A Taxonomy-Driven Model for Designing Educational Games in Visualization

Amabili, Lorenzo
University of Groningen, The Netherlands

Gupta, Kuhu
Illumio, USA

Raidou, Renata Georgia
TU Wien, Austria

Abstract—**Visualization literacy of the broader audiences is becoming an important topic, as we are increasingly surrounded by misleading, erroneous, or confusing visualizations. *How can we educate the general masses about data visualization?* We propose a twofold model for designing educational games in visualization based on the concept of constructivism and learning-by-playing. We base our approach on the idea of deconstruction and construction, borrowed from the domain of mathematics. We describe the conceptual development and design of our model through two games. First, we present a deconstruction-based game that requires the inspection, identification, and categorization of visualization characteristics (data, users, tasks, visual variables, visualization vocabulary), starting from a finalized visualization. Second, we propose a construction-based game where it is possible to compose visualizations bottom-up from individual visual characteristics. The two games use the same deck of cards with a simple design based on visualization taxonomies, popular in visualization teaching.**

INTRODUCTION

■ Data visualization is an increasingly expanding field with a growing audience—spanning beyond researchers and data scientists. Visualizations nowadays surround us in print or on-screen; and some of these include misleading or misrepresenting visuals. Whether this is done to mislead purposefully, or whether it is a genuine mistake due to inadequate and uninformed visual design choices, erroneous data visualizations have an impact on their audiences. Visualization literacy is becoming an increasingly important topic of discussion within our community. But, *how can we educate the general masses about data visualization*? Learning through play is used in education and psychology to describe how a

child can learn about the world with the help of (and through) playing.We explore the option of providing an engaging way to educate the public about visual representations through gamification. Although not as profound and intensive as taking a visualization course, an educational game on visualization is much more accessible and digestible for laymen of all ages and all backgrounds. It provides an affordable, easy, and simple way of educating the general population about basic visual representations and visual designs, about how to interpret them, and how to employ visuals in an informed way.

The contribution of our work is the conceptualization of a taxonomy-driven model for designing games. It can be employed in various educational visualization settings, such as visualization courses or self-education activities. Our concept is based on the idea that through gamification we can motivate and support visualization (semi-)agnostic audiences. They can learn more about the basic principles of visual design, understand better their use and meaning, and harvest their effectiveness and expressiveness—in case they would design their visualizations. Our concept prioritizes the audience's edutainment, where game players learn through interactive group-playing, gain new knowledge on visual representations and their design, and are rewarded for their acquired knowledge by winning the game. In the upcoming sections, we present the conceptualization of our proposed game and we discuss how it can be assessed and employed in the future to support the gamification of visualization education.

RELATED WORK

Visualization Literacy

The growing audience for data visualization has expanded beyond researchers and data scientists, reaching also the general population. Building visualization literacy among novices, i.e., people without prior visualization knowledge, has become crucial. Visualization literacy has been defined as *"the ability and skill to read and interpret visually represented data in and to extract information from data visualizations"* [1]. Recently, researchers have attempted to theorize visualization literacy by introducing a *data visualization literacy (DVL)* framework [2]. The framework states a classification of core concepts and lays out principles to help design activities to teach DVL. Constructionism has also led the creation of new pedagogical tools to build visualization literacy [3], which are designed and centred on the learner.Contrarily, modern tools often fail to support visualization literacy learners, as they intensely focus on the tool's output rather than on the learners and their learning process. Based on these studies, our aim while developing our approach was to facilitate the design of educational games to assist the learner in investigating complex concepts with ease and in recognizing their unique paths to learn something new.

Educational Games in Visualization

The visualization community has made some early contributions to building educational games or game-based learning to fill the general population's gaps in interpreting data visualizations. Gäbler et al. designed a 2D educational game for kids aged 9 to 11 to teach charts and diagrams called *Diagram Safari* [4]. The players are asked to add different obstacles to charts through drag-and-drop interactions in a pleasing virtual environment. A more recent game by Huynh et al. has leveraged the concept of story elements in data problems to create educational games [5], in which the players engage with a narrative through interactions with a character. Differently, Bishop et al. created a tablet-based tool where children can create and manipulate tokens to learn data-to-visual mapping [6]. This tool is the result of an increasing trend of considering the learning paradigm of *constructionism*, as a foundation for creating educational games in the visualization literacy space, which also motivated our work.

