post-its which together representing an aspect of data visualization. Similar aspects of both groups are merged in order to get distinct aspects.

For each aspect, a relevance score was given between one and five, where a higher score is a better relevance. The score is based on the number of similar post-its representing one aspect and on the amount of importance stickers an aspect received. The following rules were applied:

1: An aspect represented with one post-it and no importance stickers.

2: An aspect represented with multiple post-its and no importance stickers.

3: An aspect with one importance sticker.

4: An aspect with two or three importance stickers.

5: An aspect with more than three importance stickers.

The relevance score represents the relevance of aspects in the data visualization field according to the stakeholders. Logically an aspect with more stickers is considered more important. The amount of similar post-its is also considered, as multiple people acknowledged the aspect in the initial brainstorm, which speaks to the significance of the aspect in the field. Although many aspects did not receive importance stickers, a data visualization aspect that multiple stakeholders are familiar with and thus recall as aspect are more relevant in data visualization education than an aspect which a single stakeholder recalled.

After preprocessing, the data is represented in an alluvial diagram with three axes, standard, category, and relevance. Additionally, bar charts and tables are created showing numerical and percental data presented in the diagram. The diagram and tables are created in R Studio and Microsoft Excel.

The created diagram and tables are analyzed by finding results that stand out and a common description of the results. The analysis is enriched with discussion points and output from the stakeholders.

3.3.2 Analysis interviews

For the analysis of the interviews the answers of the interviewees were reviewed and ordered in a matrix for easy comparison. For each standard, the usage in their working environment and the degree of presence in their education was looked at and compared. In addition to this, their conclusions about what is needed more in education and what the technical and general work requirements are for working in their companies are reviewed. Their points of emphasis and their common perspectives together with the significant differences are used for drawing conclusions and generating recommendations. The results of the interview are matched and compared with the co-creation results.

3.3.3 Initial recommendations

Initial recommendations are generated from the results of the literature review, co-creation session and the interviews. The common and notable points are summarized and formulated as recommendations in clear and compact sentences.

3.4 Evaluation

3.4.1 Data suitability

In evaluating the suitability of the gathered data from the co-creation, various data characteristics are assessed and reviewed. The limitations of the suitability of the gathered data is explored by touching upon the use and design of visual literacy as framework and the use of the Venn diagram as classify method in the co-creation. Also, the data from the co-creation and interviews is compared with focus on the ability to answer the research questions and match the research objective.

3.4.2 Data representativeness

In evaluating the representativeness of the gathered data from the co-creation, various data characteristics are assessed and reviewed. The data's ability to represent the situation is explored by looking at the completeness of the aspects representing the broad field of data visualization, variation in stakeholder representation in the co-creation session and interviews and their ability to represent the audience.

3.5 Refinement & Dissemination

In this last living lab step, the recommendations generated in the implementation step are reviewed and adapted to specifically fit geographical data visualization in higher education in the Netherlands. The refined recommendations are summarized in compact, to-the-point sentences.

4 Results

In this chapter, the results of the implementation of the different living lab stages can be found. They cover the systematic literature review and stakeholder mapping, co-creation session and interviews with initial recommendations, evaluation of representability and suitability of the data and finally the generated refined recommendations.

4.1 Initiation & Plan development

4.1.1 Systematic literature review

This systematic literature review of the nine selected papers (Table 3-2) in section 3.1.1 identifies how data visualization courses and curricula are created, what the goals and objectives are, what the challenges are and what is needed for success in these courses and curricula. The nine papers contribute diverse perspectives on data visualization education, encompassing both theoretical frameworks and practical implementations of course designs, curricula, and insightful analyses of challenges and needs. The selection process of the papers is described in section 3.1.1.

4.1.1.1 Increasing importance

One of the main trends in the selected papers is the field of data visualization becoming more and more important for graduates in the current data-driven society. "To be competitive in the data driven workforce, students must be introduced to the process of visualizing data early and often."(Byrd, 2019). There is a strong demand for people with data visualization knowledge and skills in the industry (Camm et al., 2023). In the paper by Ryan et al. (2019), the skill need for the data visualization industry was researched by examining the visualization skills and software competencies that are in high demand in the industry. They state that, despite technical skills like programing are very important for a job, communication skills outrank them. Additionally, there is a difference in views on what data visualization is in education and industry. Some papers suggest that data visualization is a field or discipline (L. Y.-H. Lo et al., 2019; Syeda et al., 2020), where others consider it a skill or a subfield of many other disciplines (Byrd, 2019; Camm et al., 2023; Gunning, 2022), or even a process or tool (Byrd, 2021; Keck et al., 2021). Currently many data visualization courses are constructed and given as part of a broader study field and by an instructor with a multidisciplinary background, sometimes causing a lack of expertise (Camm et al., 2023). "Such a diverse audience poses a big challenge to the teaching of guided tutorials." (L. Y.-H. Lo et al., 2019). Ryan et al (2019) comments on the challenge for educators in higher education to keep pace with the changing demand and the fluctuating industry expectations. Most papers agree that education in data visualization should improve and share curriculum designs, differing in size, duration, process, setup, and goals (Byrd, 2019; Camm et al., 2023; Keck et al., 2021; L. Y.-H. Lo et al., 2019; Roberts et al., 2022; Syeda et al., 2020).

4.1.1.2 Course learning objectives

Another trend seen in most of the papers is the need for a specific idea, goal or objective behind the course and curriculum design (Byrd, 2019; Camm et al., 2023; Keck et al., 2021; L. Y.-H. Lo et al., 2019; Roberts et al., 2022; Syeda et al., 2020). A variety of considerations can be made in the preparation of a course. The choices made must be balanced and selective, as the whole data visualization spectrum is far too extensive to be able to handle in one timespan of a course (Roberts et al., 2022). The wide extend of data visualization has many branches that can be taught in different level courses, which can fit well together in a major (Byrd, 2019). This will however result in a difference in prior knowledge, which needs to be addressed in learning activities (Keck et al., 2021). Three categories of data visualization courses exist according to Camm et al. (2023). Most are exclusively focused on the design/construction of visual representations. Another category is courses where data visualization is combined with technical aspects and context of other topics like data acquisition and data management, and a third category is data visualization paired with communication topics with the context of topics like influencing and storytelling. Gunning (2022) states that one of the first considerations is whether the course mainly focusses on reading or creating visualizations. In many courses they are used together as they complement each other, however the learning objectives should be made clear (Keck et al., 2021). Keck et al. (2021) concludes that all learning activities need to be aligned with the learning objectives and outcomes and should be made transparent, which is a core message in other papers as well (Camm et al., 2023; L. Y.-H. Lo et al., 2019; Roberts et al., 2022; Syeda et al., 2020). Byrd (2021) adds to this that learning objectives are building blocks where the knowledge and skills gained should be made clear and Roberts at al. (2022) and Lo et al. (2019) make clear that for all learning objectives the right tools should be selected for the best results for the task at hand. All teaching methods should be adapted to the audience and their interest, as the landscape of visualization tools and methods changes rapidly and can become obsolete fast (L. Y.-H. Lo et al., 2019).

4.1.1.3 Curriculum design

Some selected papers provide curriculum designs and frameworks as inspiration or for usage in newer courses or programs. Some of them rely purely on the visualization process (Camm et al., 2023; L. Y.-H. Lo et al., 2019) while others are merged with pedagogical theories (Byrd, 2019, 2021; Keck et al., 2021; Roberts et al., 2022). Camm et al. (2023) mentions three fundamentals for visualization design, regardless of topic or context: creating the initial version, sanitizing the visualization, and refining the visualization. There is overlap with other curriculum designs that are more comprehensive. For example, Byrd (Byrd, 2021) explains their use of the data visualization process, based on B. Fry (2008), in both her articles. These steps are getting data (acquire), breaking the data into its component parts (parse), removing all but the data of interest (filter), exploring the data for patterns (mine), creating visual representations of the data (represent), improve some part or component of the visualization (refine) and lastly, adding functionality to enable the viewer to engage with the data (interact). In the same way, Syeda et al. (2020) describes a more methodological framework focused on education rather than the visualization process only. It is an abridged version of the design proposed by Sedlmair et al. (2012): learn, winnow, cast, discover, design, implement, reply, reflect and write. Keck et al. (Keck et al., 2021) has designed learning activities based on a didactic background using the revised taxonomy from Bloom (Krathwohl, 2002). The data visualization activities are categorized in a matrix where the cognitive processes remember, understand, apply, analyze, evaluate, and create are matched with the knowledge dimensions factual, conceptual, procedural, and metacognitive.

The bases of these frameworks diverge from each other with specific contents but are also quite similar in some respects, as they all envelop a specific process with a central goal; improving data visualization courses and enhancing the way of studying. The use of these frameworks and designs can be adapted by educators for their purpose and goals, however, when attempting to design a course not solely based on data visualization process, the frameworks by Syeda et al. and Keck et al. are more usable. The former is designed to be used in a project-based course, while the latter can be implemented for a wide variety of course setups. The different curricula designs and frameworks can be applied and changed to fit the considerations made by the course designer. Depending on choices of course setup, some frameworks may be a better fit than others.

