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Review Article

Visual Literacy in the Context of Data Literacy in Higher Education: A Systematic Review of Competencies, Empirical Findings and Assessment Approaches

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Abstract
In increasingly data-driven societies, data literacy is regarded as a key competence for informed decision-making. Within higher education, students are increasingly expected not only to analyze data but also to critically evaluate and communicate data-driven insights. In this context, visual literacy and data visualization literacy represent important dimensions of data literacy, as they support the creation, interpretation, and critical evaluation of data visualizations. However, these constructs remain conceptually fragmented, and existing research in higher education lacks consistent assessment approaches. The study presents a systematic literature review of empirical and conceptual research on visual literacy within the context of data literacy in higher education. Following PRISMA guidelines, studies published between 2010 and 2025 were identified through interdisciplinary database searches. Higher education institutions increasingly face the challenge of preparing students for data-driven communication and decision-making. 27 studies explicitly addressing higher education contexts were included in the final analysis. The review examined competence dimensions, students' competency levels, and assessment instruments. The findings indicate that visual literacy within the context of data literacy constitutes a multidimensional construct encompassing interpretative, analytical, productive, cognitive, and critically reflective dimensions. While prior research has primarily focused on methodological skills, such as visualization creation and interpretation, cognitive competencies, particularly critical evaluation, mental model construction, and reflective decision-making, remain underrepresented. Empirical evidence further suggests that students possess basic visualization skills but struggle with complex visualizations, critical interpretation, and audience-oriented communication. In addition, existing assessment instruments are heterogeneous, only partially validated, and rarely capture cognitive dimensions of competence. The review highlights the need for theoretically grounded and empirically validated assessment and instructional approaches that integrate cognitive and critically reflective aspects of visual literacy into broader data literacy frameworks. The findings provide implications for higher education teaching, curriculum development, and further research on data-informed communication and decision-making.

Keywords: Data Literacy, Higher Education, Measurement, Visual Literacy, Visualization Literacy

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1. INTRODUCTION

Data literacy is increasingly regarded as a key competence in a data-driven knowledge society. It encompasses the ability to critically evaluate, analyze, interpret, and use data to inform decision-making processes (Ridsdale et al., 2015; Ongena, 2023). While the generation and analysis of data have been

extensively addressed in research and higher education, comparatively little attention has been paid to data communication, particularly the communication of visualized data (Schüller et al., 2019).

At this intersection, visual literacy and data visualization literacy are gaining importance. Visual literacy is defined as "a set of abilities that enables an individual to effectively find, interpret, evaluate, use, and create images and visual media" (Association of College & Research Libraries, 2011, p. 1), whereas data visualization literacy more specifically focuses on the design of data-based visualizations derived from quantified, structured data that represent statistical or analytical relationships (Beschi et al., 2025; Börner et al., 2019). Both competence domains are closely interrelated and constitute a fundamental prerequisite for effectively communicating data-driven insights through visualizations, as well as for informed decision-making.

Despite the growing relevance of these competencies, their conceptual delineation and empirical assessment remain inconsistent (Beschi et al., 2025). Existing studies tend to focus on methodological aspects, such as the creation and interpretation of visualizations, while cognitive processes, particularly the construction of mental models and the critical evaluation of visual data representations, have received comparatively limited attention (Beschi et al., 2025; Varona, 2025; Brockbank et al., 2025). At the same time, empirical findings indicate that students often struggle to interpret data visualizations, critically reflect on them, and derive well-founded conclusions for decision-making (Börner et al., 2019; Galesic & Garcia-Tetamero, 2011; Beschi et al., 2025).

Although visual literacy and data visualization literacy have also been discussed in K-12 education, the present review focuses explicitly on higher education contexts. This focus is justified by the specific demands placed on students in higher education, where data-driven communication, interpretation, and decision-making increasingly form part of academic and professional qualification processes. In contrast to school education, higher education requires students not only to interpret visualized data but also to critically evaluate, communicate, and apply data-based insights within disciplinary and research-related contexts.

Furthermore, the review revealed a comparatively limited body of empirical research and validated assessment approaches specifically addressing visual literacy within the context of data literacy in higher education. The specific cognitive demands associated with interpreting and critically evaluating visualized data in academic contexts further motivate the exclusive focus on higher education. The review serves as a theoretical foundation for the development of a didactic intervention based on mental models designed for a statistics course in higher education. Consequently, the focus on higher education ensures contextual consistency between the theoretical framework, the identified competencies, and the intended instructional application.

The development of visual literacy competencies within the context of data literacy requires a clear specification of the underlying sub-competencies that enable students to communicate information derived from data products in ways that support informed decision-making. Based on the theoretical framework, this study addresses the following central research questions:

1. Which visual literacy competencies within the context of data literacy have been identified in national and international studies as relevant for data-driven communication and decision-making?
2. What empirical evidence exists regarding visual literacy competencies within the context of data literacy among students?
3. Which instruments have been used to assess these competencies in higher education contexts?

To answer these questions, a systematic literature review is conducted, analyzing relevant studies on definitions, competence models, and assessment instruments. The results indicate that visual literacy, in relation to data literacy, ought to be regarded as a multidimensional construct that includes methodological, cognitive, and critically reflective elements. At the same time, it becomes evident that these cognitive dimensions, in particular, have neither been sufficiently theorized nor adequately operationalized in empirical research.

Based on these findings, a didactic intervention grounded in mental models is developed, focusing on critical evaluation processes of visualized data to foster visual literacy competencies within the context of data literacy (Lieb & Pickhardt, 2025). The aim is to contribute to both the theoretical foundation and

the pedagogical advancement of higher education by outlining approaches to specifically promote cognitive processes underlying visualization comprehension, such as critical interpretation and pattern recognition.

For the present study, a systematic literature review was conducted to identify and analyze relevant studies addressing terminology, competence models, and assessment instruments related to data literacy, visual literacy, and data visualization literacy. A systematic review represents a methodologically rigorous and theory-driven synthesis of existing literature, guided by clearly defined research questions. Its objective is to identify, select, evaluate, and systematize relevant research findings through a transparent and replicable procedure. The applied methodology is intended to ensure the reproducibility of the review process while minimizing potential biases.

The objectives of the present study can be summarized as follows:

1. To provide a systematic overview of the existing literature on data literacy, visual literacy, and data visualization literacy in higher education contexts.
2. The goal is to identify visual literacy competencies that are particularly relevant to data literacy in the context of data-driven communication and decision-making processes.
3. To conceptually define and differentiate the terms "data literacy", "visual literacy", and "data visualization literacy".
4. The goal is to identify research gaps related to visual literacy within the context of data literacy in higher education.
5. The goal is to provide an overview of existing inventories and assessment instruments used to measure data literacy, visual literacy, and data visualization literacy competencies in higher education.

In order to ensure the objectivity of the literature search, the following guiding questions were formulated in advance:

1. For which target group was each study conducted?
2. Do the studies include explicit definitions of the terms "data literacy", "visual literacy", and/or "data visualization literacy"?
3. Which specific competencies of data literacy, visual literacy, and data visualization literacy are addressed in the studies (particularly cognitive and/or methodological dimensions)?
4. Which instruments were used to assess these competencies, and in which context were they applied?
5. Do the studies meet key scientific quality criteria of empirical research (e.g., internal consistency, reliability, validity)?

For the systematic identification and analysis of the relevant literature, a classification scheme was developed in which the identified sources were categorized according to definitions, specific competencies, and key findings or main conclusions. The entire search process, as well as the selection of included studies, was systematically documented to ensure transparency, traceability, and reproducibility (Cooper et al., 2019).

To address the research questions, the results of a systematic review are presented. Section 2 describes the methodology used to conduct the review. The findings are presented in Section 3. Section 3.1 defines the concept of data literacy and outlines relevant competencies for higher education. Section 3.2 defines visual literacy and identifies corresponding competencies in the higher education context. Sections 3.3 and 3.4 focus on the assessment and evaluation of data literacy and visual literacy, respectively, while Section 3.5 addresses the assessment and evaluation of data visualization literacy, thereby explicitly examining visual literacy within the context of data. Section 4 summarizes and discusses the findings, and Sections 5 and 6 outline implications for future research and conclude the paper.

