BattleGraphs: Forge, Fortify, and Fight in the Network Arena

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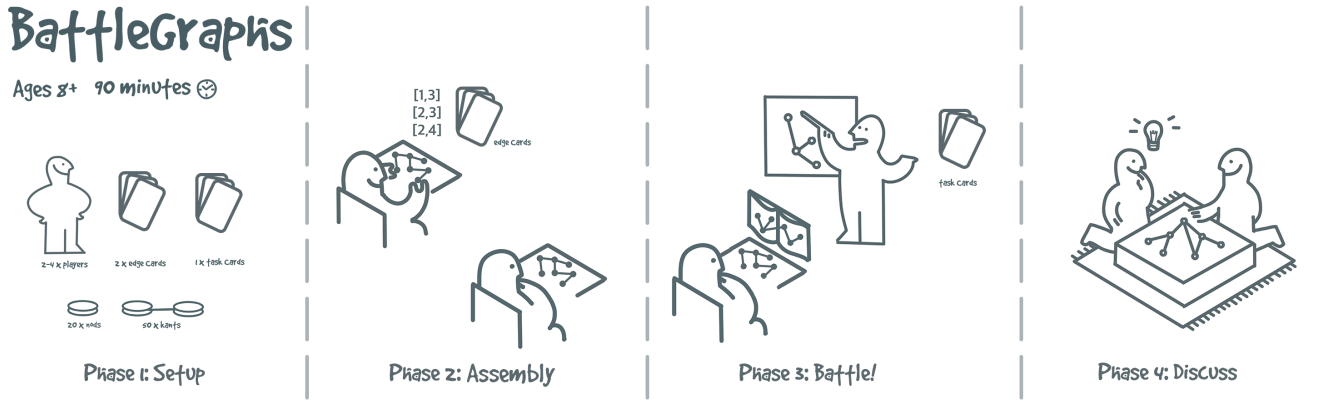


Figure 1: Two competitors playing *BattleGraphs*, a graph construction game. In order to play, players will require at least two **NODKANT** kits, two magnetic whiteboards, a deck of *Task Cards*, and two identical decks of *Edge Cards*. Each game consists of four distinct phases: the Setup Phase, the Assembly Phase, the Battle Phase, and the Discussion Phase. Players compete by creating their own personalized network physicalizations during the Assembly Phase, which they subsequently use to answer questions faster and more accurately than their opponent during the Battle Phase. The player who is able to answer the most questions correctly wins.

Abstract

Constructive visualization enables users to create personalized data representations and facilitates early insight generation and sensemaking. Based on ***NODKANT****, a toolkit for creating physical network diagrams using 3D printed parts, we define a competitive network physicalization game:* BattleGraphs*. In* BattleGraphs*, two players construct networks independently and compete in solving network analysis benchmark tasks. We propose a workshop scenario where we deploy our game, collect strategies for interaction and analysis from our players, and measure the effectiveness of the strategy with the success of the player to discuss in a reflection phase. Printable parts of the game, as well as instructions, are available through the Open Science Framework at* `https://osf.io/x6zv7/`.

CCS Concepts

• ***Human-centered computing*** → ***Visualization application domains; Empirical studies in visualization;***

1. Introduction

Games have long been recognized as effective tools for engagement, learning, and problem-solving. In visualization, games and activities have been explored as methods for enhancing the understanding of complex visualizations or concepts and promoting creativity. Construct-a-Vis [BZP*19] and Diagram Safari [GWL*19] are noteworthy examples, which encourage participants to interact with data and develop insights through structured activities and play. Physicalization—the representation of data through tangible objects—has been gaining attention [JDI*15] and promotes a method to deepen comprehension through active construction and manipulation [BWD21].