4.1.1.4 Challenges and recommendations

The analyzed papers mention challenges that arise and recommendations that should be included in a data visualization course. In the paper by Roberts et al. (2022), fourteen educators in visualization from broad and diverse backgrounds reflect on their experiences and draw a total of nine strategies to be used in data visualization classes. These resulting strategies help educators design the learning activities. As mentioned before, the learning activities in class should be aligned with the learning outcomes and objectives. By using the right tools and strategies for activities and keep the level of difficulty fitting, students are kept eager and engaged (Roberts et al., 2022), leading them to the learning objectives better. Visualization activities on higher level of the cognitive process dimension often need skills from lower dimensions. Combining these processes and skills within activities is a good way to deal with this (Keck et al., 2021). Addressing a lack of prior knowledge can be done by using non-computer tools (Roberts et al., 2022). For the advanced students, this can be compensated by including optional material (L. Y.-H. Lo et al., 2019).

It is often difficult for educators to assess the products and whether learning objectives are achieved by students (Byrd, 2021; Camm et al., 2023). The use of self-evaluation or self-assessment might help with this and is an addition to an active learning environment, also supported by letting students decide parts of activities, as it increases their motivation by adding meaningfulness (Keck et al., 2021). Activities and challenges relating to social issues with local impact provide a different lens, giving more meaning to students' efforts (Byrd, 2019). Using datasets and material to which students can relate can be an example of this (L. Y.-H. Lo et al., 2019). "Motivation is increased further by offering to incorporate content that is meaningful to learners, create collaborative social environments, and enabling self-efficacy." (Keck et al., 2021). A key component of data visualization and its process is iteration, which can take a lot of time in a course (Syeda et al., 2020). Recommendations for handling abundance of material in data visualization and limited time are explained by multiple papers as well. Pre-defined feedback sessions and working with pre-curated data are examples of reducing time stress. Additionally, maintaining effective communication and setting realistic expectations are recommended (Syeda et al., 2020).

4.1.2 Stakeholder mapping

Mapping of the stakeholders resulted in two stakeholder maps to research the stakeholder interactions. The first stakeholder map shows the variety in experience and knowledge about the two main fields regarding this research, education, and geo-data visualization (Figure 4-1). The second stakeholder map (Figure 4-2) is created based on Mendelow's matrix (Mendelow, 1981)(section 3.1.2). Some stakeholder groups can overlap. For example, visualization experts and educators are often also alumni, and alumni, educators and students can all be part of the company stakeholder as well.

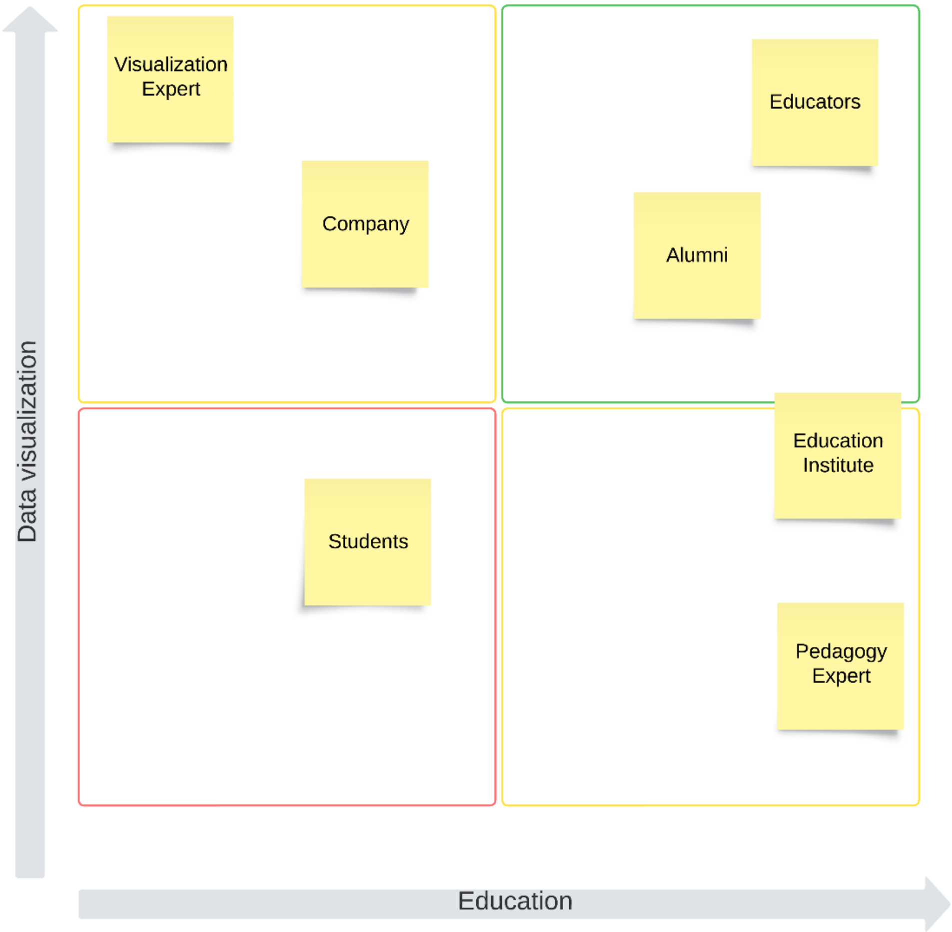

Figure 4-1: The stakeholder map shows each stakeholder type's knowledge about education and geo-data visualization.

Figure 4-1 shows the expertise and knowledge of the stakeholders on the two main fields in this research represented on the axes. The colors of the areas and the stakeholders are shown in a color scale from red, with less knowledge and expertise overall, to dark green, with much knowledge and expertise overall. Students in this sense have the least knowledge about both fields, as they are still learning about the field and have little experience in the educational aspects. Educators have the highest amount of knowledge and expertise overall, having experience teaching and creating courses in the field of geo-data visualization, among others.

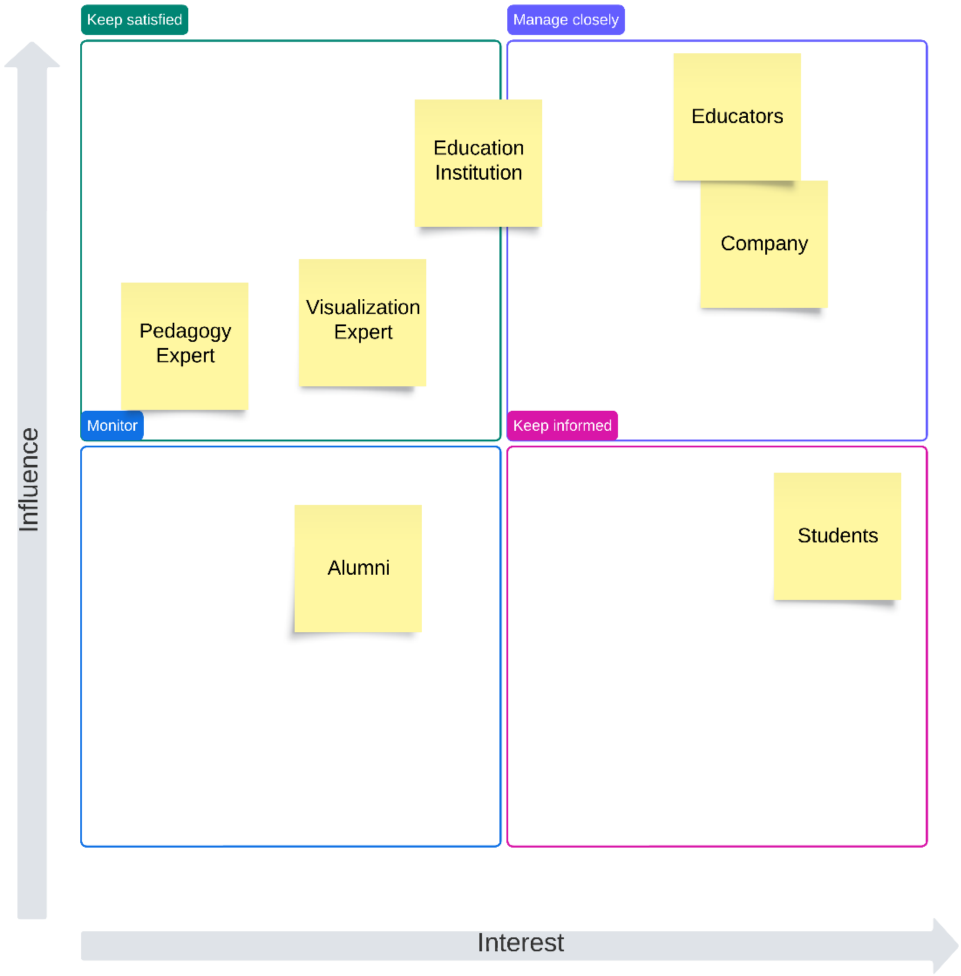

Figure 4-2: The stakeholder map represented in Mendelow's matrix shows the interest and influence each stakeholder type has on the research.