2. METHODOLOGY

The review process followed the PRISMA guidelines (Moher et al., 2009). The literature search was conducted across disciplines and included both national and international studies published in German and English. Data sources for the web-based search comprised, on the one hand, widely accessible international databases and search engines, particularly Google Scholar, Scopus, Web of Science, and SpringerLink, and on the other hand, selected international academic journals, including the Journal of Visual Literacy and the Statistics Education Research Journal. To ensure the inclusion of recent developments in the field, the

literature search was conducted in multiple stages between February 2024 and March 2026. The final dataset was retrieved on 01/03/2026. The study selection process is illustrated in a PRISMA flow diagram.

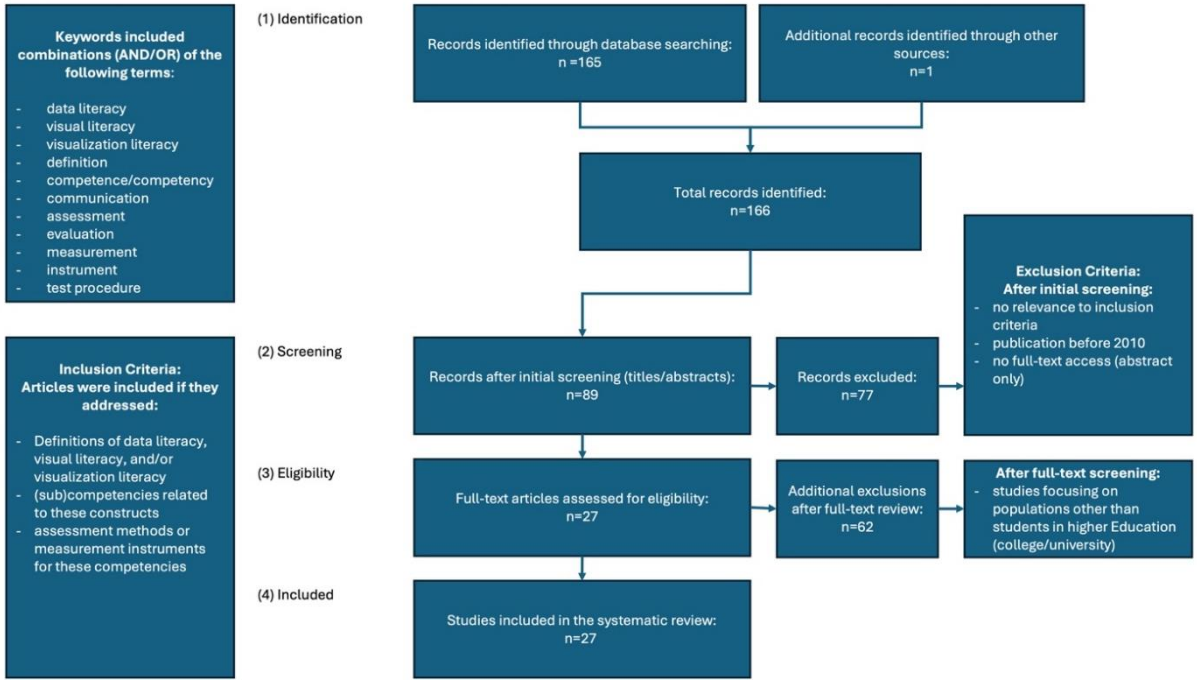


Figure 1. Classification Scheme for the Identification of Relevant Literature Sources (own illustration, adapted from Moher et al., 2009)

Empirical studies published between 2010 and 2025 were included, covering monographs, journal articles, and other scholarly contributions. Frequently cited publications were identified, and their reference lists were systematically screened to identify additional relevant sources. In total, 166 studies were identified and subsequently analyzed based on predefined inclusion and exclusion criteria. The inclusion criteria comprised the scientific relevance of the publication, measured by citation frequency, as well as its substantive contribution to the research field and the availability of the full text. Studies that did not meet these criteria were excluded.

Studies published prior to 2010 were excluded to focus on contemporary higher education contexts shaped by increasing digitalization, data-driven communication, and emerging competency frameworks. Recently, research on visualization literacy and data visualization literacy has gained increasing attention within educational and visualization research communities (Firat et al., 2020). Furthermore, key frameworks relevant to higher education, such as the Visual Literacy Competency Standards (Association of College & Research Libraries, 2011), were developed during this period. The selected timeframe therefore ensured greater conceptual and methodological comparability of the included studies.

The majority of the included studies reveal information about specific competencies related to visual literacy. However, a need for further research was identified with regard to the development and application of assessment instruments, as well as the curricular integration of these competencies. Only 27 studies explicitly address the higher education context, indicating a notable research gap (Cui et al., 2023; Schüller et al., 2019; Zhu & Lee, 2024).

The review process and analysis of the final set of 27 studies were conducted by the first author as part of a doctoral research project. To enhance the transparency and reliability of the review process, a structured review matrix was developed to categorize the included studies systematically according to research questions, methodological approaches, competency dimensions, assessment instruments, and quality criteria. The categorization and coding process was conducted iteratively and systematically reviewed throughout the analysis to ensure methodological transparency and consistency. A condensed excerpt of the review matrix is included in Appendix A.

The aim of this review is to synthesize findings on visual literacy competencies within the context of data literacy in higher education, with a particular focus on sub-competencies relevant to data-driven communication and decision-making.

3. RESULTS

3.1. Data Literacy in Higher Education: Definitions and Competencies

Only three of the 27 studies examined in the higher education context provide an explicit definition of data literacy, which contrasts with the extensive definitions and differentiated analyses found in the field of visual literacy. Likewise, only three studies identify specific sub-competencies associated with this construct.

The studies highlight, on the one hand, the ability to appropriately read and interpret data as a central component of data literacy. This includes interpreting charts and graphs, drawing well-founded conclusions, and identifying erroneous or misleading representations (Oguguo et. al., 2020; Carlson, 2011). On the other hand, data literacy also encompasses competencies related to data collection, data management, critical evaluation, and the practical application of data (Oguguo et al., 2020; Ridsdale et al., 2015).

Critical thinking plays a key role in this context. It is essential for deriving valid conclusions from data, understanding abstractions, and transferring the results of data-based analyses into practice-relevant contexts (Oguguo et al., 2020). Data literacy therefore extends beyond mere data interpretation and implies an active and reflective engagement with all phases of the data process, from data collection and analysis to the application of derived insights.

In summary, data literacy can be characterized as a critical and practice-oriented engagement with data that enables the informed use of data-driven insights to support reflective decision-making.

3.2. Visual Literacy in Higher Education: Definitions and Competencies

Of the studies analyzed in this review within the higher education context, twelve provide an explicit definition of visual literacy, while sixteen identify specific sub-competencies. The conceptualization of visual literacy varies across organizations and authors. The synthesis of these sources indicates that visual literacy is understood as a multifaceted and cross-contextual competence construct.

A central characteristic of visual literacy is the ability to derive meaning from visual representations, such as images, diagrams, or graphical displays, that is, to decode them appropriately (Börner et al., 2016; Association of College & Research Libraries, 2011; International Visual Literacy Association, 2011). Beyond these skills, visual literacy encompasses analytical and evaluative competencies, particularly the ability to critically reflect on visual materials and assess them with regard to their ethical, social, and cultural contexts (Kedra, 2018; Nalinci & Yapici, 2015; Brumberger, 2011). This reflective dimension extends beyond mere comprehension by incorporating normative and contextual perspectives.

In addition to its receptive component, some approaches emphasize a productive dimension. Visual literacy includes the ability to create visual representations and to design visual content in a way that is appropriate for specific audiences (Zhu & Lim, 2024; Bell, 2014; Brumberger, 2011). In certain definitions, digital competence is also considered an integral component. The ability to understand and produce digital visual content is regarded as a key prerequisite for participation and communication in an increasingly digital culture (Huilcapi-Collantes, 2023; Avgerinou, 2009). Accordingly, visual literacy is not limited to specific forms of representation but encompasses a wide range of visual expressions across diverse cultural and media contexts.