Visualization Taxonomies

Taxonomies can be used as a basis for visualization education. A typical example is the *visual variables* taxonomy, as designed by Jacques Bertin [7]. Taxonomies are often employed to teach the graphic dimensions, e.g., color, shape, or size, which can be used in visualization to encode information. Yet, the field of visualization deals with more than just a visual representation and its visual design. Therefore, investigations of taxonomies and typologies for *visualization tasks*

have also emerged [8], targeting the formalization and analysis of the design space revolving around a task. Finally, the *data-users-tasks design triangle* [9] considers the characteristics of the data, users, and tasks to ease the visualization design. Although it focuses on the particular characteristics of time-oriented data within visual analytics applications, it is an interesting conceptual framework that can also be used for didactic purposes.

DOMAIN SITUATION

In this section, we describe the design context and the target audience considered during the development of our design model.

Design Context

The use of data visualization for communicating data has become part of the mainstream in our society. Consequently, basic visualization design and interpretation skills are now required in both our professional and everyday life in varying levels of detail. In this heterogeneous context, educational games are suitable and flexible teaching tools, as they create highly interactive educational environments ideal for encouraging active learning in large groups of people. Moreover, with features such as the physicalization of abstract concepts and using storytelling elements, educational games are versatile tools that are easy to learn and effective to use in different scenarios. Edutainment can by no means be considered a replacement for an actual educational course, but the tangible character of a gamification approach makes the learning approach pleasant.

Audience

With the advent of digital media, rapid behavioral changes have occurred in conveying and consuming information. This phenomenon took hold quickly without giving time to the general audiences to learn the basic visualization skills. Inadequate and uninformed visual design choices generate erroneous, confusing, and misleading data visualizations, which can have, e.g., a societal or economic impact on their audiences. Seeing that a *non-expert audience* is more likely to be impacted, we decided to focus on this group. Yet, the term "non-expert audience" is very extensive and it can include a broad variety of age groups, as well as educational backgrounds. While developing our game design model, we considered teachers, managers, and children (school aged and beyond) as the target audience of the educational games to design. An important aspect to consider is the purpose for which the intended audience is interested in learning visualization, i.e., whether visualization is applicable to their professional activities or whether they are purely interested in the field. Similarly to classroom teaching, a challenge of teaching non-experts is to create connections between new concepts and the learner's pre-existing knowledge. The two may differ enormously, while no previous assumptions can be made (i.e., the "teacher" does not necessarily know the prior knowledge or level of the "learner").

LEARNING GOALS

To specify the learning goals that should be achieved by the proposed educational game, we employ Bloom's taxonomy of educational objectives [10]. This taxonomy classifies the cognitive domain in six different levels of objectives, which we also adopt for our game design:

(L1) *Identify* the characteristics of visualizations, e.g., recognizing that a pie chart is composed of slices that indicate quantities.

(L2) *Distinguish* and *associate* visualization characteristics to visualization requirements, e.g., understanding that the slices of a pie chart are used to represent numerical proportions (i.e., proportional parts of a whole) encoded to their arc lengths.

(L3) *Define* visualizations, e.g., being able to describe a pie chart and its characteristics.

(L4) *Compare* different visualizations and their characteristics, e.g., comprehending that a pie chart is a parts-to-a-whole visualization, while a bar chart is a ranking visualization.

(L5) *Infer* visualization requirements from the analysis of visualizations, e.g., understanding that a pie chart is used when we want to illustrate our data as proportions of a whole.

(L6) *Evaluate* visualization design choices, e.g., assessing that a pie chart is appropriate to use for representing the given data.

We considered identifying the elements composing a visualization as the first step a visualization

learner must take **(L1)**. This is followed by understanding the difference between visualization requirements and visualization characteristics, and how these are associated **(L2)**. Expert or experienced learners can provide visualizations **(L3)** and compare different visualizations and their characteristics to make informed design choices **(L4)**. Finally, advanced learners are expected to infer the visualization requirements **(L5)** from analyzing and critically assessing visualization design choices **(L6)**. Achieving these learning goals means being capable of correctly designing and interpreting visualizations, and we build our educational visualization games upon them.