In this Mendelow's matrix, the seven stakeholders for this research are shown in four quadrants, representing the stakeholders to manage closely, keep informed, keep satisfied and monitor. The stakeholders in these quadrants need to be handled differently. According to J. Spruce, an enterprise agile coach, the following guidelines should be regarded when engaging the stakeholders (Spruce, 2023):

- Manage closely: You must fully engage with these stakeholders and make significant efforts to help to deliver their outcomes.
- Keep satisfied: Put enough work in with these stakeholders to keep them satisfied, but not so much that they become bored.
- Keep informed: Keep them informed and talk to them to ensure no significant issues arise.
- Monitor: Monitor these stakeholders, but do not bore them with excessive communication.

4.2 Co-creation

4.2.1 Co-creation session

At the co-creation session in Amsterdam, there were 13 attendants, including the researcher. They represent four different stakeholders. Three educators, two data visualization experts, four students, and four alumni. In the initial group division, there were three students, one educator, one alumnus and one expert in group 1, and one student, two educators, two alumni, and one expert in group 2. As mentioned in section 3.2.2, a clearly absent perspective on the topic was from the stakeholder type 'company'. The stakeholder data visualization expert will be referred to as expert hereafter.

Initially the participants of the stakeholder session found it difficult to write down aspects of data visualization. After the explanation that writing down anything relating to data visualization was the intention, the stakeholders gained a lot of ideas and started formulating aspects. When the collaboration part with the other stakeholders started, it was apparent that all participants found the topic engaging.

First the stakeholders put 123 post-its on the boards, which were grouped on the two individual boards into 86 aspects, of which one is shown in Figure 4-3. When merging the aspects of the boards, there were 75 different aspects left. Three aspects were not put in either taught, used or both in the Venn diagram. As this means that these aspects are not taught or used by the stakeholders, they are irrelevant for this research, so they were left out of the analysis. In the end, 72 aspects are analyzed. The output of the Venn diagram for one of the groups is shown in Figure 4-4.

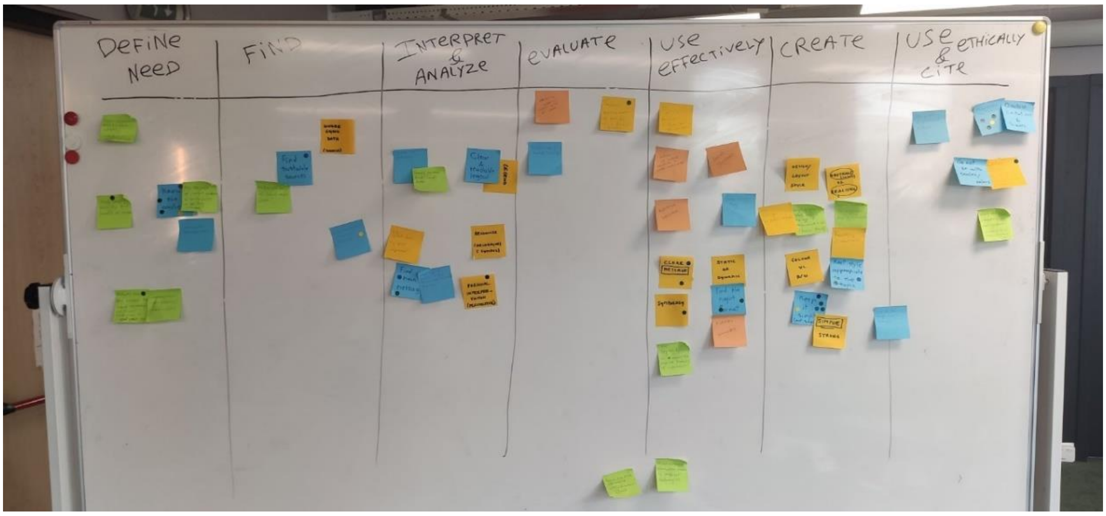

Figure 4-3: A picture of the output of the first part of the co-creation session from one of the groups is, where post-its are put on the standards, gives a view of the co-creation activity.

Figure 4-4: A picture of the output of the second part of the co-creation session from one of the groups, where post-its are put on the Venn diagram, gives a view of the co-creation activity.

4.2.2 Interviews

In total four interviews were conducted with employees of different companies. The names of the companies and employees are redacted for privacy reasons. During the co-creation session, no company stakeholder was able to attend, which was clearly a missing perspective according to the attendants and researcher. The last two interviewees are chosen to fill this stakeholder gap. Table 4-1 describes their function, company and industry, and responsibilities and focus area.

Table 4-1: Four interviews were held in the co-creation step. Their function, company and industry, and responsibilities and focus area are described.

Interviewee	Function	Company/Industry	Responsibilities and Focus areas
1	Manager Data Analytics	International company specializing in street and aerial image mapping.	Provides and analyzes data, creates applications and APIs for clients in the Netherlands, Europe, and the USA. Visualizes results in maps and overlays in web view applications for integration with client programs.
2	GIS specialist	Small consultancy focusing on nature and forest-related themes for small and large landowners.	Works on tasks ranging from tree counting to GIS analytics and lidar scanning. Specializes in assisting landowners with nature and forest-related questions.
3	Junior GIS specialist	GIS consultancy serving multiple clients internally.	Collaborates with clients on internal systems to solve GIS-related problems, daily tasks, and provides support. Works with various visualization types, including maps, dashboards, and presentations.
4	Data Analyst & Customer Success Specialist	Remote sensing company specializing in monitoring and inspection services using optical and radar satellite data.	Focuses on data analytics, research, and surveillance of supply pipelines. Engages in systems optimization, testing new monitoring methods, automating workflows with machine and deep learning, and interference detection with AI. Detects third-party interference in supply pipelines.

4.3 Implementation

In this section, the results of the co-creation session and the interviews are analyzed using visualizations, tables, and statistics. In the co-creation session analysis, the standards, Venn diagram and importance, and the relevance of aspects are inspected. In the interview analysis, the job requirement, importance of standards and potential improvements in education are reviewed. From these analyzed results, ten initial recommendations for improvement of data-visualization education are generated.

4.3.1 Co-creation session analysis

From the data gathered during the co-creation session, the alluvial diagram in Figure 4-5 and Table 4-2 to Table 4-6 were created. In Figure 4-5, the relation between the standards, Venn diagram categories and the relevance score of the aspects explained in section 3.3.2 can be viewed. The diagram presents a clear overview of the number of the proportion of aspects present in each standard in the first axis, where 'define' has the smallest number and 'interpret and analyze' the largest number of aspects. Each proportion of aspects from the standards flows to the category of the Venn diagram it belongs to in axis two, where it is clear most aspects are both taught and used, and 'define' is the largest portion of aspects only taught, while 'use ethically and cite' is the largest proportion of only used. These proportions then flow towards the third axis where the proportions of the standards with a certain relevance score is visualized. In this axis it is visible that 'define' has most aspects with relevance score 5 and 'find', 'interpret and analyze', and 'evaluate' have no aspects considered highly relevant with a score of 5.

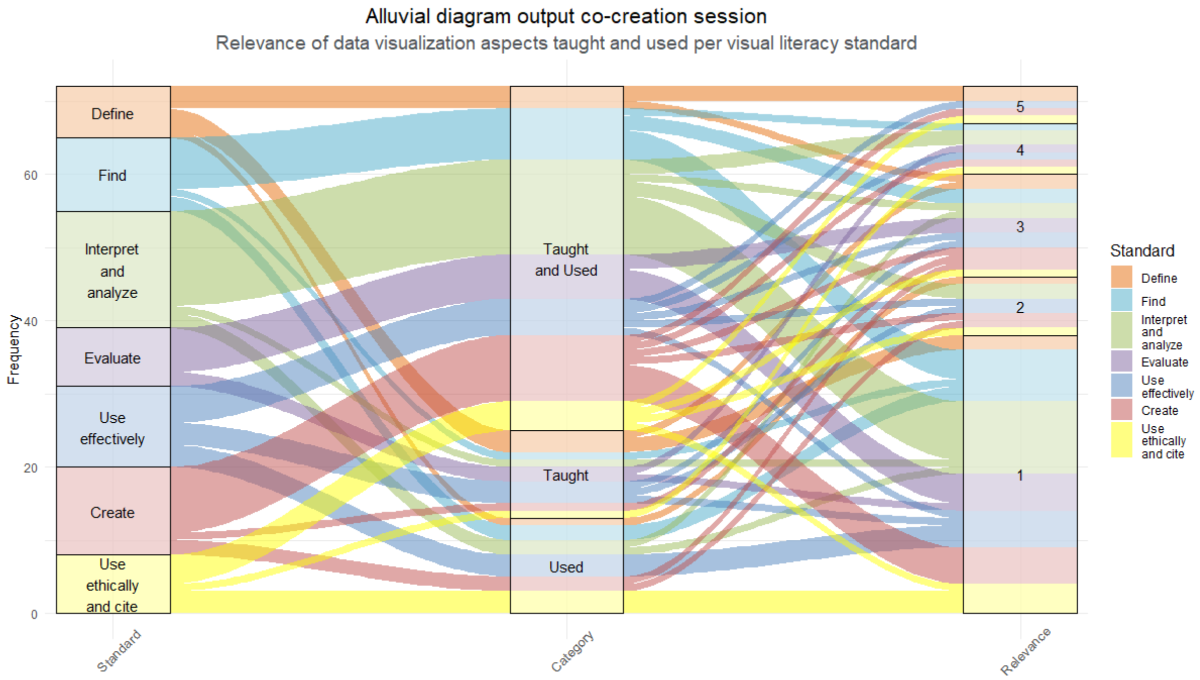

Figure 4-5: The alluvial diagram shows the main output of the co-creation session. The flows between the aspects placed in the standards (axis 1), the categories of the Venn diagram (axis 2), and their relevance score (axis 3) can be followed.