A widely cited definition in higher education is provided by the Association of College and Research Libraries [ACRL] (2011):

"Visual literacy is a set of abilities that enables an individual to effectively find, interpret, evaluate, use, and create images and visual media" (Association of College & Research Libraries, 2011, p. 1). "Visually literate individuals understand and analyze the contextual, cultural, ethical, aesthetic, intellectual, and technical components involved in the creation and use of visual materials. A visually literate individual

contributes to a shared body of knowledge and culture" (Association of College & Research Libraries, 2011, n.p.).

The Association of College & Research Libraries also published the Visual Literacy Competency Standards for Higher Education, developed in collaboration with international experts. Higher education widely applies these standards internationally, particularly in the field of visual literacy (Brumberger, 2019; Gong & Huang, 2018). The ACRL framework provides a systematic set of performance indicators and learning outcomes that support both the description and evaluation of visual competencies. The core competencies outlined in the ACRL standards (Association of College & Research Libraries, 2011) can be summarized as follows:

- Identifying and finding: Determining required visual materials and locating them efficiently.
- Interpreting and analyzing: Interpreting and analyzing the meaning of images and visual media.
- Evaluating: Critically assessing images and their sources.
- Using: Employing visual materials effectively and purposefully.
- Designing and creating: Developing meaningful and creative visual representations and media.
- Ethics and legal considerations: Addressing ethical, legal, social, and economic aspects in the creation and use of visual media.

The ACRL standards serve both as a comprehensive guideline for the design of instructional interventions and as a framework for assessing visual competencies. They provide a practice-oriented foundation for integrating visual competencies into higher education curricula (Hattwig et al., 2013).

In summary, visual literacy encompasses a broad range of abilities, spanning from the interpretation and analysis of visual information to the production and creative design of visual media. It enables individuals to understand visual messages within their cultural, social, and technical contexts, to critically reflect on them, and to communicate effectively through visual representations tailored to specific audiences. In an increasingly digital information and communication landscape, the ability to both interpret and produce visual content using digital technologies is a fundamental component of visual literacy.

Kedra (2018) extends the concept of visual literacy by proposing a thematic categorization of competencies particularly relevant for higher education. She distinguishes three central domains:

1. Visual reading: Including the interpretation and analysis of images, evaluation of visual representations, visual perception, and knowledge of visual grammar and syntax.
2. Visual writing: Encompassing the design and production of visual materials and their effective communication.
3. Advanced visual competencies: Including visual thinking, visual learning, and the reflective and ethically responsible use of images.

Kedra (2018) emphasizes the need not only to define these competency domains theoretically but also to operationalize them in practice by translating them into concrete learning objectives and appropriate assessment methods in higher education. Similarly, Bowen (2017) and Nalinci and Yapıcı (2015) highlight the importance of explicit assessment frameworks to identify strengths and weaknesses in students' visual literacy competencies and to inform targeted instructional interventions.

Huilcapi-Collantes et al. (2023) underline the particular importance of developing visual competencies in light of ongoing digitalization and the post-pandemic educational landscape. Furthermore, Kedra and Zakeviciute (2019) emphasize the role of visual literacy in fostering critical analytical processes in higher education. Visual competence is especially central for millennial and post-millennial generations, as it supports both the interpretation of visual content and the development of critical thinking and effective communication skills.

The systematic literature review indicates that substantial groundwork has been established in terms of competency frameworks and models in the fields of visual literacy and data literacy. The United States has produced the majority of this work, while German-speaking contexts have conducted comparatively few empirical studies. The models and standards presented provide a solid foundation for defining and teaching visual competencies in higher education. They enable an integrative linkage of knowledge, skills, and attitudes and support their practical application.

Studies investigating how different target groups understand visualizations often focus on the ability to extract information from graphical representations (Shah & Hoeffner, 2002; Carpenter & Shah, 1998). In contrast, empirical insights into the underlying cognitive processes involved in data interpretation remain comparatively limited (Liu & Stasko, 2010). Moreover, relatively little attention has been given to competencies related to communicating insights derived from visualized data, particularly in higher education (Schüller et al., 2019), despite their essential importance. Misleading or incorrect communication of data and statistics can render an entire analysis ineffective. Additionally, the development of valid and reliable instruments for assessing these competencies remains a key area for future research and development.

3.3. Data Literacy Competencies: Assessment and Evaluation

The following section presents key research studies in tabular form that focus on the empirical assessment of data literacy competencies, particularly within the higher education context. The studies illustrate the diversity of existing approaches and their respective points of application in higher education. They are categorized into European and international contexts.

The following section first presents assessment instruments developed and applied within the European context.

Table 1. Overview of Measurement Instruments for Assessing Data Literacy Competencies in the European Context

Author (Year)	Context	Instrument / Method	Key Findings	Country / Continent
Deja (2021)	Graduates entering the labor market; not a classical higher education assessment	Self-assessment-based competence measure; assesses perceived data literacy rather than objective competence	Fundamental data literacy competencies are closely related to professional agency and empowerment. Highlights the relevance of data literacy beyond higher education.	European sample (focus on European contexts)
European Data Science Academy (EDSA) (2015-2018)	Higher education context	Data science competence framework with accompanying self-assessment and mapping tools	Structures basic and advanced data-related competencies and serves as a foundation for curricula and training programs.	Europe (Horizon 2020 project with multiple European partners)
Schüller et al. (2019)	Higher education context and labor market	Competence framework model; no assessment; normative-conceptual approach based on expert surveys and literature	Systematization of data literacy as a cross-cutting competence with differentiated competence dimensions. Recommends curricular integration and highlights strong labor market relevance.	Germany

In the study by Deja (2021), it is demonstrated that fundamental data literacy competencies are closely linked to professional practices and action strategies. To investigate the relationship between

competency levels and professional capability, self-assessments and standardized questionnaires were employed. In addition, data literacy was examined during the transition phase from higher education to the labor market. For this purpose, a framework for data science competencies, including a self-assessment tool, was developed within the European Data Science Academy (2017), encompassing a comprehensive set of both basic and advanced competencies. This framework covers competencies in data analysis, data visualization, and data interpretation and is particularly applied in the European higher education context.

Schüller et al. (2019) propose a conceptual competence framework for data literacy with a focus on the German higher education system and the labor market. In this framework, data literacy is conceptualized as a cross-cutting competence that includes fundamental skills such as understanding, analyzing, interpreting, and communicating data, as well as critical and ethical reflection. The authors emphasize the strong labor market relevance of data-related competencies and recommend their systematic integration into higher education curricula. The study adopts a normative-conceptual approach and is not designed as an empirical measurement instrument.

The following section summarizes instruments for assessing data literacy competencies based on international studies.

Table 2. Overview of Instruments for Assessing Data Literacy Competencies in the International Context

Author (Year)	Context	Instrument / Method	Key Findings	Country / Continent
Carlson (2011)	Higher education context (scientific research environments)	Exploratory competence model based on qualitative data collection	Identification of key data and information literacy competencies in higher education and research data contexts. Conceptual structuring of competence domains such as data management, data quality, documentation, and use. Early approach to assessing data literacy.	USA
Kim et al. (2025)	Higher education context	Data Literacy Self-Efficacy Scale (DLSES); psychometrically validated instrument	Validated 29-item scale for measuring data-related self-efficacy. Multidimensional structure with strong psychometric properties. Reveals differences in students' perceived competence levels.	USA
Kim et al. (2024)	Higher education context	Data Literacy Self-Efficacy Scale; initial psychometric validation in higher education	Development of a scale for assessing data-related self-efficacy. Conceptualizes data literacy as an interplay between cognitive abilities and perceived capability to act.	USA

Author (Year)	Context	Instrument / Method	Key Findings	Country / Continent
Cui et al. (2023)	Secondary and higher education context	Systematic review of data literacy instruments	Systematic analysis of existing data literacy instruments. Identifies conceptual overlaps with statistical and information literacy and highlights deficits in validation and higher education-specific operationalization.	International

The competence model developed by Carlson (2011) is designed to assess competencies related to working with data. The associated assessment includes items covering different dimensions of data literacy, such as understanding data types and interpretation and visualization skills, as well as the ability to evaluate the quality and relevance of data.

