Knowledge Visualization for Learning in Higher Education Contexts: Systemizing the Field

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Abstract: In contexts of higher learning, students must be supported effectively in developing their knowledge, skills, and competencies. Thus, faculty members (incl. lecturers and administrators) are faced with the management task to organize and align innovative teaching and learning formats. As we know from research, the use of knowledge visualization is both a facilitating tool for cognitive processing and learning itself, and for strategic decision-making processes within organizations. However, the literature on the types of (IT-enabled) knowledge visualization for learning in higher education contexts is highly fragmented and dispersed and includes different branches for researchers and practitioners. This makes it difficult to achieve an overview and find systematic and consistent visual approaches along students' learning paths. By highlighting the role of knowledge visualization to support organizing innovative teaching and learning, we provide a systematic, structured overview of such approaches. The goal of this paper is thus to structure the field of knowledge visualization for lifelong and university-based learning based on seminal papers. For this purpose, we present a segmentation approach with six areas to analyse the role of knowledge visualization for learning in higher education contexts, namely: Visualizing Learning Offers (e.g., Curriculum Visualization Tools), Visual Learning Environments (e.g., Metaverse), Learning Content Visualization (e.g., Visual Variation Patterns), Visual Techniques for Learning (e.g., Concept Mapping), Visual Learning Analytics (e.g., Learner Dashboards), and Visualizing Learning Outcomes (e.g., Digital Course Badges). Based on systemizing key concepts, our paper concludes with promising future research avenues for each of the six areas, as well as for the domain of knowledge visualization for higher learning itself. We conclude with specific ideas how the area of visualizing learning offers can act as a spearhead for empirical research (and practice transfer) in the knowledge visualization domain. This should help practitioners and researchers from higher education contexts who consider lifelong learning as knowledge management task.

Keywords: Higher education, Knowledge visualization, Knowledge management, Lifelong learning, Segmentation approach

1. Introduction

In higher education contexts, students must be supported effectively in developing their knowledge, skills, and competencies and designing their lifelong learning and career paths. At the same time, organizations of higher learning must deal with current challenges in educational settings (e.g., digital transformation, diversity among students, or resilience issues). To further contribute to the social "corpus of knowledge" (Galgotia and Lakshmi, 2022) successfully, faculty members as lecturers and administrators are thus faced with the management task to organize and align innovative teaching and learning formats.

Knowledge visualization seems a relevant domain to build upon. It focuses on the use of (interactive) graphics to create, integrate, and apply knowledge that can be used for developing or conveying new insights, experiences, methods, or skills (Eppler, 2011). As we know from research, the use of knowledge visualization is both a facilitating tool for cognitive processing and learning itself (e.g., Wang and Tseng, 2020), and for strategic decision-making processes within organizations (e.g., Bajracharya et al, 2018). Considering this individual or organizational perspective, we thus refer to explicit knowledge to be communicated visually (Lam, 2000).

However, the literature on types of (IT-enabled) knowledge visualization for learning in higher education contexts seems highly fragmented and dispersed resulting in different branches for practitioners and researchers as well. At first sight, this range goes from curriculum visualization (e.g., Zucker, 2009) to the use of achievement badges in university environments (e.g., Hakulinen et al, 2015). This makes it difficult to achieve an overview and find systematic and consistent visual approaches that are appropriate to design students' learning paths.

In terms of a systematic, structured overview of such approaches, we thus look at main uses of knowledge visualization in higher education contexts. The goal is to structure the field of knowledge visualization for university-based, higher learning. Hence, we review seminal papers to identify related streams and opportunities for further research.

While doing this, we distinguish between three categories for segmenting the field: *Visualization AS Learning* (Learning Content Visualization, Visual Techniques for Learning), *Visualization FOR Learning* (Visual Learning

Analytics, Visual Learning Environments), and *Visualization OF Learning* (Visualizing Learning Offers, Visualizing Learning Outcomes).