4.3.1.1 Standards

When looking at the amount of data visualization aspects present per standard in Table 4-2, we see 'define', 'evaluate', and 'use ethically and cite' have the least aspects with either seven or eight. 'Find', 'use effectively', and 'create' have ten, eleven, and twelve aspects respectively. 'Interpret and analyze' has the most with sixteen aspects, almost a fourth of the aspects (22.2%). This means that according to the stakeholders present at the co-creation session, the standard 'interpret and analyze' is the broadest in terms of topics and material.

Table 4-2: The number of post-its, aspects, importance stickers, important aspects and average relevance score is calculated for every standard. Some statistics referred to in this section are coloured.

Standard	Post-its	Aspects	Importance stickers	Important aspects	Average relevance score
Define	21	7	13	4	2.85
Find	16	10	5	3	1.7
Interpret and analyze	20	16	7	4	1.75
Evaluate	11	8	4	3	1.9
Use effectively	18	11	9	4	2.18
Create	19	12	10	5	2.25
Use ethically and cite	15	8	11	3	2.25

When looking at the number of post-its put at each standard, the ability to recall aspects of that standard can be seen. The more post-its present at a standard, the more the stakeholders thought about that standard when writing down aspects of data visualization. The standard 'define' stands out in this context, as it is the standard with most post-its and least aspects at the same time (Table 4-2 , Yellow). On top of that, it is the standard with the most importance stickers on aspects and highest average relevance score of 2.85 (Table 4-2, Green). What we can take away from this is that 'define' is a visual literacy standard with a small group of aspects that are generally viewed as important compared to aspects of other standards. 'Knowing the audience' and 'Thinking carefully about the true benefit or purpose of visualizations' are central aspects of the standards and considered very important.

Like 'define', 'use ethically and cite' and 'create' have a high average relevance score (2.25, Table 4-2). For 'use ethically and cite' the reason is, like 'define', more importance stickers than aspects. For 'create' the reason is the most important aspects, aspects with importance stickers, compared to the other standards. Both result in a larger number of important aspects, and thereby a higher relevance score. The aspects of the standard 'use effectively' have an average relevance score of 2.18.

The aspects of the standards 'evaluate' (1.9), 'interpret and analyze' (1.75), and 'find' (1.7) have the lowest relevance score. Especially 'evaluate' stands out with both the lowest number of post-its and lowest number of importance stickers (Table 4-2, Blue). Also, as mentioned before, 'evaluate' has a low number of aspects, however this is a logical result from the low amount of post-it's the stakeholders matched with the standard.

Most standards either have three or four aspects perceived as important. Only 'create' has five (Table 4-2, Pink). This shows that, however broad, specific, or relevant the aspects in standards are, the extent of important aspects is remarkably similar.

4.3.1.2 Venn diagram and stakeholders

When looking at the results of the Venn diagram represented in the middle axis in Figure 4-5, it is very clear that most aspects of data visualization are both taught and used with more than 65%. The categories used and taught were assigned a similar percentage of aspects (Table 4-3). The fact that most aspects are both taught and used by the stakeholders is positive and leads to a productive and meaningful view on the way of data visualization education in the Netherlands.

Table 4-3: The number and percentage of aspects per category of the Venn diagram is calculated from the results of the co-creation session. Most aspects are both taught and used.

Aspect count and percentage per category

Category	Amount	percent
Taught	12	16.7
Taught and Used	47	65.3
Used	13	18.1

Notably, there are only seven aspects – of 27 total - considered important that are only taught or only used. The stakeholders that found these aspects important were either students or alumni. Mostly the students found aspects that have only been taught to the stakeholders important, while alumni were responsible for the important aspects in the category 'used'. The aspects in category used were 'personal interpretation' and 'tools, plug and play, programming, apps', both with a relevance score of three. Students finding data visualization aspects important that are only taught is a logical result of the co-creation, as students do not have much experience in the data visualization industry. These results can even help reviewing what students have been taught to be important aspects, while other stakeholders do not agree (Table 4-4). From these results, aspects that are taught in abundance and with too much focus can be identified and a recommendation for a switch of focus can be made.

Table 4-4:The data visualization aspects considered important by students only are presented together with their respective standard, category, number of importance stickers, number of similar postits, and their relevance score. Lack of importance stickers from other stakeholders suggests a misplaced focus in education.

Aspects only important to students					
Aspect	Standard	Category	Nr Importance stickers	Nr similar	RelevanceScore
Inclusive	Create	Taught	1	0	3
Mitigate the gap between the formal presentations and personal representations of a place	Define	Taught	1	1	3
Factual representation of perhaps not so factual information	Evaluate	Taught and Used	1	0	3
Test - end users - target group	Evaluate	Taught and Used	1	1	3
History of data	Find	Taught and Used	1	1	3
Symbology	Use effectively	Taught	1	0	3

The amount of importance stickers each type of stakeholder placed on aspects of the standards is visible in Table 4-5. These results show another way of reviewing the importance of the standards for each stakeholder. For students, aspects from the standards 'define', 'use effectively', 'create', and 'use ethically and cite' are considered most important. Overall, both 'define' and 'use ethically and cite' are the standards with the highest number of stickers, however remarkably the experts are less in agreement with this. Another result that stands out is the lack of stickers on the standards 'evaluate'. It is the only standard where types of stakeholders put no stickers, namely educator and expert. Clearly aspects of this standard are considered least important overall.

Table 4-5: The number of importance stickers per stakeholder type and the total number of importance stickers is shown for each standard. Evaluate stands out with no stickers from educator and expert. The expert finds the standards with most stickers less important than the other stakeholders.

Importance per stakeholder					
Standard	Student	Educator	Expert	Alumni	Total
Define	4	4	1	4	13
Find	1	2	1	1	5
Interpret and analyze	1	2	2	2	7
Evaluate	2	0	0	2	4
Use effectively	4	2	2	1	9
Create	4	1	3	2	10
Use ethically and cite	4	3	1	3	11

4.3.1.3 Relevance

All aspects with a relevance score of four or five, except one, were put on the boards multiple times by the stakeholder and 75% was present on both the separate boards. Of the other 25% was mentioned that the stakeholders of the other group also found these very important. This shows that the aspects perceived as important by the stakeholders are also recalled by multiple stakeholders and speaks to the familiarity and clarity of the important and relevant aspects.

All aspects with a relevance score of 4 or 5 are shown in Table 4-6. The standards and categories, and the amount of stickers per stakeholder can be read. These most relevant data visualization aspects should lay the foundation of data visualization education, both in theory and practice. A takeaway of one of the stakeholders during the co-creation session was "we have to tailor our visualizations to the audience, have a clear and simple message to transmit and keep in mind the biases and error margins in the images we create, consume and present."

Table 4-6: All data visualization aspects with relevance scores 4 or 5 are shown with their full statistics. From the twelve most relevant aspects, the standard, category, number of importance stickers total and from the stakeholder types, the number of similar post-its and the relevance score can be viewed. The aspects are shown in order of relevance and importance.

Aspects with relevance score 4 or 5									
Aspect	Standard	Category	Nr Importance stickers	Student	Educator	Expert	Alumni	Nr similar	RelevanceScore
Understand the biases	Use ethically and cite	Taught and Used	8	3	2	1	2	3	5
know the audience	Define	Taught and Used	7	2	3	1	1	7	5
Keep it simple	Create	Taught and Used	5	2	1	1	1	1	5
Think carefully about the true benefit of visualizations	Define	Taught and Used	4	1	1	0	2	2	5
Communication	Use effectively	Taught and Used	4	1	2	1	0	1	5
Data availability	Find	Taught and Used	3	0	2	0	1	2	4
Data quality! - linkability	Interpret and analyze	Taught and Used	3	0	2	0	1	0	4
Choosing effective visual product, graph type and format	Use effectively	Taught and Used	3	2	0	1	0	2	4
Keep style appropriate to the topic	Create	Taught and Used	2	1	0	1	0	2	4
Readability	Evaluate	Taught	2	0	0	0	2	2	4
Find main message	Interpret and analyze	Taught and Used	2	1	0	1	0	2	4
Misleading representation	Use ethically and cite	Taught	2	1	0	0	1	3	4

4.3.2 Interview analysis

Four interviews were conducted with employees of companies working in the data visualization field and thus representing the 'company' stakeholder (sections 3.1.3 and 3.2.2). Their perspectives on the standards were asked in the working environment and their education (section 3.3.2). The four interviewees are employees with varying functions from varying companies (section 4.2.2).