A TWOFOLD MODEL FOR EDUCATIONAL GAMES DESIGN

Although they are very different processes, there are conceptual analogies between the visualization design process and the mathematical process of solving an equation. By considering the visualization design process as a data-driven problem-solving task (involving different variables to take into account), we can follow a mathematical approach for its solution, similar to solving an equation. In mathematics, deconstructing an equation requires breaking it down into separate parts to simplify the equation. Oppositely, constructing an equation involves assembling different terms. The deconstruction and construction of a visualization represent the process of identification of the visualization components and the process of designing visualizations, respectively.

This led us to develop a twofold model for creating educational games, where *deconstructing* and *constructing* visualizations can facilitate the development of the learner's mental models for interpreting and designing visualizations. In Fig. 1, we illustrate our model. Reading the model from left to right describes the process of *construction*, while reading the model from right to left describes *deconstruction*.

The core of our model comprises visualization taxonomies for the data–users–tasks categorization [9], the visualization variables [11] and the visualization vocabulary[1]. This model can be used for schematizing the visualization design process.
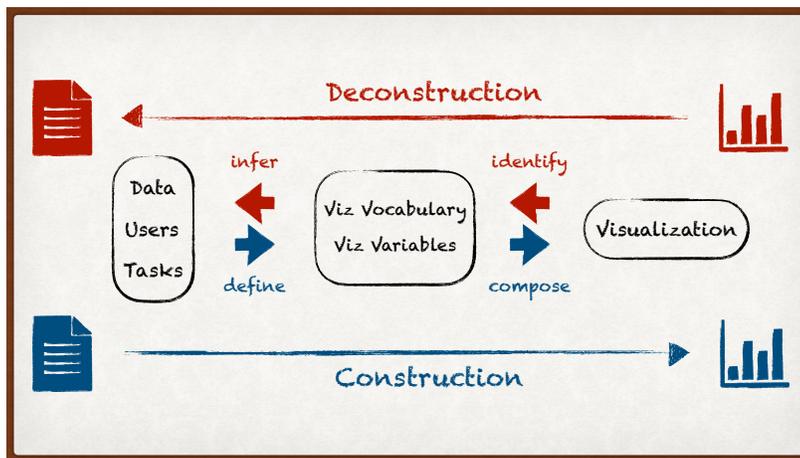
Deconstruction We use the term of *deconstruction* to imply the process involving activities related to the inspection, identification, and categorization of the visualization components and their relationships starting from a *finalized* visualization. Visualization deconstruction is a *top-down approach*, in which visualization learners decode visualizations by discerning their components. This approach entails that learners use a wide range of cognitive skills since tasks such as differentiation and extrapolating the visualization characteristics are involved. As a consequence, they are expected to improve their interpretation skills and visualization literacy. At a higher cognitive level, the visualization deconstruction involves inference, where the learner investigates the design principles and requirements associated with visualizations. With the deconstruction, all learning objectives can be pursued, but this process is more suitable for completing learning objectives **(L1)**, **(L2)**, and **(L5)**.

Construction We use the term of *construction*, as opposed to deconstruction, to denote the process of composing visualizations from single visual elements, defined by predetermined requirements. Constructing a visualization requires identifying, selecting, and associating various visualization characteristics to match a domain situation to obtain the building blocks of the visualization. Construction is a *bottom-up approach*, which demands visualization learners to navigate the multidimensional visualization design space to find a visual representation that satisfies the initial (domain) requirements. This approach involves various cognitive activities—from a comprehension level to an evaluation level—and learners are anticipated to improve their design skills and visualization literacy. With the construction, all learning objectives can be pursued, but this process is suitable for completing learning objectives **(L3)**, **(L4)**, and **(L6)**.

