Let's Play: Design Games and Other Strategies for Introducing Visualization through Active Learning

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ABSTRACT

Active learning provides an engaging alternative to the typical one-sided lecture in which students passively listen to the instructor. In this paper, I discuss a collection of active learning strategies for designing a course in Information Visualization. The primary strategy, design games, consists of a goal-oriented session during class in which students are given a task and directed to solve the task independently or in teams. Design games challenge students to come up with novel solutions for applying the material of the course to real-world situations. Secondary strategies provide additional support for active learning in the classroom through a combination of group projects and in-class presentations. I present lessons learned from applying these strategies to an undergraduate upper-level course in Information Visualization, and discuss perceived benefits and practical challenges for this approach.

1 INTRODUCTION

The traditional approach to pedagogy is conceived as a well-versed instructor standing before a packed classroom and serving as a guide to the finer points of a discipline. This approach is being challenged, however, by new course designs that move learning outside the classroom, encourage student participation, and alter the role of the instructor. Information visualization is a domain well-suited for such an unconventional approach to course design because practitioners must develop an appreciation for subjective aesthetic appeal while adhering to disciplined objective principles. Determining what is a "good design" can require iteration and intense debate. While traditional lecture-based courses can certainly impart many of the important principles that are required to create effective visualization, they must often rely on large stables of examples to illustrate how these principles are put into practice and do not allow students to try their hand at designing and critiquing something creative of their own.

Approaches based on active learning place a heavy emphasis on encouraging student participation during in-class sessions. A truly diverse set of strategies have been put forward that meet this requirement, and can range from simple pauses in the lecture to complex activities with many steps [5]. Evidence is mounting that strategies based on active learning are resonating with students and leading to gains in both engagement and performance in college courses [14, 13]. The *situative* and *cognitive* nature of active learning is itself a departure from the *behaviorist* conception of cognition and learning underpinning the traditional classroom [3], and the more fully it is adopted the more opportunities a student will have to apply concepts and develop expertise within the domain.

In this paper, we propose design games as a primary strategy for encouraging active learning within an Introduction to Information Visualization course at the undergraduate level. Design games are typically employed as a method for facilitating participatory design during the early stages of HCI research, and are used to explore the requirements of stakeholders from multiple perspectives [2, 1]. Students are encouraged to explore a design scenario by adopting alternative roles and switching perspectives often. These design games utilize existing strategies from active learning, such as the think-pair-share activity [5], but are intended to encourage the student to confront their own preconceived notions about the requirements of a challenge before jumping ahead to a design that may be unsuitable for other users [4]. Students are encouraged to compete not for the approval of the instructor, but for recognition from their peers.

In this paper, I describe the application of this approach to an upper-level introductory course in Information Visualization. 19 students were enrolled in the course and a teaching assistant helped in the grading of many assignments and the exams. Outcomes of the course are discussed, noting aspects of the course that were successful and challenges that remain. Guidelines and suggestions are discussed to help other instructors to adopt aspects of the course in whole or in part.

2 DESIGN GAMES

Design games take on many forms throughout the course, but consistently challenge students to apply what they have learned in previous sessions and from the assigned reading. Design games can be competitive, and require that students challenge each other to improve their approach throughout the design exercise. Through think-pair-share activities, students design their own solution to a problem independently then come together to critique and build upon their individual work. In a jigsaw design game, students design separate and distinct components that must be merged together to complete a more fully realized solution. While each design game is uniquely tailored to the lesson goals of the in-class meeting, they are intended to provide sufficient space so that students can still creatively explore new directions of inquiry that the instructor may not have foreseen. In this section, example design games are given that were utilized in an undergraduate Introduction to Information Visualization course in the summer of 2015. These examples are by no means exhaustive, but are meant to illustrate the diversity of approaches for design games in introducing information visualization to undergraduates.

Competitive Strategies and Isomorphism In this initial design game, students are introduced to the game of 15 [12]. Students pair up and are challenged to take turns choosing a number between 1 and 9. The first participant to choose a set of numbers that add to 15 is the winner, but the same number must cannot be chosen twice or used by both participants. Initial rounds are challenging, as students will struggle to think ahead for themselves and anticipate the competition at the same time. As play progresses and students begin to get more comfortable with the game, they should begin to observe patterns in chosen numbers and force rounds into a tie. After a few rounds, the classroom is then paused, and the instructor describes the game of tic-tac-toe, in which players take turns claiming positions on a square board with nine possible positions until one of them has claimed three spaces in a row. Several rounds of play follow, until the classroom is paused again. Finally, students are introduced to the Magic Square, in which the same tic-tac-toe board is used to position the set of numbers between 1 and 9 so that

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each row, column, and diagonal adds to 15. Students are given the opportunity to complete a magic square, but should not be required to complete it before moving on.

A classroom discussion follows to evaluate how the completed magic square board could be used as a support for the Game of 15 to reduce the cognitive burden of remembering previous moves, planning future moves, and anticipating the moves of their opponent. Attention should be drawn to the similarity in playing the Game of 15 on a magic square and the play of tic-tac-toe, as it provides an opportunity for the discussion of externalized support mechanisms, problem isomorphism, and distributed cognition [8]. For an extended discussion and follow-up design game, students can be directed to choose other challenging mental tasks and, in small groups, discuss methods for creating external support mechanisms that enable distributed cognition for these tasks.