4.3.2.1 Job requirement

Almost all interviewees stated that in data visualization professions a basic knowledge and skills in data visualization and the applications and software used is most important for graduates. Depending on the focus of the company and the activities done, more specific skills are needed like programming. Interviewee 4 explained that for their work, experience with satellite data, programming and machine learning is greatly appreciated. Also, the ability to translate and simplify data and outputs to clients is an important skill according to multiple interviewees. All the interviewees mentioned that in their working environment there are options to learn and refine skills and to be educated during work. It is normal to be lacking some skills, as data visualization and GIS in general are such widespread fields. Some companies offer classes or traineeships and others share knowledge with colleagues through presentations or plainly working together to find solutions. In addition to practical data visualization skills, all interviewees stated the importance of non-technical competencies. Communication, working together, independence, problem solving and being solution oriented, and pro-activeness are skills that were said to be of importance multiple times. One of the more important and relevant data visualization aspects according to the results of the co-creation, communication, matches this view (Table 4-6). Interviewee 1 stated that these competencies might be more important than the practical skills, as practical skills are easier to learn and refine.

4.3.2.2 Standards

Interviewee 1 did not have much explicit knowledge about the use of data visualization of his employees and had no education on data visualization. The questions about the visual literacy standards were asked to interviewees 2,3, and 4. This section explains the importance of the standards for the interviewees' profession and the presence of the standards in their education.

The standard 'define' is for interviewee 2 very important in his work, as his clients mostly do not know what they want, and they need to acquire their own concepts and ideas to satisfy them. This need matches with the data visualization aspect 'know the audience' (Table 4-6). Interviewees 3 and 4 do not agree and state that this standard is preset for them, as only basic knowledge is needed because their clients know what they want and there is no need for defining the data visualizations. In education interviewee 3 says she has not been taught any guidelines for this standard and interviewee states that in the Netherlands this is not really taught, whereas it was in her bachelor in Spain. She does state that an important thing she learned was learning to keep data visualizations as simple as possible and to have as much information as possible. This is emphasized by the results of the co-creation session, where an important aspect is 'keep it simple' (Table 4-6).

Interviewee 2 states the standard 'find' is not very usable in niche markets like theirs, as most visualizations are created by themselves. The same argument was mentioned by interviewee 3, as they get their data from clients. For interviewee 4 it is very important when developing tools, as they need to be approved when using commercially. This connects to the seventh standard. In education the finding visuals is left for the students themselves. This is confirmed by an alumnus in the co-creation session, where he mentioned they discussed about quality of initial data, even though according to him students do not learn anything on how to identify bad data or dubious sources.

All interviewees agree on the high importance of the standard 'interpret and analyze'. This skill is focused on a lot in education and used often in their work. Explanation and context are very important in this standard, as well as background knowledge and multidisciplinary knowledge. This links to the aspect of 'finding the main message', viewed as very relevant (Table 4-6).

The standard 'evaluate' exhibits variations in importance. Interviewee 2 emphasizes the collaborative nature of evaluation in their work, making the standard less important for the individual, while interviewee 3 notes its absence in studies and highlighted the need for more education on evaluating sources and metadata. Interviewee 4 notes evaluation of visual data has a long learning curve, which expects people to learn after their studies.

Across all interviews the standard 'use effectively' is viewed as important in the working environment, as well as it being taught in education. The clients need to understand the meaning behind the insights presented, as they need to use them and work with the results. Especially in internships and project courses working together with the industry the standard is handled.

The standard 'create' was regarded as important by all interviewees, both in the working environment and in education. They mention that this aspect is handled extensively in the studies. Interviewee 4 notes that it is one of the most important standards and is closely linked to 'use effectively'.

About the standard 'use ethically and cite' the interviewees mention that it is not, partially, or superficially taught in education. They all agree that the standard is very important, growing in significance in work due to data sensitivity and the need for ethical considerations. Interviewees 2 and 4 mention that in practice this standard is considered far less important than it should be, and some people do not think about biases. Lack of knowledge might result in costly mistakes, sharing private information, and wrongful presentation of data. A stakeholder mentioned similarly: "During education about data visualization, we focus a lot on the communication and design aspects. Still, we don't talk that much about the ethical implications of our partialized view of the world, potential biases, or the quality of the data that we use to produce them." The relevant data visualization aspects 'understand the biases' and 'misleading representation' in Table 4-6 back up this opinion.

4.3.2.3 Improvement in education

Throughout the interview the interviewees came by things they missed during their studies. Interviewees 2 and 4 both mentioned that they clearly lacked practical experience in education through, for example, case studies. There is quite some theoretical and technical education, as also "making a simple map is quite theoretical" according to interviewee 2. Interviewee 4 mentioned an internship is very good for this. In the co-creation session, an alumnus explained: "We learn many things by doing and experience instead of having a theoretical framework to rely on."

Interviewee 3 states most courses explain subjects very superficially and there is no chance to become an expert on a subject. Interviewee 4 agrees with this about the standard courses, although this is negated by the non-compulsory courses, "as it gives the opportunity to dive into a subject further when you want to". Also noted was that this changes per study.

A third main component that could be improved in education is the use of applications and software. Interviewee 3 mentions the use of applications and software that are not used in the industry anymore, and the lack of practice on applications and software that are used widely in the industry. Also, interviewee 2 states affinity with software used in the industry is very important and is missing in education. There is a need for more and faster adaption to the working environment, as it is no use being taught outdated material. This is one of the two important aspects also found in the only used category in the co-creation results, confirming its lack in education.

Another thing lacking in education that was mentioned was feedback and training on standards without material results, like 'define' and 'find'. Mostly these subjects are left for the students to find out for themselves and no or little guidance is given. During the co-creation an alumni explained "Since most people in the session were trained to create data visualizations, that's where we focused the most. We didn't discuss that much on how to deal with visualizations that already exist (online or in books) and how to choose the right one for the right audience." A student added he had never really considered the steps preceding creating a data-visualization. The interviewees also mentioned a lack of education on the use of metadata and pre-processing, both stated to be of great importance in the industry for data quality, readability and linkability, which are all considered very relevant according to the results in Table 4-6.

Even though the interviewees mentioned these possible improvements and lacking components of geo-data visualization education in the Netherlands, they all agreed upon the statement that not everything needs to be taught in education. This was also discussed and agreed upon in the co-creation session. Many aspects of data visualization have a long learning curve that continues into the student's future careers.

4.3.3 Initial recommendations

Based on the results from the stakeholder research about data visualization education, several initial recommendations can be made to enhance the effectiveness of data visualization education in the Netherlands. Each paragraph is followed by one or more recommendations.

4.3.3.1 Learning outcomes and activities

As data visualization is such a broad field, one course cannot teach all aspects and a focus should be applied, emphasizing specific learning activities. From the co-creation and interview results we know stakeholders see too much superficial information and more in-depth learning is wanted.

Recommendation 1: In all courses and curriculum designs there should be a focused approach with specified learning outcomes and transparent learning activities for clear vision on what is important and relevant.

4.3.3.2 Broad field

On the other hand, a variety of wide basic skills are very important for the future careers of students in data visualization. To manage teaching a wide variety of subjects while still being able to cover the wide range of aspects in data visualization in a study, good coordination between courses is needed to get least overlap. Another much appreciated combination of these two opposites are free choice with active learning environment in courses, optional material, and non-compulsory courses specialized in niche topics.

Recommendation 2: Coordinate between multiple courses so the subjects link and relate to each other, while avoiding unnecessary overlap.

Recommendation 3: Make use of free choice with active learning environment in courses, optional material, and non-compulsory courses for niche subjects.

4.3.3.3 Affinity with technology

As there are many disciplines related to data visualization it is impossible to prepare students for all appliances, which is why basic practical and applied skills are needed to be able to quickly learn working with new software, applications, and methods. "Being capable with software in general and adaptability is a very useful skill, as recent history and trends show that technological improvements come along fast, and changes are imminent." (Interviewee 2, 30 January 2024).

Recommendation 4: Educate on the basic concepts of software, applications and methods used, to stimulate students to be adaptable to new working environments.

Something that was mentioned in the interviews multiple times is the lack of concentration in education on the tools and software used in the industry. One of the two aspects that received stickers in the category used of the Venn diagram was 'tools, plug and play, programming, apps', which coincides with this. An affinity with software used in the data visualization industry is said to be very positive for recent graduates applying for a position.