PUTTING THE MODEL INTO PRACTICE

Applying the previously discussed model, we developed a prototype of the cards[2] to be used in the educational game. An illustration of the

---

[1]https://ft-interactive.github.io/visual-vocabulary/

[2]https://github.com/kuhu12/Supplemental-Material

Figure 1. Graphical representation of our model for designing educational games in visualization, inspired by the concept of *deconstruction* (red) and *construction* (blue) in mathematics to generate a twofold game.
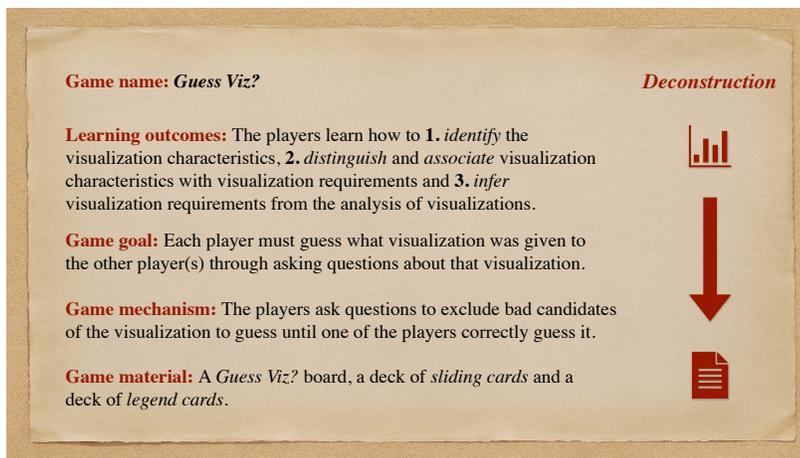
Figure 2. Description of the deconstruction-based visualization game *Guess Viz* to support learning objectives **(L1)**, **(L2)**, and **(L5)** .

design is shown in Fig. 4.

The card design was conceived to allow different reading levels based on the visualization literacy of the learners through the use of two layers: each card consists of two rectangular layers on which visualization and the related information are illustrated (Fig. 4, upper deck). We call these "*sliding cards*". On the top layer of each card, a visualization is represented. By sliding the top layer, the bottom layer is revealed. In this layer, *visual hints* and the *chart name* are presented. On the bottom layer of each card, we color encode the type of information to facilitate the players' interaction with this information (i.e., data-related, users-related, tasks-related, visual-variables-related, visualization-vocabulary-related), following the guidelines from ColorBrewer[3]. The dual-layer card design allows players to retrieve information on-demand according to their needs based on how much they slide the card up.

On top of this, we have a number of additional cards (Fig. 4, lower deck), where the type of visualization characteristics are depicted. We call these "*legend cards*" and they include data-related characteristics (e.g., numerical or categorical), users-related characteristics (e.g., experts vs. non-experts), tasks-related characteristics (e.g., exploration or presentation), visual-variables-related

[3]https://colorbrewer2.org/

characteristics (e.g., location or transparency), and visualization-vocabulary-related characteristics (e.g., show distribution or change over time). The color-codings are consistently used in both sets of cards.

Deconstruction: *Guess Viz?* To illustrate the deconstruction approach, we design an educational game, *Guess Viz?*, as an adaptation of the popular game *Guess Who?*[4]. Our proposed conceptual design for *Guess Viz?* is shown in Fig. 2. The *game mechanism* of *Guess Viz?* is that one player chooses one visual representation, while the other asks questions about its characteristics (e.g., visual variables) to guess the identity of the visualization. In this educational game, visualizations must be deconstructed in their components (i.e., the features of the visual representations) to identify the visualization through questions. The *goal of the game* is that each player must guess what visualization was chosen by the other player(s) through asking questions about that the components of the visualization. The game satisfies three of our previously discussed *learning outcomes*, namely *identifying* the visualization characteristics **(L1)**, *distinguishing and associating* visualization characteristics with visualization requirements **(L2)**, and *inferring* visualization requirements from the analysis of visualizations **(L5)**. As *game material*, we provide a *Guess Viz?* board, composed of several cards representing different visualizations and related information. The design of the *Guess Viz?* board allows to discard visualizations and to narrow down the search. *Guess Viz?* encourages and supports learners to observe the visualizations, to identify and compare their characteristics, and to find the sought visualization by elaborating the information gained through questions. The design of *Guess Viz?* enables learners to strengthen their interpretation skills by deconstruction, association, and elimination of the information at their disposal. Supported by the sliding cards and encouraged to investigate visualization characteristics, learners are provided with a constructionist and constructivist learning environment, in which they use physical visualization representations to develop abstract visualization thinking.