Physical interaction with data representations enhances understanding, engagement, and long-term retention [PBE*25]. Prior work suggests that actively constructing representations leads to more profound insights compared to passive observation [SSB15, HMC*20]. Studies [vHR08] indicate that people will naturally organize network structures in meaningful ways, i.e., enclosing clusters in hulls. Data Strings [Dom14] highlights the benefits of participatory physical visualization, allowing individuals to actively shape collective data through direct interaction. Further related work investigates interactive physical representations of networks, including **NODKANT** [PBE*25], suggesting that this added interactivity enhances perception, memorability, and analytical reasoning. WonderNet [MGD*24] similarly explores the physicality of network structures, transforming them into tangible objects that highlight their inherent connectivity and spatial relationships. This approach reinforces the importance of physicalization as a method for deepening comprehension and engagement. Willett and Huron [WH16] introduce the concept of input visualizations, highlighting how visual structures can serve not only as representations but as interactive mechanisms for data input. Their framework expands our understanding of how visualization can facilitate engagement and structured exploration, offering new perspectives on physicalization and interactivity. HoloGraphs [PEF25] demonstrates how dynamic networks can be represented physically and how they can raise visualization literacy by offering engaging interfaces and tangible interactions.

Inspired by such examples, we investigate whether competitive, hands-on network construction can enhance graph comprehension, memorability, and problem-solving in an interactive and playful setting. Here, we introduce *BattleGraphs*, a two-player competitive board game that integrates physical network construction with analytical problem-solving. Drawing from the findings of prior research on user-generated layouts [DLF*09] and interactive physicalization of networks [PBE*25], with *BattleGraphs* we explore how the familiarity of self-constructed representations of networks influences task performance, particularly in competitive time-constrained scenarios. The intended contribution of the game is to provide an experimental platform for studying network construction through physical and interactive means as well as to investigate the benefit of engagement through competition.

BattleGraphs is designed to engage players in various levels of cognitive processes as defined by Bloom's Taxonomy [Blo56]. The proposed game aligns with the following levels (progressing from easy to complex): (1) *Remember*—players must recall basic graph concepts such as nodes, edges, and connectivity; (2) *Understand*—Players need to understand the visual encoding to construct their graph and understand graph analysis problems; (3) *Apply*—Players apply their knowledge of graphs to construct a physical representation using the NodKant kit; (4) *Analyze*—Players must break down the structure of graphs to solve tasks efficiently; (5) *Evaluate*—Players evaluate the effectiveness of a graph layout, which promotes reflection on learning strategies and problem-solving approaches. They judge the speed and accuracy of answers against their opponents; and (6) *Create*—Players develop strategies for organizing and constructing their networks. We intend to further validate this alignment using the workshop setting as a platform to elicit feedback and reflect on our visualization game in practice.

2. Sources & Materials

BattleGraphs is based on the **NODKANT** toolkit by Pahr et al. [PBE*25]. **NODKANT** is designed to be a simple, dynamic, and effective toolkit [HCT*14], specifically aimed at the construction of physical network diagrams. For *BattleGraphs*, we additionally introduce two types of card decks, representing the graph's edge list and the graph tasks to be solved, as an aspect of gamification.

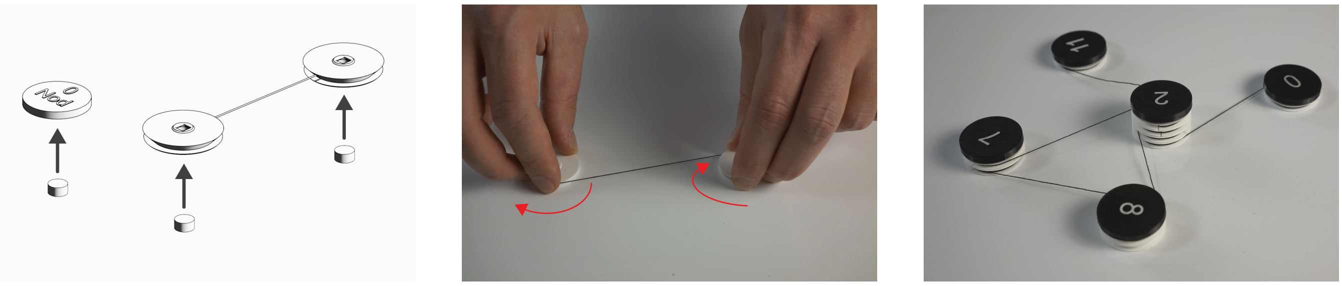
Toolkit **NODKANT** consists of two 3D printable parts (Figure 2), for which the mesh files are available on osf.io. Firstly, *edges* consist of two spools with a yarn in between them (Figure 2a). The spools can be rotated to alter the length of the yarn freely after placement (Figure 2b). Secondly, *nodes* are represented by cylindrical disks with labels printed on top (Figure 2a). Placing small magnets in the rotational center of the parts allows for quick assembly, while also ensuring the parts can be freely rotated individually (Figure 2c). Using a magnetic whiteboard as a base provides a 2D canvas to embed physical graphs.