Recommendation 5: The technology used in education should match the technology used in the data visualization industry.

4.3.3.4 Focus on relevant aspects and standards

Certain aspects are viewed as important by students only (Table 4-4), which tells us that there is a mismatch between their view and the view of other stakeholders on those aspects. A switch on focus from these subjects in education to other subjects viewed as important by more experienced stakeholders in the data visualization industry gives students the chance to prepare for the right aspects to support their future career. Stakeholders also mentioned a lack in education and knowledge in certain standards like 'define' and 'find' and a concentration on the design aspect of data visualization. A more refined division in education of the different standards could amplify the importance of the relevant aspects in standards with less attention.

Recommendation 6: Realign focus in curricula on the aspects viewed as highly relevant.
Recommendation 7: Divide the course attention among all standards, as they all contain important and relevant data visualization aspects.

4.3.3.5 Adapt to audience

The importance of the different aspects and standards differ greatly per stakeholder, company, and function. This means that for different audiences, another method of teaching or other subjects might be more suitable. In addition to this, in today's data driven world material and methods change fast in this evolving field, which educators and courses need to be prepared for. Encouraging students to pursue additional knowledge and skills beyond formal education can help with this.

Recommendation 8: Educators and courses should be able to adapt to their audience and their interest, as the landscape of visualization tools and methods changes rapidly and can become obsolete fast.
Recommendation 9: Encourage the pursuit of additional knowledge and skills beyond formal education, potentially through workshops, webinars, or industry events.

4.3.3.6 Develop non-technical competencies

Besides the importance of skill requirements for the data visualization industry, the importance of non-technical competencies was emphasized by various stakeholders. As much work is done in projects and groups, communication and collaboration skills are of great significance. Also, independence, pro-activeness and problem solving are widely appreciated.

Recommendation 10: Incorporate activities and assignments that promote the development of non-technical competencies and skills alongside technical knowledge.

4.4 Evaluation

4.4.1 Suitability of data

This section addresses the suitability of the information gathered from the co-creation of the living lab theory to determine the state of geo-data visualization in higher education in the Netherlands and give recommendations for improvements. With the data gathered in the co-creation session, multiple characteristics of the aspects can be reviewed, answering the research questions, and giving the opportunity to be able to speculate what can be improved in education and what the varying opinions are of the stakeholders.

During the co-creation session, there were concerns about the use and design of the visual literacy standards framework. Some standards were identified as procedural steps, while others were considered vital throughout the entire data visualization process, resulting in overlap and a lack of coherence in the framework. The use of another framework with a more coherent outline to guide the stakeholders might have a positive influence on the suitability of the data to generate recommendations.

The use of a Venn diagram was found limiting by stakeholders, as certain aspects defy easy categorization into the prescribed options of used, taught, or both. Introducing a scale with more than three options could offer a more nuanced understanding of the data visualization aspects. This adjustment would provide a detailed perspective on the varying degrees of use and education associated with different aspects in the realm of geo-data visualization.

Data from interviews is focused on the difference between the visual literacy standards in education and industry, what is missing in data visualization education, and the job requirements. This does not fully match the data from the co-creatin session. The data from the co-creation session focused on the data visualization aspect, which was not handled specifically in the interviews. The interviews are however suitable for the addition of the company stakeholder perspective on the standards and on what skills are needed for a career start in data visualization.

Generally, the data gathered suits the research well. Concerns did arise about the visual literacy standards framework, suggesting a more coherent and fitting outline. Also, the use of the Venn diagram was limiting, and a more nuanced scale can be more useful. Interviews provided insights into the industry perspective on skills needed for a career in data visualization, complementing co-creation findings.

4.4.2 Representativeness of data

This section addresses the representativeness of the information gathered from the co-creation of the living lab theory to determine the state of geo-data visualization in higher education in the Netherlands and give recommendations for improvements.

Firstly, the resulting aspects of the co-creation are limited to what the stakeholders initially thought of. The 13 participants had limited time to come up with aspects which leads to possible missing aspects, as people might forget things that they have not used in a long time. Also, as data visualization is such a broad topic, a stakeholder might only think about a small part and not the whole picture. This means the analysis of the aspects is not complete and relevant aspects might be missing, which means that the data is not fully representative. Nevertheless, the similarity between the important aspects in the groups does speak to the completeness of the results, as 60% of the aspects with relevance scores 4 or 5 were present in both groups.

In addition to possible aspects missing, the low number of participants leads to an easily skewed representation of the results. This can be seen in Table 4-7, where the number of aspects per group in the co-creation has large differences. ‘Interpret and analyze’ might seem the broadest standard with most aspects, while 11/16 are from only one group. Group 1 also generated a large number of aspects for the standards of ‘use effectively’ and ‘create’, while the end results do not show this, because the aspects of group 2 mask this.

Table 4-7: The number of aspects per group before merging the boards, and their overlap, is shown. Group 2 stands out with most aspects. Only four standards have overlapping aspects.

Aspect count per group			
Standard	1	1 and 2	2
Define	1	3	3
Find	1	2	7
Interpret and analyze	5	0	11
Evaluate	2	0	6
Use effectively	5	2	4
Create	7	0	5
Use ethically and cite	3	2	3

There were variations in the representation of the stakeholders present at the co-creation session. The experts were represented less than the other stakeholders, and the company stakeholder was missing. Even though this might lead to misrepresentation in the results, attention was paid to this in the analysis and interviews were done to fill in some blanks. For the data of both the co-creation and the interviews to be more representative, a larger pool of participants or stakeholders should be present. Answers to certain questions, for example, depend largely on what data a respondent works with and what job they have. As geo-data visualization is such a broad industry, like mentioned before, only four company representatives does not cover the full scale. Additionally, the contents of the interviews after the co-creation session deviated from the initial interviews, so comparison might not represent the actual situation because of lacking information. This is, however, always the case in semi-open interviews as opinions, experiences and perspectives differ per person.

The research focusses on Dutch education and geo-data visualization specifically, which are represented properly. The stakeholders do, however, represent only certain study programs and academic institutions. They do represent the Dutch education, however there is no indication if the situation in other countries would be any different, so comparison is impossible.

Overall, the stakeholder representation in the research is limited to key stakeholders. More research and data from a larger pool of diverse participants is needed for a complete view upon the research topic. The data gathered does have adequate representation, reflecting the perspectives of the stakeholders present.

4.5 Refinement & Dissemination

As in the results and analysis of this research there is no clear distinguishment between data visualization and geo-data visualization, a focus is needed to clarify the recommendations for implementation in courses and curricula. In this section, the recommendations generated in the implementation step are reviewed and tailored to enhance the effectiveness of geographical data visualization in higher education in the Netherlands.

4.5.1.1 Broad field

Geographical data visualization involves not only understanding data representation but also other geographical concepts like spatial relationships. Geo-data visualization is a specialization in terms of extra theoretical and practical knowledge needed to become adequate in its field. A focused approach on learning objectives and activities emphasizing the understanding of, among others, Geographical Information Science (GIS) concepts, spatial analysis and cartographic principles ensures that graduates possess the specialized skills necessary for working with spatial data, distinguishing them from general data visualization professionals. The recommendation is refined as follows: In all courses and curriculum designs there should be a focused approach with specified learning objectives and transparent learning activities linked to geo-information concepts, providing clarity on what is important and relevant for spatial data understanding and visualization.

As it is apparent from the results, mastering the basics of geo-data visualization is important for a student's future career. A clear view on the fundamentals and their relevance in the bigger geographical picture is important to gain in-depth knowledge. By linking subjects like GIS fundamentals and cartographic design, students can see the interconnectedness of these concepts, facilitating a more holistic and applied learning experience. To be able to transfer a more complete knowledge about geo-data visualization and all geographical concepts needed for a full understanding, coordination between courses is crucial to cover all basics. The recommendation is refined as follows: Coordinate between multiple courses to establish interconnected subjects, while avoiding unnecessary overlap and teaching the fundamentals of geo-data visualization.

Geographical data visualization encompasses a wide range of applications, from environmental mapping to urban planning and stakeholder communication. Offering an active learning environment with optional courses and material, and free choice in projects and subjects, allowing students to explore specific geographic interests and ensuring they acquire skills tailored to subfield within their extended interest. Many occupations dealing with geo-data visualization entail project and group work, which offers an easy possibility of free choice and varying subjects when applying this way of work in courses. The recommendation is refined as follows: Make use of free choice with active learning environment in courses, optional material, and non-compulsory courses, allowing students to explore specific geographic interests and develop skills tailored to their chosen subfield.