This paper is structured as follows: In section 2, we refer to the rationale of our segmentation framework with its six areas of knowledge visualization. Then, we describe the methodology we have employed for our field review (section 3), whereas section 4 presents the results that we use to derive underlying key concepts. Finally, we conclude with promising future research avenues for these areas respectively the whole domain of knowledge visualization in higher education. We argue how the area of visualizing learning offers can act as a spearhead for further research and practical transfer in the knowledge visualization domain (section 5).

2. "Vis2Learn": A Segmentation Approach for Higher Education

To create significant learning experiences in higher education settings, learning goals, learning activities, and feedback respectively assessment must be integrated efficiently (Fink, 2013). Drawing on this three-part-division of integrated course design, we thus introduce a corresponding framework to structure the field of knowledge visualization for higher learning. We summarize this segmentation approach as "Vis2Learn" (see Figure 1).

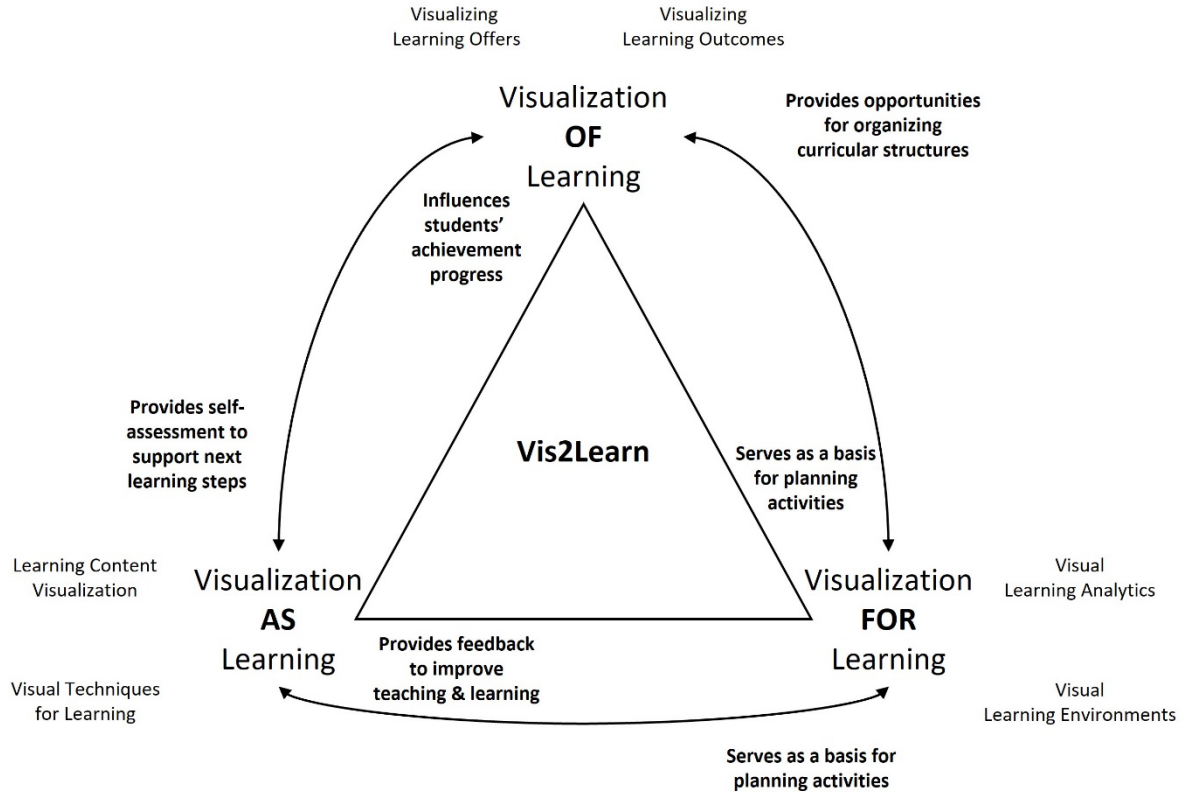

Figure 1: "Vis2Learn" in Higher Education

The categories are in line with other branches that reflect the structure of an integrated course design (e.g., Brady et al, 2019). Thus, the components of the "Vis2Learn"-Framework are the following:

- *Visualization AS Learning:* Focuses on the learning process itself. Visualization aims at causing positive learning effects in terms of student's knowledge acquisition and understanding.
- *Visualization FOR Learning:* Provides technical conditions and didactical resources to support teaching and learning activities. Accordingly, visualization is also used for (data-driven) feedback towards students.
- *Visualization OF Learning:* In terms of anticipated achievement, it shows what can be expected in a certain course of a given curriculum. Visualization can further be used to communicate learning achievement.