Cards The *Edge Card* deck serves the construction of the graph, each card containing an edge of the graph. Pahr et al. [PBE*25] propose to use an edge list, sorted by associated node degree, to provide users with step-by-step instructions during construction. For *BattleGraphs*, we decide to gamify this aspect by providing each player with a random initial sorting (in the form of a shuffled deck of cards, each representing a particular edge of the graph) to create their own construction strategy. We propose an *Assembly Phase* of about 30 minutes, similar to Pahr et al. [PBE*25], choosing the same dataset of animal interactions, `mammalia-raccoon-proximity-50` [RA15] to produce comparable results. The *Task Card* deck contains textual descriptions of the tasks used by Pahr et al. [PBE*25] for their study. Each card presents a (low-level) graph task, derived from Lee et al.'s [LPP*06] graph task taxonomy, on one side, and solutions to the question on the other.

Replay Value and Difficulty Selection In order to ensure *BattleGraphs* can be enjoyed multiple times by players, the game can be played in one of three difficulty settings: easy, medium, and hard. Each difficulty setting corresponds to a graph of increasing complexity [YAD*18], i.e., easy difficulty corresponds to a graph of lower complexity (i.e., few interesting structures, low density, low number of nodes and edges), whereas high difficulty corresponds to a graph of high complexity (many interesting structures, motifs, and a larger number of nodes and edges). Depending on the difficulty selected, i.e., graph data selected, a different set of *Edge Card* decks is selected, shuffled, and given to players. Conceptually, players can easily create their own decks of cards, based on their own selection of graph data, in order to replay *BattleGraphs* at their preferred and custom difficulty setting.

3. BattleGraphs: Game

BattleGraphs is a two-player, competitive, educational board game centered around the construction of one's physical network layout (see Figure 1). Subsequently, players answer a set of graph analytical questions faster than their opponent and in doing so correctly, gain a point. Intuitively, the more readable one's constructed network layout, the faster and more accurately one should be able to solve graph analysis tasks [GFC04,GFC05]. Broadly speaking, this roughly 90-minute game consists of four distinct phases, namely a 15-minute (instruction and) *Setup Phase*, a 30-minute *Assembly Phase*, a 30-minute *Battle Phase*, and a final 15-minute *Discussion*



(a) (b) (c)

Figure 2: The **NODKANT** toolkit. (a) Each node is represented as a 3D-printed "puck" with a magnet fitted underneath. Edges are represented as two such magnetic "pucks" connected by an adjustable length of yarn. (b) Edge length, i.e. the length of yarn between an edge's endpoints, is adjusted by turning the endpoints' spools until the desired length is achieved, (c) To construct a network, edges and nodes are stacked vertically on the magnetic whiteboard surface. Reprinted, with permission by Pahr et al. [PBE*25].

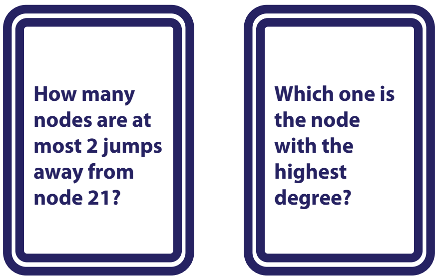


Figure 3: Example of task cards used during the *Battle Phase*.

Phase. To play, the following materials are required: i) a count-down timer to keep track of time, ii) two magnetic whiteboards, iii) two **NODKANT** kits, iv) a physical divider to visually separate each player's whiteboard, v) two identical, but shuffled decks of *Edge Cards*, each representing the edges of the graph to be assembled, and vi) another shuffled deck of *Task Cards*, in which each card is a graph task to be solved (Figure 3).