[4]https://en.wikipedia.org/wiki/GuessWho%3F

Construction: *From* A *to vi*Z To illustrate the construction approach, we design a second educational game, *From* A *to vi*Z, as a simulation of the data-driven visualization design process. Our proposed conceptual design for *From* A *to vi*Z is shown in Fig. 3. The *game mechanism* is to associate visualization characteristics with specific visualization requirements to compose a visualization which the other players evaluate. In this game, learners are challenged in finding an appropriate combination of visualization characteristics matching a variety of visualization requirements. In addition, learners are also asked to evaluate the other players' visualization characteristics to determine whether the visualization requirements are met. The *goal of the game* is to compose the highest number of visualizations meeting the visualization requirements to win.

The game satisfies three of our previously discussed *learning outcomes*, namely *defining* visualizations **(L3)**, *comparing* different visualizations and their characteristics **(L4)**, and *evaluating* visualization design choices **(L6)**. As *game material*, we use a set of cards depicting the design space. We decided to support the process of visualization construction through the categorization and representation of the variables involved in this process. By making use of the visualization taxonomies considered in our model, we designed different sets of cards (i.e., legend cards) to be used for constructing visualizations, expecting that physically representing the process variables facilitates to perform the design process in a structured way. In *From* A *to vi*Z, players use the legend cards to build bottom-up a visualization that fulfills all the dimensions of the visual design space. This design space has to be matched to the top layer of one of the available sliding cards, while the bottom layer can be used to verify the correctness of the player's answer.

While designing this game, we aimed to let learners emulate a simplified visualization design process to improve their visualization design skills through construction. Additionally, peer-reviewing the choices during the game help learners to achieve critical visualization skills interactively and engagingly. Similarly to *Guess Viz?*, *From* A *to vi*Z is a card-based educational game, and it creates a constructionist learning environ-

6
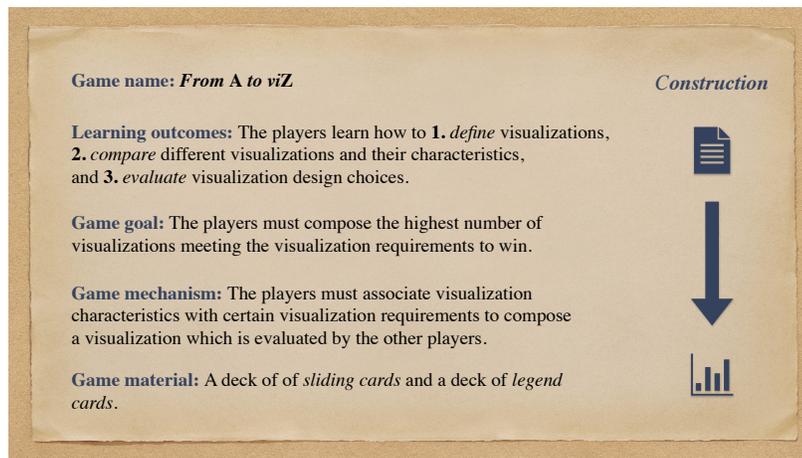
Figure 3. Description of the construction-based visualization game *From* A *to vi*Z to support learning objectives **(L3)**, **(L4)**, and **(L6)**.

ment in which learners interact with physical representations of abstract concepts to develop visualization design and evaluation skills. Inversely from *Guess Viz?*, the input of *From* A *to vi*Z is several data-users-tasks elements to drive the construction of visualization rather than finalized visualizations, following a bottom-up approach.

Game Course Example

We anticipate that both games are intuitive and easy to play. We hereby give an example of a game course, using the cards shown in Fig. 4.

In *Guess Viz?*, player A picks a visualization card with a pie chart (Fig. 4, upper deck), which player B must guess. Player B asks questions to player A, such as *Is your visualization representing nominal data?* or *Is your visualization a ranking chart?*, to exclude visualizations, which do not match with the information collected from the *Guess Viz?* board. During this process, player A can slide the card up to receive more information about the visualization card at hand, easing the progress of the game. The legend cards (Fig. 4, lower deck) are used as visual aids or legend. The more questions are asked, the number of good candidate visualizations becomes smaller, making easier to identify the target visualization. The game ends when player B correctly guesses that player A picked a pie chart.