According to that, we presume six subfields to structure the contemporary field of knowledge visualization for higher learning. Table 1 shows the respective subsets of every knowledge visualization category with its corresponding visualization form; underpinned with a practical example. We consider these as relevant for the present task to organize and align innovative teaching and learning in university environments. Additionally, and

from a process perspective, this systematization corresponds with formative and summative evaluation aspects within the student life cycle.

Table 1: Fields of Knowledge Visualization (KV) for Learning in Higher Education

Fields of KV	Subset	Visualization Form	Example
AS Learning	Learning Content Visualization	Graphic Organizers, Infographics	Visual Variation Patterns
	Visual Techniques for Learning	Mapping Methods	Concept Mapping
FOR Learning	Visual Learning Analytics	Graphs, Diagrams	Learner Dashboard
	Visual Learning Environments	Immersive Learning in 2D/3D	Metaverse
OF Learning	Visualizing Learning Offers	Interactive Maps	Curriculum Visualization
	Visualizing Learning Outcomes	Badges, Emblems, Icons	Digital Course Badge

As depicted in Figure 1, the proposed dimensions "are not mutually exclusive" (Brady et al, 2019). For instance, the way of visualizing learning content can be influenced by certain insights from applying visual learning analytics "as the use of computational tools and methods for understanding educational phenomena through interactive visualization techniques" (Vieira et al, 2018).

3. Methodology

For systemizing the field of knowledge visualization in contexts of higher learning, we primarily used the Web of Science Core Collection and included seminal papers (based on their citation impact). Ideally, such papers have achieved at least a hundred citations (with exceptions for certain subfields). In case the search has not led to satisfactory results in the respective subfield, we also included further highly relevant papers (based on Google Scholar Rank by title search through the 8th version of *Harzing's Publish or Perish* software tool). To ensure a current view on visualization for learning contexts, we have limited our search to articles published after 2010.

To find relevant literature based on our segmentation approach, we have searched for articles by applying the following keywords listed in Table 2. We gathered our basis of analysis between 17th April and 1st May 2023.

Table 2: Search Strategy for the Review Process

Venues of Applied Keywords	Search Strategy (Web of Science)
Learning Content Visualization	("Graphic Organizer" OR "Graphic Organizers") AND Education; (Infographic OR Infographics) AND Education [Title OR Abstract OR Topic]
Visual Techniques for Learning	("Mind Map" OR "Mind Mapping" OR "Concept Map" OR "Concept Mapping" OR "Argument Map" OR "Argument Mapping") AND Students [Title OR Abstract OR Topic]
Visual Learning Analytics	("Visual Analytics" OR Visualization OR Visualisation) AND "Learning Analytics" AND Education [Title OR Abstract OR Topic]
Visual Learning Environments	("Augmented Reality" OR "Virtual Reality" OR "Mixed Reality") AND Education [Title OR Abstract OR Topic]
Visualizing Learning Offers	"Curriculum Visualization" OR "Curriculum Visualisation" [Title OR Abstract OR Topic]
Visualizing Learning Outcomes	(Badge OR Badges) AND Students [Title OR Abstract OR Topic]

Further selection criteria were the following:

- The paper was published between 2010 and 2022.
- The paper is written in English.

- Journal or proceeding papers contribute to education and educational research (e.g., Citation Topics Meso in Web of Science).
- The paper relates to university environments (e.g., university students).
- Visualizations described in the paper are considered as a (technical) solution or intervention. This means that this "review did not include papers that used visualizations only to present results of a study—e.g., a histogram used to communicate results of an experiment" (Vieira et al, 2018).