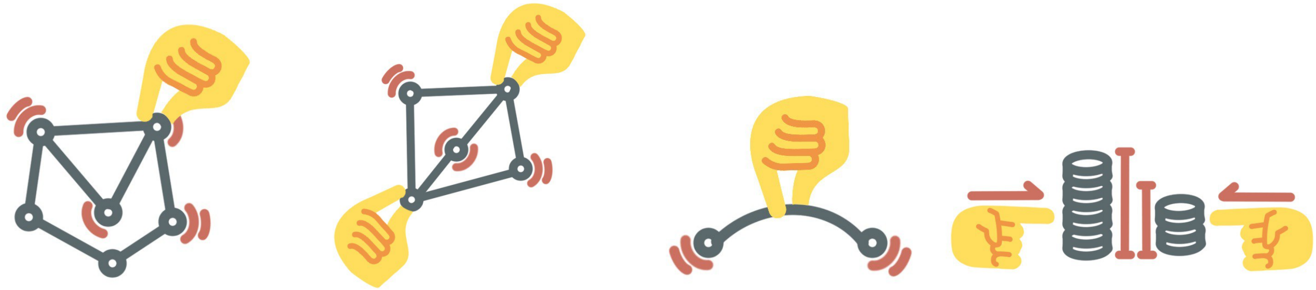
Setup Phase At the start of a game of *BattleGraphs*, each player receives their magnetic whiteboard, a well-shuffled, face-down deck of *Edge Cards*, and a **NODKANT** kit. Each player places the whiteboard and their deck of face-down *Edge Cards* in front of them. A physical divider is then placed between each player's whiteboard such that the view of the other's board is obstructed. Place the well-shuffled deck of *Task Cards* out of view for now. Finally, set the timer to 30 minutes and place it in an area visible to both players. Once the timer starts, the *Assembly Phase* begins.

Assembly Phase During the *Assembly Phase*, each player has 30 minutes to construct their physical layout of the graph represented by the deck of *Edge Cards*. Each card, in the currently face-down deck of *Edge Cards*, represents one edge of the graph to be assembled and contains the start and end nodes of the edge. In essence, the shuffled *Edge Cards* are a random arrangement of the graph's edge list. Each player may now flip the deck of *Edge Cards* face-up in order to view, re-arrange, and organize the entirety of the deck as they see fit. Using the provided **NODKANT** kit, each player, following their organization of their *Edge Cards*, now constructs their graph on the provided whiteboard. The **NODKANT** kit consists of physical representations of both nodes and edges (Figure 2). Nodes are represented by black, magnetic, labeled disks. Edges are represented by two white, magnetic, unlabeled, connected by a length of adjustable string. To represent a basic graph of two connected vertices, one edge is magnetically placed on the whiteboard, and each node is magnetically placed atop each end of said edge. Once the timer notifies both players that 30 minutes have elapsed, the *Assembly Phase* has concluded, and the *Battle Phase* begins.

Battle Phase During the *Battle Phase*, players compete for 30 minutes to answer a set of graph analysis questions as quickly as possible using their own constructed network layout. Each question (task) is represented by one of the *Task Cards*. These cards are two-sided, one of which features the graph analysis question, the other the answer (Figure 3). To start the *Battle Phase*, set the timer to 30 minutes. The well-shuffled deck of *Task Cards* is placed question-side-up in an area visible to both players. Once the timer is started, the *Battle Phase* has commenced. During each round of this phase, players read the question of the currently revealed *Task Card* in silence and subsequently attempt to answer this question as quickly as possible using their own constructed graph layout. The first player to call out an answer checks the correctness of their provided answer using the back-side of the current *Task Card*. If correct, they keep said card, thereby gaining a point. If incorrect, the opponent has a chance to answer to answer said question correctly to gain a point. If neither player is able to answer the question correctly, neither gets to keep the card. Players continue to answer questions in such a manner until either the 30 minutes elapse, or all *Task Cards* have been answered. The player with the most *Task Cards*, i.e. points, wins the game.

4. Reflection

Discussion Phase During the final 15-minute *Discussion Phase*, players remove the physical divider in order to reveal their network layouts to each other and discuss strategies for both graph layout and graph analysis. Questions worth asking include, but are not limited to: What was learned about the graph? What strategies did



(a) (b) (c) (d)

Figure 4: Different interactions with **NODKANT**: (a) Wiggling to reveal adjacency; (b) & (c) Pulling to reveal common connections; (d) Pushing nodes together to show their degree. Reprinted, with permission by Pahr et al. [PBE*25].

players utilize when organizing their *Edge Cards* and subsequently building their networks? What strategies did they employ to answer task analysis questions? Why did one player do better than the other?