Kim et al. (2025) validated the Data Literacy Self-Efficacy Scale (DLSES) as part of their study, providing a significant advancement. This revised scale comprises 29 items and measures students' perceived self-efficacy in the domains of data management, data analysis, and data interpretation. The validation study was conducted at two universities in the United States and demonstrated strong psychometric properties, indicating that the scale is a suitable instrument for use in higher education contexts. Similarly, Kim et al. (2024) developed a scale for assessing data literacy self-efficacy that focuses on the interplay between cognitive abilities and individuals' perceived capability to act effectively.

In addition to validated scales, there are also project- and practice-based approaches to assessing data literacy, such as institution-specific surveys (e.g., at Carnegie Mellon University) or index models applied in specific contexts, which, however, lack standardized validation. These instruments illustrate the breadth of current assessment practices while simultaneously emphasizing the necessity of theoretically grounded and psychometrically validated measurement tools (DeVellis, 2017; Delacre et al., 2017).

Large-scale educational studies also incorporate data-related competencies as part of broader assessment frameworks. For example, the National Assessment of Educational Progress (NAEP) includes task formats across various domains that address aspects of data analysis, interpretation, and the application of quantitative information in real-world scenarios (NCES, 2022). Furthermore, in higher education contexts, various questionnaire-based approaches are used for the self-assessment of data-related competencies, capturing dimensions such as data processing, analysis, and statistical interpretation (Kim et al., 2025; Kim et al., 2024; Deja, 2011; Carlson et al., 2011).

This heterogeneous landscape of instruments reflects the increasing importance of assessing data literacy competencies and also indicates a lack of standardization in existing measurement approaches.

A systematic review by Cui et al. (2023) provides an in-depth overview of existing approaches to assessing data literacy and offers a critical evaluation of these methods. The authors demonstrate that many existing instruments either focus narrowly on statistical skills or overlap conceptually with related constructs such as information literacy or numeracy. Moreover, their analysis highlights a substantial need for validated instruments specifically designed to assess data literacy competencies in higher education.

Overall, the studies presented indicate that a range of instruments for assessing data literacy in higher education contexts already exist and are in use. While earlier approaches primarily focused on foundational knowledge and skills (e.g., the Data Literacy Assessment by Carlson et al., 2011), more recent work increasingly emphasizes validated self-assessment scales (e.g., the Data Literacy Self-Efficacy Scale by Kim et al., 2025). A common characteristic across these instruments is that they conceptualize data literacy as a multidimensional competence encompassing technical knowledge and analytical skills, as well as reflective and ethical dimensions in working with data.

3.4. Visual Literacy Competencies: Assessment and Evaluation

The following section summarizes key research studies that focus on the empirical assessment of visual literacy competencies and are relevant to the higher education context. The evaluation of visual literacy competencies is inherently complex, as it must account for receptive, productive, and reflective dimensions.

Table 3. Overview of Instruments for Assessing Visual Literacy Competencies in the European Context

Author (Year)	Context	Instrument / Method	Key Findings	Country / Continent
Wagner & Schönau (ENViL Project, 2016); Schönau et al. (2020)	Art and design context; not explicitly focused on higher education but transferable to higher education curricula	Common European Framework of Reference for Visual Literacy (CEFR_VL); competence framework model	European competence framework for visual literacy. Differentiates between production ("creation") and reception ("reception") as well as a metacognitive dimension. Provides curricular orientation but does not constitute an empirically validated measurement scale.	Europe (e.g., Germany, Austria, Switzerland)
Groenendijk et al. (ENViL Project) (2018)	Higher education context, but not exclusively higher education-specific (art/design)	Conceptual analyses with assessment components; self-assessment approaches	Conceptual analysis of the operationalization of visual literacy. Highlights methodological and conceptual challenges in validating assessment instruments, particularly self-assessment tools.	Europe
Huilcapi-Collantes et al. (2022)	Higher education context	Analytical assessment rubric	Development and application of a differentiated rubric for evaluating student-generated visual artifacts. Operationalizes visual literacy into clearly defined criteria and competence dimensions. Enables structured performance assessment but is primarily practice-oriented and not comprehensively psychometrically validated.	Spain

The studies presented in the table below illustrate the diversity of existing approaches and their points of application within higher education. In line with the studies on data literacy presented in Section 3.3, they are categorized into European and international contexts. The following section first introduces assessment instruments developed and applied within the European higher education context.

Within the ENViL project, the „Common European Framework of Reference for Visual Literacy (CEFR_VL)" was developed to address existing gaps between educational research and curriculum development in the field of art and design (Schönau et al., 2020; Wagner & Schönau, 2016). The second version of this framework differentiates the main domains of „creation" and „reception" into a total of 16 sub-competencies. Based on more recent research analyses, these competencies were further structured into the domains of producing and responding, each comprising specific sub-competencies.

Groenendijk et al. (2018) also emphasize that the development of validated self-assessment instruments for visual literacy presents both conceptual and methodological challenges. Consequently, further research is required to ensure the validity of such instruments.

Building on the standards of the Association of College & Research Libraries (2011), Huilcapi-Collantes et al. (2020) developed, on the one hand, an assessment framework for evaluating in-service teachers' competency levels and, on the other hand, an evaluation rubric for assessing visual projects (2022, Table 4). These studies illustrate the translation of established competency standards into concrete assessment instruments.

The following section presents studies from the international higher education context.

Table 4. Overview of Instruments for Assessing Visual Literacy Competencies in the International Context

Author (Year)	Context	Instrument / Method	Key Findings	Country / Continent
Kim et al. (2020)	Higher education context	Analysis of questions and answers related to bar and line charts	Empirical analysis of students' responses to bar and line charts. Identifies typical misinterpretations and heuristic processing patterns. Provides didactic implications for fostering visual literacy in the context of data.	USA
Huilcapi-Collantes et al. (2022)	Higher education context	Learning analytics-based assessment approach	Development of a data-driven approach for assessing visual literacy in higher education. Uses learning analytics methods to analyze student artifacts and interaction data. Demonstrates the potential of automated or semi-automated competence assessment, though without comprehensive psychometric validation.	International

Author (Year)	Context	Instrument / Method	Key Findings	Country / Continent
Arslan & Nalinci (2014)	Higher education context	Visual Literacy Levels Scale (VLLS)	Development of a scale instrument with 41 items and seven dimensions (α = 0.947) for assessing visual literacy in higher education. Covers analytical, evaluative, design, and ethical aspects of visual competence.	Turkey
Beaudoin (2016)	Higher education context	Reflections on historical photographs; no validated instrument; no scale development	Intervention study aimed at fostering visual analysis skills in higher education. Improvements in image description are observable, while deeper reflective processes remain challenging.	USA
Bell (2014)	Higher education context (biology)	Comparison of hand drawing vs. computer-based drawing; no validated instrument; no scale validation	Experimental study in a biology context. Students achieve better learning outcomes through hand drawing compared to computer-based drawing. Provides evidence for the learning benefits of active visual construction.	USA
Emanuel & Challons-Lipton (2013); Emanuel et al. (2017)	Higher education context (arts/cultural domain)	Cultural Image Literacy Assessment USA (CILA)	Development of an objective test instrument for assessing cultural image literacy in higher education. High reliability (α = 0.94); identifies deficits in the recognition and contextualization of artworks and paintings.	USA
Huang & Liu (2022)	Higher education context	Empirical analysis of visual expression skills; no standardized test instrument; no scale development	Empirical analysis of students' visual expression skills. Identifies deficits in communication, application, and practical implementation of visual content. Highlights the need	China