4.5.1.2 Affinity with technology

The rapidly evolving landscape of geospatial technologies requires graduates to be adaptable to new tools and methods, even more so than with general data visualization. Educating students on fundamental GIS concepts and software, applications and tools used in the industry creates adaptability, ensuring they can quickly grasp and apply emerging technologies in their geographical data visualization practice. A focus on the general usability instead of the specific functionality of the applications helps realizing this basic technological skill level. The recommendation is refined as follows: The tools and software used in geo-data visualization education should align with the tools and software frequently used in the geo-data visualization industry to ensure familiarity with the technology.

As geo-data visualization is heavily reliant on industry-standard tools. Aligning educational tools with those used in the industry ensures that students feel at home working with the software commonly employed by professionals(Rip et al., 2014). This enhances their employability and easing the transition from education to the workforce. Software like ArcGIS, QGIS, and FME are used often in the geo-data industry and familiarity with them is oftentimes asked from graduates. As mentioned before, the technological environment evolves rapidly, which is why courses should keep being informed of the technologies used in the industry and have clear communication lines to acquire new information. The recommendation is refined as follows: Educate on the fundamental concepts of GIS software, applications, and methods, stimulating adaptability to new tools and working environments in the dynamic field of geo-data visualization.

4.5.1.3 Focus on relevant aspects and standards

The aspects and standards applied in this research generally deal with data visualization and are not specified in the geographical field. The aspects seen as highly relevant still apply, although a closer look needs to be taken by course coordinators to refocus them to be applied in geo-data visualization courses, in addition to incorporating aspects specifically relevant to the geographical components of the courses. The recommendation is refined as follows: Realign the curricula in geo-data visualization to focus on aspects highly relevant to spatial data interpretation and practical skills essential for working in the geospatial industry.

Extra focus should be granted to the distribution of course attention to the visual literacy standard. Even though stakeholders stated that this framework is not the best fit for geo-data visualization, it was mentioned that all standards were considered important in the field as they complement each other. Nonetheless, there is a clear preference within geo-data visualization courses on the standards 'create' and 'interpret and analyze' according to the stakeholders. The recommendation is refined as follows: Distribute course attention among all visual literacy standards to ensure a comprehensive understanding of the field, as all aspects present important and relevant geo-data visualization aspects.

4.5.1.4 Adapt to audience

Geo-data visualization is highly context dependent. Adapting educational content to the audience's needs and incorporating examples from diverse geographical contexts prepares students for the varying demands of the field, considering the dynamic nature of geospatial technologies and methods. Especially in respect of this dynamic nature, there is a wide variation of possibilities to teach and learn aspects and components. An educator should be able to let the students follow their own path while continuing to guide them in the journey. The recommendation is refined as follows: Educators and courses should be able to adapt to their audience's needs and interests, as the landscape of geospatial technologies and methods changes rapidly and can become obsolete fast.

Considering the evolving geo-data visualization environment combined with its broad field, the pursuit of additional knowledge and skills alongside their study progress can be a great asset. In the geo-data visualization field, continuing this learning curve after completion of the study is common and often needed to stay informed of advancements and prepared for unavoidable change. The recommendation is refined as follows: Encourage students to pursue additional knowledge and skills beyond formal education, possibly through workshops, webinars, or industry events, recognizing the necessity for continuous learning in the ever-evolving field of geo-data visualization.

4.5.1.5 Develop non-technical competencies

As mentioned, working in the geo-data visualization industry often involves collaborative projects. This is why companies in this field often mention non-technical competencies as requirements, sometimes considering them more important than other requirements. The significance of interpersonal skills in successfully conveying spatial information and problem solving is recognized by most companies and institutions. Therefore, incorporating activities and assignments courses that promote the development of non-technical competencies are essential for success in the field. The recommendation is refined as follows: Integrate activities and assignments in geo-data visualization courses that promote the development of non-technical competencies alongside technical knowledge, recognizing the importance of collaboration, communication, and problem-solving in the industry.

5 Discussion

The outcomes of this research provide recommendations for the improvement of geo-data visualization courses to be used by educators. However, the results should be interpreted with caution due to the limitations of the current research. This chapter provides a reflection on the research process, its limitations, and the potential consequences of the design, as well as implications for the interpretation of the results.

The consideration of stakeholder perspectives on the problem statement and their involvement in the research made the research novel in its field. This choice had positive effects on the research, as new insights are obtained, relating the issues and possible improvements for geo-data visualization. The living lab methodology presents a valuable opportunity to introduce stakeholders to research in a structured manner and be able to obtain recurring feedback from involved actors in an iterative method (AMS Institute, 2020). Within this research however, the living lab methodology could have been better executed. In the research process the only effective contact with the stakeholders was during the co-creation session and during the interviews. Attempts were made to receive additional feedback and evaluation on results and process through email contact and a survey but yielded little response. With more time, more iteration could have taken place to refine the process and communicate with the stakeholders with every step, which is common in living labs.

Interpretation of the co-creation part of the living lab methodology resulted in contrasting, varying and comparable outcomes with which further analysis could be done. The findings from the co-creation session and interviews provide insights into specific aspects of data visualization education (section 4.3.1), complementing the broader recommendations from the literature review (section 4.1.1). The identified areas for improvement in the literature review align with several results from the co-creation, such as adapting teaching methods to the evolving industry landscape and addressing challenges like a lack of prior knowledge. Also, focus on practical skills (Roberts et al., 2022), non-technical competencies (Ryan et al., 2019), data visualization fundamentals (Camm et al., 2023), and industry relevance (Rip et al., 2014) are similar needs in the research sections, highlighting helpful improvements for refining data visualization education. Using the complementing and comparable results from the research sections, elaborate recommendations were generated, refined to help improve geo-data visualization education (section 4.5). This research states change is needed to enhance the education of geo-data visualization and bridge the existing gap between education and industry (Camm et al., 2023), which is supported by other literature. A review by F. Capra-Ribeiro (2022), similar to the systematic literature review in this thesis, mentions several similar recommendations, like using practical exercises over theoretical content, exposing students to all stages of the visualization process, and including the development of complementary (non-technical) skills for data visualization like communication. A report by the Life Learning Programme, describing the situation regarding the demand for and the supply of education and training in the domain of geographic information, concludes there is a teaching gap between demand and supply of competencies (Rip et al., 2014). Recommendation 5 and 6 are results found purely from stakeholder collaboration and are unique to this research.

An evaluation done about the suitability and representability of the data gathered in the co-creation of the living lab presented some limitations. Concerns arise regarding the suitability of the gathered data, particularly regarding the ability of the visual literacy standards framework to adequately capture the complexities of geo-data visualization education. The visual literacy standards framework by the ACRL can be implemented to structure curricular needs and overall learning goals for the visualization topic in higher education and “individual disciplines may choose to articulate additional discipline-specific visual literacy learning outcomes” (ACRL, 2011). This generality of the framework about visualization should be more specified to geo-data visualization, according to the stakeholders and the results of the co-creation. To attain a more nuanced understanding of geo-data visualization aspects, there is a suggested need for a comprehensive framework. A more refined scale replacing the Venn diagram used in the co-creation session for classification of the aspects (Figure 3-2) should yield more specific results. Another improvement of the co-creation session would be to record the discussions of the stakeholders, so that they can be used in the analysis to a fuller extent and additional data can be gathered aside from the limited data from the framework only.

The representativeness of the data is questioned due to time constraints and the limited number of participants in the co-creation session, reflected in disparities in aspect counts between groups. In the results, not all stakeholders of the research were represented, as only students, educators, data visualization experts and alumni were present at the session. During and after the session it was clear that mainly the perspective of that company stakeholder was missing, for a complete view upon the importance of the visual literacy standards and their aspects, and presence in the industry. This stakeholder gap was filled with the conducted interviews (section 4.3.2), where four company employees with different backgrounds, functions and companies shared their perspectives. In addition to this, it was hard acquiring data specifically for the geo-visualization field. Not all stakeholders had knowledge about this subject, which is why most responses and discussions in the co-creation were about data visualization in general. Overall, an improvement would be to acquire a larger and more diverse participant pool to enhance the representativeness and validity of the assessment of the state of geo-data visualization in higher education within the context of this thesis (section 4.4.2).

From the articles used in the literature review, the perspective of mostly educators was described. The articles give insight and guidance for the pedagogical way to teach data-visualization. Although the articles did represent the pedagogical aspect of data visualization education, the insights were mostly limited to the writer's own experiences in education. Possibly acquiring more pedagogical understanding in this research from the stakeholders pedagogy expert and educational institutes will increase the representability of the data and a more complete set of recommendations can be made for data visualization courses.

A positive prospect of the mentioned lack of specification on geo-data visualization and the use of a generic visualization framework is the usability of this research in other data visualization fields. From the data gathered, it is clear that there are issues overlapping multiple disciplines in data visualization, possibly even other educational fields.

Keep these discussion points in mind when interpreting the outcomes and employing the results of this research into course design. A false understanding or an incomplete view of the recommendations and from what arguments and perspectives they origin can lead to wrongful implementation in courses and might reduce the quality of education.