In *From* A *to vi*Z, player A is asked to pick a number of legend cards (one from each color, i.e., design space dimension). For instance, player

A wants to build a visualization for querying a part-to-whole within ratio data that can be used by non-expert users and that employs area, as a main visual variable. Among the available sliding cards, the one that satisfies all the previous requirements is a *pie chart*. If player A identifies this as a solution to the requirements, can verify its correctness by looking its bottom layer. For the correctly identified visualization, player A gets, e.g., 5, points. The player with the highest amount of points wins.

PROPOSED EVALUATION

Our proposed educational game has not been yet evaluated in an actual game course with players. Therefore, we cannot infer its true educational value at the time being. An actual evaluation should be conducted in the form of a contextual inquiry, i.e., as a field observation combined with interviews. Although it would be particularly interesting to assess this in comparison to traditional educational processes, this might not be feasible for practical reasons. In our future evaluation, we will target a user-centered design method, where players will be first observed while being engaged in the game and then they will be interviewed to assess the educational value of the game and to solicit their opinion. The observation needs to happens in a real world setting, to understand how users interact with the game under real circumstances and to derive potential information that can be useful for improving the
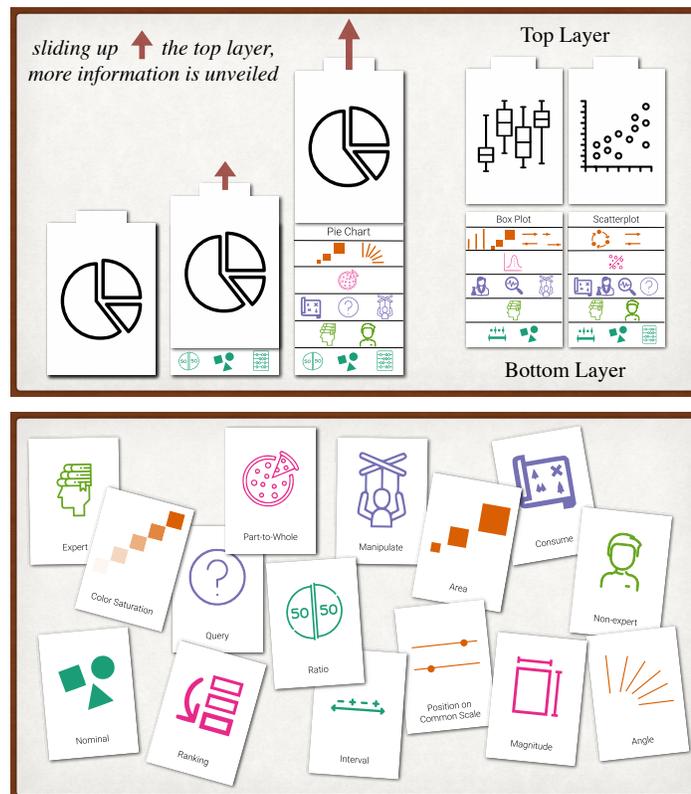
Figure 4. Prototype of the cards used for *Guess Viz?* and *From* A *to vi*Z. The *upper set of cards* shows the proposed *sliding cards:* In the top layer, a visualization is shown. In the bottom layer, the related label and the visualization characteristics are represented. The *lower set of cards* shows the proposed *legend cards:* We encoded the type of visualization characteristic with color (i.e., data-related, users-related, tasks-related, visual-variables-related, visualization-vocabulary-related). In *Guess Viz?*, players use primarily both layers of the sliding cards (the legend cards are used as a legend). In *From* A *to vi*Z, players use primarily the legend cards and match them to the top layer of the sliding cards (the bottom layer is used as a solution).