Author (Year)	Context	Instrument / Method	Key Findings	Country / Continent
			for targeted support.	
Zhu & Lim (2024)	Higher education context (visual communication design)	Self-assessment questionnaire; no scale development	Assessment of perceived visual literacy competencies among students in visual communication design. Differentiates competencies across identifying, locating, interpreting, and evaluating visual materials. Emphasizes the need for targeted curricular support.	China / East Asia
Wang et al. (2023)	Higher education and professional context (health sciences)	Visual Literacy Scale – Health Students & Professionals (VLS-HSP); validated scale instrument; psychometrically grounded	Development and validation of the VLS-HSP for assessing visual literacy in the health domain. Multidimensional structure with strong psychometric properties. Focus on interpretation and application of visual information.	China
Uminski et al. (2025)	Higher education context (natural sciences)	Empirical performance study; no scale instrument; no formal assessment framework	Empirical analysis of students' performance in interpreting drawn scientific representations. Reveals persistent misinterpretations and highlights the need for explicit support of visual interpretation skills.	USA

Kim et al. (2020) investigated typical question types that arise in the analysis of charts. Learners were presented with different types of bar charts (simple, grouped, and stacked) as well as line charts and were asked to formulate questions, answers, and explanations. The analysis of the initial questions revealed common errors in the interpretation of visualized data. The findings provide valuable implications for teaching visual literacy, particularly with regard to preventing typical interpretation errors.

Arslan and Nalinci (2014) introduced the Visual Literacy Levels Scale, a reliable instrument for assessing students' competencies, encompassing dimensions such as locating, analyzing, evaluating, and creating visual content, as well as ethical considerations.

In addition to these predominantly standardized approaches, there are also studies that assess visual literacy using more qualitative methods. Beaudoin (2016), for example, employed reflections on historical photographs to examine improvements in image description skills. Furthermore, Bell (2014) demonstrated

that hand-drawing biological structures led to better learning outcomes than computer-assisted drawing. Emanuel and Challons-Lipton (2013) investigated students' ability to recognize cultural symbols and artworks and subsequently developed the Cultural Image Literacy Assessment-USA (Emanuel et al., 2017), which demonstrated high reliability ($\alpha = 0.94$).

Huang and Liu (2022) identified weaknesses among undergraduates in visual communication and practical implementation, while Zhu and Lim (2024) developed an instrument for students in visual communication design aimed at fostering critical thinking. In other domain-specific contexts, such as the health sciences, tailored instruments have also been developed—for example, the Visual Literacy Scale – Health Students and Professionals (VLS-HSP), which was designed to assess the interpretation and use of visual materials in this field (Wang et al., 2023). Uminski et al. (2025) examined, within a higher education science context, students' ability to correctly interpret drawn scientific representations. Based on performance-based tasks, the study indicated that even advanced students experience difficulties in interpreting schematic diagrams and in transferring information between visual and textual representations. The findings highlight persistent misconceptions and emphasize the necessity of explicit support for visual interpretation skills in science education at the tertiary level.

Overall, the findings indicate that visual literacy competencies can be assessed using various instruments that capture both general and domain- or context-specific dimensions. While frameworks such as the Common European Framework of Reference for Visual Literacy (CEFR_VL) and the ACRL standards provide a theoretical foundation, empirical studies demonstrate that visual literacy should be regarded as a key competence that does not develop automatically (Association of College & Research Libraries, 2011; Yeh & Cheng, 2010). Rather, similar to reading and writing skills, it requires deliberate instruction and systematic development (Pohl, 2023; Krekhov, 2019).

Section 3.5 addresses the intersection of data literacy and visual literacy in terms of data visualization literacy. As the distinction between these constructs remains conceptually ambiguous in current research, the following section also presents measurement instruments designed for adult populations, which can therefore be applied in higher education contexts.

3.5. Visual Literacy in the Context of Data: Assessment and Evaluation of Data Visualization Literacy

The intersection between data literacy and visual literacy is often discussed under the term "data visualization literacy" (Börner et al., 2019). Empirical studies, both standardized and experimental, have investigated various approaches to assessing data visualization literacy among students in higher education. The table below summarizes these approaches.

Table 5. Overview of Instruments for Assessing Data Visualization Literacy

Author (Year)	Context	Instrument / Method	Key Findings	Country / Continent
Börner et al. (2019)	General and higher education context	DVL framework; no test; no scale; no empirical validation	Conceptual framework for systematizing data visualization literacy. Differentiates key competence dimensions and calls for the development of valid assessment instruments.	USA (internationally recognized)
Lee et al. (2017)	Higher education context	Visualization Literacy Assessment (VLAT); performance-based test instrument	Development of the Visualization Literacy Assessment Test. Reliable instrument with 53 items and 12	USA

Author (Year)	Context	Instrument / Method	Key Findings	Country / Continent
			visualization types; covers eight task categories of chart interpretation.	
Boy et al. (2014)	Higher education and adult education	IRT-based test instrument with chart tasks (line, bar, and scatterplots); objective performance-based measure; psychometrically grounded	Development of an IRT-based test instrument for assessing visualization literacy. Operationalizes tasks for line, bar, and scatterplots. Enables latent ability modeling and visualization-type-specific competence analysis.	USA / international
Brockbank et al. (2025)	Higher education context	Validation and comparative study (comparison of VLAT with another DVL instrument)	Comparison of two performance-based data visualization literacy instruments. Shows significant but incomplete convergence and indicates differing operationalizations of sub-competencies. Relevant for construct validation of data visualization literacy.	USA
Rogers & Jeffcoat (2024)	Higher education context (information science)	Application of the VLAT	Students demonstrate overall basic data visualization literacy skills but show notable deficits for specific visualization types, indicating a need for explicit instruction in higher education.	USA
Rodrigues et al. (2020)	Higher education	Empirical error analysis / performance study; no standardized measurement instrument	Empirical analysis of typical misinterpretations among students. Identifies recurring misconceptions in chart interpretation and provides didactic implications.	Brazil
Rodrigues et al. (2024)	Higher education	Performance-based test instrument with 15 visualization types; broader	Development and analysis of a comprehensive performance-based test for assessing	Brazil

Author (Year)	Context	Instrument / Method	Key Findings	Country / Continent
		coverage than VLAT	data visualization literacy, incorporating 15 visualization types. Enables differentiated competency diagnostics.	
Firat et al. (2020)	Higher education (computer science / human–computer interaction)	Empirical performance study; no standardized measurement instrument	Students demonstrate significant difficulties in interpreting hierarchical visualizations (treemaps), particularly regarding structural understanding, area encoding, and relational comparison. Complex visualization types increase cognitive load.	Turkey
Krekhov et al. (2019)	Higher education	Intervention study; no standardized measurement instrument	A 12-week intervention study involving regular visualization tasks shows a systematic improvement in visualization competencies over time, highlighting the importance of continuous practice.	Germany/Austria
Donohoe & Costello (2020)	Higher education	Empirical comparative study; no standardized instrument	Comparison of self- and external assessment reveals a systematic overestimation of students' own data visualization literacy competencies, emphasizing the limitations of purely self-report-based measures.	Ireland
Wang et al. (2020)	Higher education	Experimental evaluation study; no independent measurement instrument	Evaluation of "cheat sheets" as structured support for selecting and interpreting data visualization techniques. Results show improved task performance and	USA / international

Author (Year)	Context	Instrument / Method	Key Findings	Country / Continent
			increased confidence when dealing with complex visualizations.	
Huron et al. (2014)	Higher education and general adult population	Experimental and design study; no standardized test instrument, no psychometric assessment	Investigation of the creation of data visualizations as a constructive process. Identifies 11 subtasks and key challenges (simplicity, expressiveness, dynamics). Provides didactic implications for fostering productive visualization competencies.	France

A central theoretical reference model is provided by the data visualization literacy (DVL) framework proposed by Börner et al. (2019), which systematizes core dimensions of data visualization literacy and thus offers a conceptual foundation for the development of appropriate assessment instruments. To measure data visualization literacy, a range of empirical studies have been conducted, employing diverse methodological approaches.