6 Conclusion

In this research, the areas of approvement are identified and recommendations are made for educators in the field of geo-data visualization education for the Netherlands, using the living lab methodology. Through a systematic literature review, and analysis of stakeholder perception via a co-creation session and interviews, the areas of approvement are pinpointed and a set of ten recommendations for geo-data visualization courses resulted.

The current state of research on the topic of data visualization in higher education in the Netherlands was exploited in a systematic literature review. This review of nine selected papers concerning data visualization in education revealed critical insights into the creation of courses and curricula in this field. It emphasizes the increasing significance of data visualization skills in today's data-driven society, highlighting the strong industry demand for individuals proficient in this domain. The papers acknowledge the challenges faced by educators, including the diverse nature of the subject, varying views on data visualization, and the need for a clear educational goal. They suggest a focused approach in curriculum design, emphasizing alignment with specific learning outcomes and transparent learning activities. Moreover, the reviewed papers offer various curriculum designs and frameworks, providing educators with valuable tools to structure their courses effectively. Important recommendations are the use of learning activities linked to learning objectives, adapting teaching methods to the audience, and creating an active learning environment. These findings emphasize the evolving landscape of data visualization education and provide guidance for educators striving to enhance teaching methodologies in data visualization.

The importance and relevance of the visual literacy standards and their aspects according to stakeholders was researched in the co-creation session and conducted interviews. The co-creation session provided a comprehensive overview of stakeholder perspectives on data visualization standards. Analyzing the number of aspects per standard, 'interpret and analyze' emerged as the broadest, garnering the highest number of aspects. Notably, the standard 'define' stood out with the most post-its, importance stickers, and the highest average relevance score, emphasizing its importance. The relevance scores revealed that standards like 'define,' 'use ethically and cite,' and 'create' were consistently viewed as crucial. The Venn diagram depicted much overlap, indicating that most aspects are both taught and used, depicting the already meaningful approach to data visualization education in the Netherlands. The aspects deemed important exclusively by students suggests a reconsideration of the emphasis on certain aspects in the curriculum. Examining the importance stickers placed by stakeholders highlighted varying perspectives, with 'define' and 'use ethically and cite' receiving the most attention. The identified aspects with high relevance scores form a solid foundation for shaping data visualization education, emphasizing the importance of tailoring visualizations to the audience, maintaining clarity, and being mindful of biases and error margins.

The interviews with company stakeholders, functioning to fill the gap of stakeholders present in the co-creation session, provided valuable insights into the job requirements, standards, and potential improvements in geo-data visualization education. Job requirements highlighted the significance of foundational data visualization skills, with specific emphasis on programming, translating complex data for clients, and non-technical competencies like communication and problem-solving. Standards such as 'define,' 'interpret and analyze,' 'use effectively,' and 'create' were consistently deemed important, while 'evaluate' faced variations in importance. The standard 'use ethically and cite' revealed a gap in education, where its importance is recognized but not adequately taught. Interviewees expressed the need for practical experience, deeper subject expertise, and relevance to industry tools in education. Additionally, the lack of guidance on standards like 'define' and 'find,' and insufficient focus on metadata and pre-processing were identified as areas needing improvement. Despite these concerns, there was a unanimous acknowledgment that not everything can be taught in education, as the learning curve for certain aspects extends into professionals' future careers.

6.1 Recommendations

From the results of a literature review, co-creation session and conducted interviews, a set of ten recommendations for improvement are made for existing and new courses covering geo-data visualization in higher education in the Netherlands. The recommendations are refined to fit specifically geo-data visualization courses and are explained in more detail in section 4.5.

Recommendation 1: In all courses and curriculum designs there should be a focused approach with specified learning objectives and transparent learning activities linked to geo-information concepts, providing clarity on what is important and relevant for spatial data understanding and visualization.

Recommendation 2: Coordinate between multiple courses to establish interconnected subjects, while avoiding unnecessary overlap and teaching the fundamentals of geo-data visualization.

Recommendation 3: Make use of free choice with active learning environment in courses, optional material, and non-compulsory courses, allowing students to explore specific geographic interests and develop skills tailored to their chosen subfield.

Recommendation 4: The tools and software used in geo-data visualization education should align with the tools and software frequently used in the geo-data visualization industry to ensure familiarity with the technology.

Recommendation 5: Educate on the fundamental concepts of GIS software, applications, and methods, stimulating adaptability to new tools and working environments in the dynamic field of geo-data visualization.

Recommendation 6: Realign the curricula in geo-data visualization to focus on aspects highly relevant to spatial data interpretation and practical skills essential for working in the geospatial industry.

Recommendation 7: Distribute course attention among all visual literacy standards to ensure a comprehensive understanding of the field, as all aspects present important and relevant geo-data visualization aspects.

Recommendation 8: Educators and courses should be able to adapt to their audience's needs and interests, as the landscape of geospatial technologies and methods changes rapidly and can become obsolete fast.

Recommendation 9: Encourage students to pursue additional knowledge and skills beyond formal education, possibly through workshops, webinars, or industry events, recognizing the necessity for continuous learning in the ever-evolving field of geo-data visualization.

Recommendation 10: Integrate activities and assignments in geo-data visualization courses that promote the development of non-technical competencies alongside technical knowledge, recognizing the importance of collaboration, communication, and problem-solving in the industry.

These recommendations can be used as a basis for educators to improve the education of geo-data visualization with the main goal of preparing students for their future careers. Improvement in both the academic environment and the practical application of geo-data visualization courses can be implications of this research. As the recommendations can be altered to be more generic, their use in other data visualization fields is also a possibility. With the accomplished results, the research objective has been achieved.

6.2 Future research

This research serves as a good starting point for additional research into the improvement of geo-data visualization education in higher education in the Netherlands. There is an abundance of ways to expand on this research and dive more into the specific components of this research. Some of them are divulged in this section.

As this research is novel in incorporating stakeholder perspectives in this topic, conducting more extensive and focused research on a larger and more diverse group of stakeholders can provide insight to a more comprehensive and complete understanding of the needs and dynamics in geo-data visualization education. By changing the stakeholder participation and widening the scope to a more international group can give insights in the differences between countries, giving more room for stakeholders with pedagogical knowledge might result in more focus on the teaching theories, and assembling a stakeholder group from various industry fields might adapt the whole research to fit another type of education. Making use of the living lab methodology is encouraged, however, a more iterative process and increased contact with the stakeholders throughout the research is needed for improved results.

For future research on this subject, more detailed research on the specific teaching methods and aspects of geographical data visualization and geo-information science is needed to further specify recommendations and fit specific course types and teaching objectives. The visual literacy standards are perfect for researching the best fitting course objectives for data visualization. Extended research with this framework can help educators to easily design courses and be able to adapt to the audience. For more research in existing courses, a comparative analysis of courses across institutions is possible. This could involve examining curriculum structures, teaching methodologies, and industry collaborations to identify best practices and areas for improvement and the possibility of immediate adaption into the existing curricula. Lastly, more research in the requirements of geo-data visualization occupations can help prepare students more extensively for their future careers. Both the focus on technical and non-technical competencies, as focus on applications, software and tools used are pathways to a better match between the working environment and study programs.

By exploring these suggested areas for further research, scholars and educators can contribute to the continuous improvement and evolution of geo-data visualization education, ensuring its relevance and effectiveness in a rapidly advancing technological landscape.

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8 Appendix

8.1 Appendix I: Questions interviews

Focus of the company

1. What is your function in your company?
2. Can you provide an overview of the company's objectives and operations within the geo-data visualization field?
3. What specific geo-data visualization projects or products is the company currently involved in or has completed recently?
4. Why is data visualization important for your company?

Hiring and expectations

1. When hiring for roles related to geo-data visualization, what specific skills or experiences do you primarily look for in candidates?
2. What technical tools or software are commonly used within the company for geo-data visualization purposes?
3. From your experience, what skills or knowledge have you found graduates often bring from their studies that prove highly beneficial for geo-data visualization roles in your company?
4. From your experience, what skills or knowledge have you found graduates often bring from their studies that is missing or abundant?
5. How does the company encourage or support the application of academic knowledge or research findings in the realm of geo-data visualization?
6. Are there specific academic backgrounds or disciplines (e.g., geography, computer science, geomatics) that often bring valuable perspectives to your team?

Importance of standards

1. Of the following standards in visual literacy, what do you and your company value the most?
    - Determine the nature and extent of the visual materials needed
    - Find and access needed images and visual media effectively and efficiently
    - Interpret and analyze the meanings of images and visual media
    - Evaluate images and their sources
    - Use images and visual media effectively
    - Design and create meaningful images and visual media
    - Understand many of the ethical, legal, social, and economic issues surrounding the creation and use of images and visual media, and access and use visual materials ethically
2. Which of these standards would you expect studies to focus on most, focusing on later career prospects?
3. Do you think the importance of these standards changes when working with different types of visualizations? Think about 2D, 3D, video, cartography, infographics, etc.

Do you have any additional information you think is important for this topic, my thesis, or the preparation of the co-creation sessions?

What is the best way to for a data visualization class inspired and coming?