design. The subsequent questionnaires or interviews can further clarify these findings. Of additional interest would be to observe whether our model led to the creation of (other) games that are effectively promoting active learning and critical thinking around the different aspects involved in the visualization process. Educational professionals could also assist us in this task providing their expertise and knowledge in evaluating the players' behavior and the model itself. Additionally, comparative studies with similar educational games in visualization can be conducted to better understand in what our game differs from current visualization games and, especially, how it can be improved based on these games' features. Furthermore, although the game has been initially thought as a physical game for two (see *Guess Viz?*) and multiple players (see *From* A *to vi*Z), it can be played digitally and by teams of players and a more direct observation of the difference in terms of learning should be made in a future game evaluation. Similarly, the effectiveness of using the sliding cards as flashcards for self-learning activities and the complexity of playing the game without any prior visualization knowledge should be tested for providing players with more informed guidelines on the game setting.

The game should also be carefully evaluated from a practical perspective, i.e., with regard to feasibility. Players should not encounter scenarios in which the game course might be interrupted, for instance, when no visualizations meets the requirements indicated by the combination of legend cards chosen. For making the game course

more fluid in these cases, in future we aim to introduce mechanisms to allow players to perform special actions and to avoid bottlenecks of the game mechanism. Specific rules can also be adopted to facilitate the gameplay. For instance, players can decide to exchange cards with each other at the end of each round to obtain new cards.

DISCUSSION

For our game design, we took into account the concept of *constructivism*, according to which knowledge is not acquired passively, but follows rather an active, contextualized learning process. Interaction and experience are achieved in our game through an edutainment process, which follows the lines of *learning-by-doing/playing* and also goes along with the concept of *scaffolding* in teaching, where players/learners can build upon the previous steps of acquired knowledge. A guided independent learning curve is sought. By *peer-reviewing* the design choices involved over the game course, the players/learners are required to actively participate to every game phase and to develop critical thinking about the visualization design. This can also be fostered through discussions which are expected to take place among players/learners when the reviews are communicated and explained. In this way, novice players can also learn from more experienced players. Players/learners can accept or refute an argument made by another player/learner supported by the cards which can be used as references during the discussions to facilitate sustaining an argument and formulating questions.

In our game, the players/learners can determine the *level of knowledge* they want to achieve by unraveling different levels of information regarding the dynamic data visualizations. This makes creating different variants of our game possible by constraining the usage of the sliding cards based on the given audience. For example, in professional environments where the focus of the learning experience is on training practitioners in practically using the correct visualization in a specific case scenario, the only additional information regarding the data-users-tasks related to the visualization can be asked to be shown to let learners correctly associate the visualization characteristics to the visualization requirements.

In contrast, in educational environments where the focus is on teaching students to deeply understand the different visualization characteristics, the game can be extended by the teachers who can ask questions to connect information presented in different cards. In addition to that, the players/learners can follow two different approaches to edutainment by playing the game in two different ways based on the usage context. For instance, managers are generally more interested in being able to interpret visualizations rather than to design visualizations. This reversibility allows for optimizing material and mental resources, as the same deck of cards is used.

In our game design, we have integrated several *taxonomies*, through which the players can be educated about the data visualization design by taking into account the most essential aspects. This is often the way that students are taught about visualization principles in many curricula. Our educational game aims at providing its players, who are assumed to be people belonging to a general audience without prior visualization knowledge, an initial (and popularized) version of the principles, as extracted from these taxonomies. The theoretical framework created by interconnecting these taxonomies is not expected to be deeply understood by all players, who, however, can benefit from it as it guides them in deconstructing and constructing the visualizations in a structured manner. In addition, by visually representing and encoding each class of the taxonomies and by using pictographs, we aimed to make abstract concepts more accessible and memorable to a general or young audience [12]. The game cannot achieve profound learning—as opposed to an organized curriculum or a detailed visualization course—but it can provide a starting step for the education of laypeople through an entertaining game.