To analyse the main uses within the fields of knowledge visualization, we screened the articles along related main objects and visual approaches. We then contrasted the respective items to achieve a theoretical saturation with structural similarities. While doing this, we considered differences in type of knowledge, its purpose, domain of usage, and application context to identify the underlying key concepts.

4. A Review of Knowledge Visualization for Learning in Higher Education

The results of our review of the included literature are summarized in Table 3. It shows corresponding insights in terms main objects and visual approaches in the use of knowledge visualization for learning in higher education.

Table 3: Results of Systemizing the Field of Knowledge Visualization in Higher Education

Learning Content Visualization		
Authors	Main Objects	Approaches
Bicen and Beheshti (2022); Nussbaum et al (2019); Polman and Gebre (2015); Rum and Ismail (2017)	Argument-counterargument integration; Metacognitive support system for learning; Students' academic achievement levels; Visual culture of infographics	Argument Vee Diagram; Flipped Classroom Instructional Infographics (image-based, video-based, game-based); Graphic Organizers used for organizing information during learning (expression tree); Science infographics
Visual Techniques for Learning		
Authors	**Main Objects**	**Approaches**
Davies (2011); Liu et al (2010)	Associations between ideas, topics, or things; Relations between concepts; Inferences between claims/conclusions and support/premises	Combination of diagrams and outlines; Convergence of mapping (Specificity-Generality)
Visual Learning Analytics		
Authors	**Main Objects**	**Approaches**
Macfadyen and Dawson (2012); Williamson (2016)	E-learning data (use patterns and trends, relationship to student learning outcomes); Knowledge about education systems	Data visualization software (Tableau); Digital interactive data visualizations of massive online data ("The Learning Curve")
Visual Learning Environments		
Authors	**Main Objects**	**Approaches**
Cheryan et al (2011); Codd and Choudhury (2011); Dieker et al (2014); Khot et al (2013); Moro et al (2017); Stepan et al (2017)	Students' knowledge in anatomy; Design of virtual classrooms; Teacher education (personalized learning, suspension of disbelief, cyclical procedures as critical components)	AR, VR, and tablet-based applications with computerized interactive 3D model; Immersive Simulator (mixed-reality, avatar-based simulation environment); Virtual computer science classrooms in Second Life

Table 3: Results of Systemizing the Field of Knowledge Visualization in Higher Education *(Continued)*

Visualizing Learning Offers		
Authors	**Main Objects**	**Approaches**
Blasco Soplon et al (2014); MacNeil et al (2020); Nelson-Fromm and Fagen-Ulmschneider (2022); Siirtola et al (2013); Takamatsu et al (2019); Tee et al (2021); Quintana and Tan (2021)	Course Structure; Curriculum overlaps; Prerequisites and corequisites for courses and degree programs; Shared competences; Students' pathways through the curriculum	Bottom-up synthesis of curriculum data (courses, topics, themes, weighted connections); Course Composition Diagram; Dependencies between curriculum and student academic data; Dynamic curriculum mapping; Metro Map; Multi-dimensional and interactive curriculum map tool; Relationship between subjects and competences
Visualizing Learning Outcomes		
Authors	**Main Objects**	**Approaches**
Anderson et al (2014); Hakulinen et al (2013); Hanus and Fox (2015); Hew et al (2016); Kyewski and Krämer (2018)	Achieving badges with no elaborated description; Behavioral and cognitive engagement; Students' activity in online learning environments; Students' engagement inside and outside the classroom; Students' forum engagement in massive open online courses (MOOCs)	Badge Leaderboard (e.g., ranking with combination of badges and coins as gamified elements); Badges, points, and leader board as game mechanisms; Categorial Achievement Badges (e.g., Time Management, Carefulness, Learning); Cumulative "Milestone" and Great Achievement Badges (e.g., Bronze, Silver, Gold, Diamond); Hidden Badges; One-Time Badges (e.g., to welcome users); Varied visibility of awarded badges ("own-others" badges, "own"-badges)

Drawing on this selective review, we propose the following four key concepts that structurally define the use of knowledge visualization in higher education. The main insights are described in Table 4.