Lee et al. (2017) developed the Visualization Literacy Assessment Test (VLAT), a standardized instrument consisting of twelve visualizations, including line charts, histograms, and scatterplots, and 53 multiple-choice items. The instrument covers eight task categories in data visualization, including retrieving specific values, characterizing distributions, and comparing trends. The VLAT was validated with a sample of 191 participants and demonstrates high reliability.

Boy et al. (2014) conducted a similar study, assessing visualization competencies using item response theory (IRT). Their approach tested adults' ability to correctly interpret line charts, bar charts, and scatterplots. Each visualization type was operationalized through specific test items targeting different cognitive demands.

In addition to these standardized instruments, a number of experimental studies investigate data visualization literacy within specific teaching and learning contexts. Rodríguez et al. (2020), for example, analyzed typical errors and patterns in students' interpretation of visualized data, deriving didactically relevant implications for instructional design. Furthermore, Rodríguez et al. (2024) extend the predominantly U.S.-centric discourse on data visualization literacy by developing a comprehensive assessment instrument. Firat et al. (2020) found that computer science students experience particular difficulties in interpreting treemaps. Krekhov et al. (2019) demonstrated in a twelve-week experimental study that regular engagement with visualization tasks leads to a systematic improvement in competency levels. Donohoe and Costello (2020) additionally identified a discrepancy between self-assessment and external assessment, with students often overestimating their abilities in handling data visualizations.

Further studies focus on targeted instructional interventions aimed at fostering data visualization literacy. Wang et al. (2020), for instance, developed so-called "cheat sheets" as structured support tools for interpreting complex visualizations. These materials were effective didactic instruments by facilitating access to demanding visual representations.

Huron et al. (2014) examined the practical dimension of creating visualizations and identified specific challenges within this process. Based on their findings, they developed eleven subtasks categorized under

"constructing" and "combining" data representations. This framework provides a structured basis for fostering productive visualization competencies.

To further expand the empirical evidence base, Rodrigues et al. (2024) developed a test instrument incorporating different visualization types, specifically designed to assess visualization competencies among students at varying levels. Complementary work on the refinement of existing instruments indicates that different measurement approaches capture partially overlapping but also distinct sub-competencies in data visualization literacy. For instance, the short form of the VLAT (Mini-VLAT) offers a more compact operationalization of core visualization comprehension skills (Pandey & Ottley, 2023), while multidimensional instruments such as Multidimensional Assessment of Visual Data Literacy (MAVIL) capture more differentiated facets of visual data competence (Saske et al., 2024). Although the study does not focus on higher education, it gives valuable insights into general competency levels and deficits in visual data literacy. These developments highlight the continued heterogeneity of the assessment landscape and the conceptual diversity in measuring visualization competencies. Rogers & Jeffcoat (2024), using the VLAT (Lee et al., 2017), found that although students in information science programs possess basic competencies, substantial differences and specific deficits remain across visualization types.

Overall, a broad range of approaches to assessing data visualization literacy exists within higher education. Standardized instruments such as the VLAT (Lee et al., 2017) and IRT-based tests (Boy et al., 2014) represent valid and reliable measurement tools that capture both foundational and advanced aspects of visualization competence. Experimental studies (e.g., Krekhov et al., 2019; Wang et al., 2020; Rodríguez et al., 2020, 2024) provide practice-oriented insights for the design of effective teaching and learning environments.

In the European context, theoretical models such as the Common European Framework of Reference for Visual Literacy (CEFR_VL) (Wagner & Schönau, 2016) and the framework of the European Data Science Academy (2017) currently dominate. However, there remains a lack of empirically validated and widely applicable assessment instruments. While various instruments exist internationally, such as the Data Literacy Assessment (Carlson, 2011) and the Data Literacy Self-Efficacy Scale (Kim et al., 2025) in the domain of data literacy, as well as the Visual Literacy Levels Scale (Arslan & Nalinci, 2014) and the Visual Literacy Scale – Health Students and Professionals (VLS-HSP) (Wang et al., 2023) in the domain of visual literacy, these tools are often tailored to specific disciplines and thus have limited integrative applicability.

The analysis of the relevant literature indicates that visual literacy has been investigated empirically more frequently than data visualization literacy in higher education contexts. Empirical findings suggest that fostering both competence domains has positive effects on student learning outcomes (Faridha et al., 2023; Schoonover, 2021) and should therefore remain a focus of future educational research. Zhu and Lim (2024) particularly emphasize the importance of critical thinking in this context.

Building on this insight, the present study develops a scaffolding model as a didactic intervention, representing a component of a broader competence model. In addition to visualization literacy and the derivation and communication of data, this model integrates critical evaluation as a central sub-competency of visual literacy within the context of data literacy.

4. DISCUSSION

4.1. Content-Related Discussion

4.1.1. Identified Visual Literacy competencies in the context of Data Literacy in Higher Education

The intersection between data literacy and visual literacy is frequently conceptualized under the term "data visualization literacy" (Börner et al., 2019). The findings of the systematic literature review indicate that visual literacy, within the context of data literacy, can be understood as a multidimensional competence construct encompassing several interrelated domains (Beschi et al., 2025; Börner et al., 2019).

Central to this construct are receptive competencies, which enable individuals to decode visual representations, such as charts, graphs, and complex data visualizations, extract relevant information, and identify patterns and relationships (Association of College & Research Libraries, 2011; Beschi et al., 2025;

Börner et al., 2019). In addition, visual literacy includes analytical and critical competencies that support the reflective evaluation of visual representations in terms of their validity, quality, and potential biases (Lee et al., 2016; Beschi et al., 2025; Börner et al., 2019). This critical perspective also entails consideration of ethical, social, and cultural contexts (Kedra, 2018; Nalinci & Yapici, 2015; Brumberger, 2011).

Beyond receptive and analytical dimensions, visual literacy also encompasses productive competencies related to the creation and audience-appropriate design of visual representations (Avgerinou & Ericson, 1997; Börner et al., 2019; Beschi et al., 2025). Students are expected to select appropriate visualization formats and prepare data in ways that enable accurate and target-group-specific communication (Zhu & Lim, 2024).

Furthermore, cognitive and metacognitive competencies are gaining increasing importance, particularly with regard to the construction of mental models that facilitate the integration of visual information into existing knowledge structures and support its application in decision-making processes (Schnotz, 2005; Schnotz & Bannert, 2003). Finally, digital and contextual competencies represent another key dimension, as the ability to use digital visualization tools and to interpret visual information in digital environments is considered a fundamental prerequisite for effective data-driven communication (Huilcapi-Collantes et al., 2023; Avgerinou, 2009).

Overall, however, the findings indicate that cognitive competencies, in particular, have received comparatively limited attention in previous research, highlighting a need for further investigation (Varona, 2025; Liu & Stasko, 2010).

4.1.2. Fostering Visual Literacy competencies in the context of Data Literacy in Higher Education

The findings of the present systematic literature review indicate that visual literacy competencies within the context of data literacy constitute a key prerequisite for data-driven communication and informed decision-making (Schüller et al., 2019). At the same time, empirical evidence suggests that these competencies are often insufficiently developed among students and do not emerge implicitly (Pohl, 2023; Krekhov et al., 2019). This calls into question their systematic and curricular integration in higher education (Hattwig et al., 2013; Schüller et al., 2019).

Effective instructional approaches should therefore go beyond the mere teaching of methodological skills and explicitly address cognitive and metacognitive processes (Varona, 2025; Lieb & Pickhardt, 2025). Of particular importance is the support of mental model construction, enabling students to interpret visual data representations, critically evaluate them, and integrate them into decision-making processes (Schnotz, 2005; Schnotz & Bannert, 2003). Instructional designs that gradually guide learners from scaffolded analytical processes toward independent evaluation and creation are particularly well suited for this purpose (Smit et al., 2013; Schukajlow et al., 2015).

Furthermore, learning environments should be designed to integrate both receptive and productive dimensions of competence. This includes not only the analysis of existing visualizations but also the independent construction of visual representations, as well as their reflection in terms of clarity, validity, and potential biases (Börner et al., 2019; Lee et al., 2016). Empirical findings suggest that iterative learning formats and problem-based tasks, in particular, have a positive impact on the development of these competencies (Krekhov et al., 2019; Prince, 2004; Wang et al., 2020).