We anticipate that our card design supports a wide range of visualization activities for learners with different level of visualization literacy. In *Guess Viz?*, players can check the visual hints to ask/answer questions and explore the visualization design space defined by the taxonomies included in our model. In *From* A *to viZ* players can take advantage of the dual-layer design to learn about the relationships among the different cards through the visual items shown in

the bottom layer and critically reflect on different pieces of information. The cards can also serve as *flashcards*, which may be employed for acquiring or reinforcing knowledge about the primary representation, as illustrated on the top layer of each card. For *players of different levels or different ages*, the card design can be customized to include more and more complex visual representations increasingly. For instance, in the context of elementary schools, the visualizations can be represented with a low level of detail to avoid to overwhelm young learners. At the same time, advanced learners can decide to play the *Guess Viz?*, using only the top layer of the sliding cards, and challenging themselves in recalling the hidden information, and the *From* A *to vi*Z, using only the legend cards, and without restricting themselves with the sliding cards.

Our proof-of-concept game can be *extended* to cover specific applications. It can be used in data science courses to learn about the use and the encodings of visual representations, or it can be used by graphical designers that are designing infographics for broad audiences. The game can also be extended to cover additional learning goals, such as step-by-step design of visual representations, algorithmic or visual encoding improvement of the representations, and more advanced topics like combinations of visual representations for multiple linked views together with interaction principles. A more detailed version could also be employed in visualization courses, while more targeted visualizations could be included, depending on the context of learning and on the background of the learners.

CONCLUSION

In this work, we propose a twofold model for designing educational games in visualization based on the concept of constructivism and learning-by-playing. We describe our model's conceptual development and design, and we exemplify it with a reversible game. Our first direction for future work would be validation with broader audiences from different backgrounds and different age groups. An additional investigation of the game's potential benefits for different target groups within our audiences should also be conducted, trying to identify the strengths and limitations of our proposed game and card design.

■ REFERENCES

1. S. Lee, S.-H. Kim, and B. C. Kwon, "Vlat: Development of a visualization literacy assessment test," *IEEE Transactions on Visualization and Computer Graphics*, vol. 23, no. 1, pp. 551–560, 2016.

2. K. Börner, A. Bueckle, and M. Ginda, "Data visualization literacy: Definitions, conceptual frameworks, exercises, and assessments," *Proceedings of the National Academy of Sciences*, vol. 116, pp. 1857–1864, 2019.

3. C. D'Ignazio and R. Bhargava, "Creative data literacy: A constructionist approach to teaching information visualization," *Digital Humanities Quarterly*, 2018.

4. J. Gäbler, C. Winkler, N. Lengyel, W. Aigner, C. Stoiber, G. Wallner, and S. Kriglstein, "Diagram safari: A visualization literacy game for young children," in *Extended Abstracts of the Annual Symposium on Computer-Human Interaction in Play Companion Extended Abstracts*, CHI PLAY '19 Extended Abstracts, (New York, NY, USA), pp. 389–396, Association for Computing Machinery, 2019.

5. E. Huynh, A. Nyhout, P. A. Ganea, and F. Chevalier, "Designing narrative-focused role-playing games for visualization literacy in young children," *IEEE Transactions on Visualization and Computer Graphics*, vol. 27, pp. 924–934, 2021.

6. F. Bishop, J. Zagermann, U. Pfeil, G. Sanderson, H. Reiterer, and U. Hinrichs, "Construct-a-vis: Exploring the free-form visualization processes of children," *IEEE Transactions on Visualization and Computer Graphics*, vol. 26, pp. 451–460, 2020.

7. J. Bertin, "Semiology of graphics: diagrams, networks, maps," *University of Winsconsin Press, Madison, WI*, 1983.

8. M. Brehmer and T. Munzner, "A multi-level typology of abstract visualization tasks," *IEEE Transactions on Visualization and Computer Graphics*, vol. 19, no. 12, pp. 2376–2385, 2013.

9. S. Miksch and W. Aigner, "A matter of time: Applying a data – users – tasks design triangle to visual analytics of time-oriented data," *Computers Graphics, Special Section on Visual Analytics*, vol. 38, pp. 286–290, 2013.

10. B. Bloom, "Taxonomy of educational objectives," *The Cognitive Domain*, 1956.

11. T. Munzner, *Visualization Analysis and Design*. AK Peters Visualization Series, CRC Press, 2015.

12. B. Alper, N. H. Riche, F. Chevalier, J. Boy, and M. Sezgin, *C'est la vis: Visualization Literacy at Elementary School*, pp. 5485—5497. New York, NY, USA: Association for Computing Machinery, 2017.