Table 4: Key Concepts for Knowledge Visualization in Higher Education

Key Concept	**Main Insight**
Knowledge Visualization considers different perspectives and interpretations.	Criteria as relevance, accuracy, adequacy, completeness, or sufficiency provide a common basis to involved stakeholders. In that sense, it serves as a boundary object (e.g., Leigh Star, 2010). Depending on the context-specific purpose, users' background knowledge and/or background experience must be considered.
Knowledge Visualization follows visual (and conventual) rules.	Depending on its communicative function, the use of knowledge visualization depends on the respective knowledge type which determines how its representation is organized (e.g., hierarchy, flow).
Knowledge Visualization allows technical flexibility in visual design.	Tools and forms of knowledge visualization and its semiotic functions must be adaptive to the application context. They then provide appropriate settings in terms of color, size, or shape and the possibility to integrate further representational elements (e.g., charts, diagrams, maps, graphs, icons, text, sketches).
Knowledge Visualization incorporates an engaging and explorative design.	Knowledge visualization considers relevant affordances of representation (e.g., bird's eye view, additional details, balance, movement, pattern, repetition, rhythm, variety). Thus, users get more involved and keep up their interest.

5. Conclusion

The aim of this paper was to structure the field of knowledge visualization for university-based, higher learning. For this, we derived a segmentation framework (Vis2Learn) that consists of six subfields to structure the contemporary field of knowledge visualization for higher learning: Learning Content Visualization, Visual Techniques for Learning, Visual Learning Analytics, Visual Learning Environments, Visualizing Learning Offers, and Visualizing Learning Outcomes. Based on our results, we identified four generic key concepts that systemize

the use of knowledge visualization in higher education contexts: *Multi-Stakeholder-Inclusiveness, Rule-Orientation, Technical Flexibility,* and *Engaging/Explorative Design*. Accordingly, this implies promising future research avenues based on related key questions for each of the six areas of knowledge visualization, as well as for the domain of knowledge visualization for higher learning itself (see Table 5).

Table 5: Research Agenda for Knowledge Visualization in Higher Education

Key Concept	Key Questions
Multi-Stakeholder-Inclusiveness	How can knowledge visualization be used to provide a common point of reference for different stakeholders in higher education contexts? What are the critical factors?
Rule-Orientation	How can users be made aware of the appropriate usage of tools and forms of knowledge visualization? How does it correspond to working or learning strategies?
Technical Flexibility	Under which conditions does the integration of additional representational elements create value? How does it affect usability issues?
Engaging/Explorative Design	Which individual or group-related effects are associated with the use of knowledge visualization? How do (motivational) affordances influence respective outcomes?

In this sense, future work on these avenues must keep track of the "cognitive, social, and emotional benefits" (Eppler and Burkhard, 2004) generally associated with knowledge visualization at different recipient levels (i.e., coordination, attention, recall, motivation, elaboration, new insights). For us, the underlying segmentation approach (Vis2Learn) also serves as an initial step to further explore and develop a "validated prescriptive framework" (Eppler and Burkhard, 2004) that links knowledge type (declarative, procedural, experimental, orientational, and individual knowledge), visualization goals (e.g., learning, assessing) and visualization format (e.g., interactive visualization) while considering the functional interplay of visualization as learning, visualization for learning and visualization of learning. This would also highlight, for instance, "how complementary visualization … can be fruitfully used" (Eppler and Burkhard, 2004).

We particularly see the area of visualizing learning offers as a spearhead for empirical research and practical transfer in the knowledge visualization domain. By now, this subfield rather focusses on exhaustively communicating curricular structures for organizational or planning activities of different higher education stakeholders. But visualization of learning offers can also relate to course electives in university environments. At this point, empirical research is planned to contribute to the choice overload debate by considering psychological effects in the use of interactive visualization to support students' course decisions. Besides, group-related effects are also worth to be analysed. For example, these can refer to the question if interacting with an interactive visualization tool can stimulate information exchange processes in higher education expert groups (Spletter and Eppler, 2023). Therefore, the derived findings and related key questions might help practitioners and researchers from higher education contexts who consider lifelong learning as an important task.

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