The game's design aligns with Bloom's taxonomy's [Blo56] on the six cognitive levels–Remember, Understand, Apply, Analyze, Evaluate, and Create. However, we aim to explore and validate this aspect further to investigate how effectively the game supports each level in practice and whether it facilitates meaningful cognitive engagement across these domains. We aim to use the results of the discussion phase from the workshop to perform a brief qualitative analysis of construction strategies and interaction techniques with the **NODKANT** toolkit. Prior work emphasizes the role of interactive physicalization in supporting deeper comprehension of visualization concepts [BWD21, PBE*25]. By actively constructing representations, players are expected to develop a stronger understanding of network structures, reinforcing prior findings on hands-on engagement in visualization tasks [SSB15, HMC*20].

Evaluation Plan We aim to assess how players construct and interpret network structures, as well as the level of engagement facilitated by *BattleGraphs* using the VisEngage questionnaire [HP17]. Engagement is a complex construct encompassing multiple dimensions, including captivation, discovery, and challenge. The questionnaire provides a method for assessing interaction-driven immersion in visualization, aligning well with *BattleGraphs*' goal of increasing engagement in network visualization tasks. We will assess these aspects through post-game discussions and ethnographic observations throughout the workshop to determine how *BattleGraphs* encourages deep engagement and involvement. Participants' reflections will be transcribed and analyzed qualitatively. The qualitative coding will cover observations of player interactions, including strategic adaptations. This process will result in higher-level sentiments that form the basis for our analysis of how players approach network construction in *BattleGraphs*. Our focus will be on (i) Graph comprehension (i.e., players' understanding of network structures, like cliques, clusters, and bridge/hub nodes); (ii) Engagement factors (utilizing the VisEngage questionnaire [HP17]); and (iii) Impact of physicliazation and interaction (i.e., comparing to the workshop results to the interactions identified by Pahr et al. [PBE*25]–see Figure 4a-d).

Preliminary Expectations We anticipate that, by the end of a game of *BattleGraphs*, players will have a better understanding of graph (sub)structures, such as cliques (a complete subgraph within a larger graph), clusters (a set of highly interconnected nodes in a graph), bridges (nodes that connect to otherwise disconnected subgraphs), or hubs (highly connected nodes). Through interactive physical construction, we expect participants to actively manipulate these structures. We expect this process to lead to an improved comprehension of networks structures compared to passively observing them on virtual screens [SSB15, HMC*20].

The game mechanics encourage problem-solving under constrained conditions, requiring players to analyze graph connectivity while applying strategic decisions in real-time. Depending on the set of (correctly answered) questions asked, players might also develop an understanding of more abstract descriptive graph metrics, such as a graph's density, diameter, or average degree [EBK*24].

Furthermore, engagement indicators, such as captivation, discovery, and challenge measured via the VisEngage questionnaire [HP17] are expected to correlate with effective learning outcomes. Observing how players approach network construction provides valuable insights into the cognitive benefits of actively interacting with tangible objects and being part of the construction and creation process. *BattleGraphs* will also explore emerging strategies in graph construction, identifying key approaches in layout design, optimal edge placement, and adaptive problem-solving that are still ongoing problems within the broader field of network visualization [FAM23]. Preliminary findings will contribute to research on interactive visualization literacy and network physicalization, establishing a method for engagement-driven learning in network visualization.

Acknowledgments This work was funded by the Austrian Science Fund (FWF) projects ArtVis [10.55776/P35767] SANE [10.55776/I6635], [ESP 513-N], Vis4Schools [10.55776/I5622] (in cooperation with the Czech Science Foundation [No. 22-06357L]). The financial support by the Austrian Federal Ministry of Labour and Economy, the National Foundation for Research, Technology and Development and the Christian Doppler Research Association is gratefully acknowledged. The authors acknowledge TU Wien Bibliothek for financial support through its Open Access Funding Programme.

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