Another key approach lies in the targeted promotion of critical thinking (Zhu & Lim, 2024; Lee et al., 2016). Students should be enabled not only to understand visualizations but also to critically question their underlying data, assumptions, and potential manipulations (Zhu & Lim, 2024; Kedra & Zakeviciute, 2019; Börner et al., 2019). Supporting materials, such as structured guiding questions or visual "cheat sheets," can help reduce cognitive load and facilitate complex analytical processes (Wang et al., 2020).

Against this background, higher education institutions play a central role in systematically fostering visual literacy competencies within the broader framework of data literacy. The process of visualization, both in terms of production and reception, supports the structuring, condensation, and interpretation of complex information (Card et al., 1999; Ware, 2013). Studies demonstrate that active engagement with visualizations, for example through their independent creation or iterative refinement, contributes to a more profound understanding of data-driven relationships (Krekhov et al., 2019; Wang et al., 2020; Börner et al.,

2019). At the same time, misleading or poorly designed visualizations can significantly impair data comprehension (Pandey et al., 2015; Cairo, 2016), further emphasizing the value of well-developed visual literacy within the context of data literacy (Lee et al., 2016; Beschi et al., 2025).

The findings clearly indicate that these competencies cannot be assumed to develop implicitly but must be deliberately fostered (Pohl, 2023). This requires curricular integration that addresses both methodological and cognitive dimensions, including critical-reflective processes and pattern recognition. Higher education teaching should therefore create learning environments that integrate the design, analysis, and reflection of data visualizations and enable students to use them competently for communication and decision-making purposes. At the same time, there is a need for appropriate diagnostic instruments to validly assess competence development.

Building on these findings, the didactic intervention developed in this study addresses existing research gaps and specifically targets the identified discrepancy between methodological and cognitive competence dimensions. It places particular emphasis on fostering critical evaluation and the construction of mental models (Lieb & Pickhardt, 2025). At the same time, it aims to reduce existing deficits among students by enabling them not only to analyze data visualizations but also to use them reflectively in decision-making processes, with particular attention to both critical evaluation and the origin of the underlying data (Lieb & Pickhardt, 2025). Ultimately, the goal is to contribute to strengthening data-informed decision-making in higher education.

4.1.3. Empirical Findings on Visual Literacy Competencies in the Context of Data Literacy Among Students

Overall, the empirical findings present a heterogeneous picture of students' competency levels. While students often possess basic skills for interpreting simple visualizations, they demonstrate significant difficulties when dealing with more complex forms of representation (Beschi et al., 2025; Börner et al., 2019; Galesic & Garcia-Retamero, 2011; Lee et al., 2017). In particular, recurring misinterpretations are observed, for example, in relation to axis scaling, area encoding, or relational comparisons (Rodrigues et al., 2020; Kim et al., 2020). Furthermore, many students struggle to transfer and integrate information across visual and textual representations (Ainsworth, 2006; Beschi et al., 2025; Lee et al., 2016).

Another notable deficit concerns the analytical and critical dimension of visual literacy. Students often exhibit limited ability to evaluate visualizations in terms of their quality, validity, and potential biases (Lee et al., 2016; Zhu & Lim, 2024; Kedra, 2018). Visual communication also poses a challenge, particularly with regard to the creation of clear, audience-appropriate visualizations (Börner et al., 2019; Huang & Liu, 2022). In addition, studies indicate a discrepancy between self-assessment and external assessment, with students tending to overestimate their competencies in handling data visualizations (Donohoe & Costello, 2020; Dunning, 2011; Kruger & Dunning, 1999).

At the same time, empirical research shows that targeted instructional interventions can have positive effects on competency development. In particular, regular practice formats, problem-based tasks, and supporting materials have been shown to improve both the understanding and application of visual data competencies (Krekhov et al., 2019; Wang et al., 2020). Overall, these findings underline that visual literacy competencies cannot be assumed to develop implicitly but require systematic support within higher education contexts (Pohl, 2023; Krekhov et al., 2019; Beschi et al., 2025).

A large proportion of empirical studies focus on the comprehension of visualizations and on methodological competencies related to graphical representations. In particular, these studies examine skills such as extracting information, comparing data points, and identifying trends (Shah & Hoeffner, 2002; Carpenter & Shah, 1998). The findings indicate that while students are often able to handle basic tasks, difficulties arise when dealing with more complex visualization types and higher-level analytical demands (Firat et al., 2020). Recurring misinterpretations, in particular, point to an insufficient understanding of visual encoding and representational logic (Rodrigues et al., 2020; Kim et al., 2020). These results highlight that methodological competencies are a necessary but not sufficient condition for a profound understanding of visualized data (Liu & Stasko, 2010).

4.1.4. Instruments for Assessing. Visual Literacy competencies in the context of Data Literacy

The analysis of the literature indicates that a wide range of instruments is used to assess visual literacy competencies within the context of data literacy in higher education; however, these instruments are characterized by a high degree of heterogeneity. These are standardized test instruments, some of which have been validated psychometrically, that are based on performance tasks for interpreting visualizations. Examples include the Visualization Literacy Assessment Test (VLAT) and IRT-based testing approaches, which allow for a differentiated analysis of specific sub-competencies (Lee et al., 2017; Boy et al., 2014). On the other hand, scale-based instruments have been developed that primarily rely on self-assessment, such as the Data Literacy Self-Efficacy Scale and the Visual Literacy Levels Scale (Kim et al., 2025; Arslan & Nalinci, 2014; Calzada-Prado & Marzal, 2013).

In addition to these empirical measurement instruments, competence frameworks play an important role. However, these primarily serve conceptual structuring and curricular orientation rather than direct measurement. Examples include the Visual Literacy Competency Standards and the Common European Framework of Reference for Visual Literacy (Association of College & Research Libraries, 2011; Wagner & Schönau, 2016). Furthermore, performance- and process-oriented approaches are employed, for instance in the form of diagram interpretation tasks, error analyses, or learning analytics-based methods (Börner et al., 2019; Rodrigues et al., 2020; Huilcapi-Collantes et al., 2022). Complementary qualitative approaches, such as assessment rubrics or reflective task formats, are also used to capture productive and reflective dimensions of competence (Huilcapi-Collantes et al., 2022; Beaudoin, 2016; Liu & Stasko, 2010).

The current landscape of instruments exhibits limited standardization and, in some cases, insufficient validation, according to the findings. Moreover, many instruments primarily focus on methodological aspects, while cognitive and critically reflective competencies remain only partially operationalized (Cui et al., 2023; Beschi et al., 2025). This points to a clear need for the development of integrative, theoretically grounded, and psychometrically validated instruments capable of addressing the complex requirements of visual literacy within the context of data literacy in higher education (Cui et al., 2023; Beschi et al., 2025; Börner et al., 2019).

The reviewed studies also demonstrate that substantial groundwork has already been laid in terms of the conceptual modeling of visual literacy, data literacy, and data visualization literacy competencies. In particular, competence frameworks such as the ACRL standards and the Common European Framework of Reference for Visual Literacy (Schönau et al., 2020; Wagner & Schönau, 2016) provide differentiated descriptions of relevant sub-competencies and offer an important foundation for the development of assessment instruments (Association of College & Research Libraries, 2011; Wagner & Schönau, 2016; Hattwig et al., 2013). At the same time, it becomes evident that translating these theoretical models into empirically testable instruments poses considerable challenges. These challenges primarily concern the operationalization of complex and partly abstract competence dimensions, such as critical evaluation or mental model construction. Equally demanding is the representation of the interplay between receptive, productive, and reflective competencies (Groenendijk et al., 2018; Huilcapi-Collantes et al., 2022; Liu & Stasko, 2010).

Many instruments are tailored either to specific subdomains or to particular disciplines and are therefore limited in their generalizability. In the European higher education context, conceptual models continue to predominate over empirically validated measurement instruments (Wagner & Schönau, 2016; Schüller et al., 2019). In addition, the conceptual ambiguity and overlap between the constructs of visual literacy, data literacy, and data visualization literacy complicate clear construct specification and, consequently, the development of distinct and discriminant measurement instruments (Cui et al., 2023; Börner et al., 2019).

Overall, there remains a lack of integrative instruments capable of systematically and comparably capturing the multiple dimensions of visual literacy within the context of data literacy (Cui et al., 2023; Beschi et al., 2025).

4.2. Methodological Discussion

When interpreting the results, one must consider several methodological limitations. First, the present analysis is based on a limited number of studies that explicitly address the higher education context, which restricts the generalizability of the findings (Zhu & Lee, 2024; Cui et al., 2023). Second, the included studies exhibit a high degree of heterogeneity in terms of theoretical approaches, research designs, and operationalizations, which limits the comparability of the results (Cui et al., 2023).

Furthermore, a significant portion of the existing research comes from international, particularly U.S. contexts, leaving empirical studies from German-speaking regions underrepresented. Finally, it should be noted that many of the analyzed studies are either conceptual in nature or do not employ fully validated measurement instruments, which reduces the robustness of individual findings (Groenendijk et al., 2018; Huilcapi-Collantes et al., 2022; Beschi et al., 2025).

At the same time, these limitations emphasize the necessity for further empirical research in higher education contexts.

5. CONCLUSION

The findings of the systematic literature review demonstrate that visual literacy within the context of data literacy should be understood as a multidimensional competence construct integrating receptive, analytical, productive, cognitive, and critically reflective dimensions. Across the reviewed studies, visual literacy emerges not only as the ability to interpret and create visual representations but also as the capacity to critically evaluate visualized data, recognize patterns and potential biases, and communicate data-driven insights appropriately within higher education contexts. The review further reveals several recurring empirical trends. Although students often demonstrate basic competencies in interpreting common visualizations, substantial difficulties persist regarding complex visual representations, critical interpretation, reflective evaluation, and audience-oriented communication. In particular, both empirical research and existing competence models comparatively underrepresent cognitive processes such as mental model construction, pattern recognition, and critical reflection.

Furthermore, the findings indicate a highly heterogeneous landscape of assessment approaches. Existing instruments range from self-assessment scales and conceptual competence frameworks to performance-based visualization tests. While several validated instruments already exist, many approaches continue to focus predominantly on methodological skills and only partially operationalize cognitive and critically reflective dimensions of competence. In addition, conceptual overlaps between data literacy, visual literacy, and data visualization literacy continue to complicate the development of integrative assessment models.

Overall, the review highlights both the growing relevance and the conceptual complexity of visual literacy within the broader framework of data literacy in higher education. At the same time, the findings reveal persistent theoretical, empirical, and methodological gaps that continue to shape the current state of research.

6. IMPLICATION OF THE STUDY

The findings of this systematic literature review indicate several implications for higher education teaching, curriculum development, instructional design, assessment, and future research. Overall, the review demonstrates that visual literacy in the context of data literacy should not be regarded as an implicit byproduct of statistics or data-related instruction, but rather as a multidimensional competence construct that requires explicit and systematic support in higher education contexts.

For educators and instructional designers, the findings suggest the importance of learning environments that integrate receptive, analytical, productive, cognitive, and critically reflective dimensions of competence. Students should not only learn to interpret visualizations but also to critically evaluate data sources, identify potential biases, and communicate data-driven insights appropriately within disciplinary and professional contexts. In this regard, authentic and application-oriented learning environments appear particularly relevant. The review indicates that problem-based, case-based, and iterative learning approaches

may support the development of these competencies by enabling students to engage critically with visualized data from scientific, professional, and media-related contexts.

Furthermore, the findings highlight the importance of supporting cognitive processes underlying visualization comprehension, particularly the construction of mental models, pattern recognition, and reflective decision-making. Instructional approaches should therefore move beyond purely technical training and increasingly incorporate scaffolded analytical processes that guide learners toward independent interpretation and critical reflection. At the curricular level, the interdisciplinary relevance of visual literacy competencies becomes evident across domains such as economics, social sciences, health sciences, teacher education, and other data-intensive fields. Consequently, curriculum developers should consider integrating visual literacy competencies systematically across higher education programs.

Based on these identified shortcomings, we can derive several key requirements for future measurement instruments. First, such instruments should conceptualize visual literacy within the context of data literacy as a multidimensional construct, integrating not only receptive and productive but especially cognitive and critically reflective dimensions of competence (Beschi et al., 2025; Börner et al., 2019; Association of College & Research Libraries, 2011). Varona et al. (2025) provide an in-depth review of visualization literacy research across contexts and propose a multidimensional framework that integrates cognitive, analytical, and critical competencies without focusing specifically on higher education. Second, greater emphasis should be placed on performance-based task formats that reflect authentic application scenarios and go beyond mere knowledge recall (Lee et al., 2017; Boy et al., 2014). Third, subjective self-assessments should be complemented by objective measurement approaches to reduce biases, such as the overestimation of one's own competencies (Donohoe & Costello, 2020; Kruger & Dunning, 1999).

Another important requirement lies in the development of theoretically grounded and psychometrically validated instruments that are both transferable across domains and adaptable to specific disciplinary contexts (Calzada-Prado & Marzal, 2013; Cui et al., 2023; Kim et al., 2025). Finally, greater attention should be given to measuring competence development within learning processes to enable the valid evaluation of the effectiveness of instructional interventions (Krekhov et al., 2019; Wang et al., 2020; Prince, 2004).

The literature review thus provides a basis for identifying and designing didactic interventions aimed at strengthening visual literacy within the context of data literacy. Building on these insights, a didactic intervention grounded in mental models has been developed and evaluated, as presented in the contribution "A didactic intervention to strengthen critical thinking in the interpretation of visualized data" (Lieb & Pickhardt, 2025). Future research will examine the study design and outcomes to explore the potential relationship between visual literacy and pattern recognition competence.

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Appendix A

Table A1. Condensed Excerpt of the Review Matrix Used for the Systematic Categorization and Analysis of the Included Studies

Reference	Country	Sample		Results for skills			Research strategy				Survey methodology		
Reference	Country	Target group	Number of partici-pants	Data Literacy	(Data) Visualization Literacy	Visual Literacy	Quanti-tative	Quali-tative	Mixed-Methods	Not specified	Assess-ment tool	Response scale	Quality criteria
Arslan & Nalinci (2014)	Turkey	Post-secondary students	414			Based on the Competency Standards (ACRL, 2011), seven different fields and twenty-four performance indivators have been determined. In an interdisciplinary, higher education environment, a visually literate individual is able to: - 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 soruces - use images and visual media effectively - design and create meaningful images and visual media - understand many of the ethical, legal, social, and econimic issues surrounding the creation and use of images and visual media, and access and use visual materials ethically.	x				Self-reported scale/ques-tionnaire	Likert scale	reliability and validity
Beaudoin (2016)	USA	Post-secondary students	31			- find - interpret - evaluate use and create images and visual media (ACRL, 2011).	x				Exercises	Con-structed response	N/A
Bell (2014)	Canada	Post-secondary students	33			N/A	x				Self-reported scale/ques-tionnaire	Likert scale	N/A
Carlson et al. (2011)	USA	Research-ers/Post-secondary students	19, 27	- access - assess - manipulate - summarize - present data					x		Semi-structured interview	Con-structed response	N/A
Donohoe & Costello (2020)	Ireland	Post-secondary students	32		N/A		x				Ques-tionnaire	Multiple Choice/ Likert scale	The adapted VLAT test for this study needs to be reliably validated.
Emanuel & Challons-Lipton (2013)	USA	Post-secondary students	358			'- read - decode and - interpret visual images.	x				Ques-tionnaire	Con-structed response	reliability
Emanuel et al. (2017)	USA	Post-secondary students	309			Visual literacy involves five conceptual components: - visual perception - visual language - visual thinking - visual learning - visual communication (Avgerinou & Pettersson, 2011).	x				Ques-tionnaire	Con-structed response ("fill in the blank")	reliability