2.1 Think-Pair-Share

Think-pair-share design games require students to work individually to complete a challenge before being paired up and discussing their approach. This allows students to use the information that they have obtained from studying the material on their own, much like in a homework assignment, but then come together to refine the individual design or take additional steps. Students must be able to apply the design concepts of information visualization to their own efforts but must also be able to think quickly and constructively to improve a design that they did not construct. When paired, students may also be asked to take on roles that require them to design additional components in collaboration with their partner.

Designer and Stakeholder In this think-pair-share activity, students work independently to design a dataset that describes something that they are passionate about but do in their spare time, like a hobby. Students are advised to pick something that they know well enough to answer detailed questions about. Once students choose the items and attributes that describe the domain, they pair up with a partner and take turns playing the role of the stakeholder. Each stakeholder is familiar with the dataset they have described, and without looking, must make requests of their partner for the design of a visualization that can be used to explore the dataset. The partner playing the designer is free to ask questions about the domain, but should try to avoid using terms specific to the information visualization community. Once each student has had a turn playing both stakeholder and the designer, they are encouraged to show each other their designs and discuss the potential strengths and weaknesses of what was created. If time is available, this design game can be repeated by allowing students to keep the dataset they have designed for the domain but switching to new partners who have not designed a visualization for them yet.

2.2 Jigsaw and Group Design

Jigsaw design games challenge students to contribute different, but equally challenging, components to an overall design as part of a team. For example, if the design game is to complete a geospatial visualization, students can be assigned to pairs in which one student draws the map and coordinate system for the visualization and the other assigns relative coordinates within that visualization to the list of items in the data set. For more complex challenges, students can be assigned to subteams that work together to complete a smaller task before these teams are merged together to complete the larger design challenge. Jigsaw activities work to support the students in understanding how individual team members with different skill sets can contribute to a larger effort, which is essential to successfully completing the group project for the course. The following is a detailed example of a jigsaw activity conducted during a class.

Design a Multi-Domain Dataset In this jigsaw activity, students are initially tasked with designing a dataset in a domain that is likely to be familiar to them, such as music. The domain should be the same for all students, but the exact structure of the set is left purposefully open-ended, and students may design node-link sets that connect artists, tabular sets that describe individual tracks, and more. The purpose of this initial activity is to get them thinking about the types of elements that would be needed for an exploration of a given domain. As this is intended as a follow-up to an assigned reading assignment on data types and associated tasks, students are encouraged to think about the individual items and descriptive attributes that make up the data set and what types of activities they might afford. Some class discussion about different types of music data sets may follow so that students hear about solutions that differ from their own. Then, students are given a secondary individual assignment to design a dataset in a different domain that would be familiar to them, such as a dataset around crime and public safety, student activities, or sports.

Students are then paired up and encouraged to merge the datasets that they have created across the domains, resulting in two new datasets that combine items and attributes. For example, say Student A designs a node-link music database of artist connections and a tabular dataset of reported crimes. Student B designs a spatial dataset of popular music genres by area code and a list of NFL Superbowl pairings with the scores. One potential set of multi-domain datasets resulting from the collaboration of Students A & B could be a social network of artists who have performed at Superbowl halftime events, or a map of the united states that correlates musical genre with reported crimes by state. A group discussion should follow this activity to determine what types of merges the students have designed, and what types of questions they might be able to facilitate.

2.3 Peer Review: Give Credit

Throughout the course, students are given opportunities to give credit to other students for hard work, novel ideas, and constructive participation. This can depend on the nature of the design game. For example, if students were formed into teams, they may be asked to individually nominate the member of the team (other than themselves) that contributed the most to the discussion during the design game. If students worked alone or in pairs to design a potential solution to a design challenge, then these solutions would often be shown to the class at the end of the lecture to promote discussion. Students then turn in a sheet listing their three favorite designs in order from first to third. These numbered lists are then used to determine an overall ranking of the top three submitted designs in the class using a ranked voting scheme. Students that receive credit from their peers in class are then given extra credit on their participation grade for the course.

By allowing students to give credit to each other it encourages them to think critically about what they like or dislike about visualization designs that they are more familiar with. Students will be familiar with the prompt and the data source used to create the submitted designs, and will be familiar with the types of challenges encountered during the design game because they have faced them, too. In practice, students do not always choose the design that the instructor would have chosen as the best, which provides an opportunity for discussion of why the chosen design was favored. For example, if the designs are aesthetically pleasing but not functional, then an intervention is possible in which the instructor discusses the relative merits of each.

3 Support Strategies

While the core strategy of design games encourages active learning within the classroom, several support strategies are recommended in order to help encourage constructive participation by students. While it is not required to utilize every aspect of the following strategies for the design game strategy to be effective, they place an unmistakable emphasis on preparedness, engaged discussion,

and creative problem solving that could be challenging to reproduce within a standard lecture format.

3.1 Entry & Exit Tickets

Entry & Exit Tickets encourage students to create a record of attendance and participation for each class that they attend. As a physical artifact, the ticket consists of a single 3x5 index card handed to students or available for pickup at the beginning of class. Students record their name at the top of the ticket. The first action at the start of class is to successfully answer one of the questions on the previous night's reading, which servers as the student's *entry ticket* into the lecture for that day. During that day's design game, students are encouraged to take notes on the challenge using the blank side of the index card, which serves as a record of participation. If an opportunity to *give credit* to other students has been made available during that day's class, then the student's vote is also recorded on the index card. Finally, each class ends with an *exit ticket*, a prompt for reflection on the day's discussion or in anticipation of the coming topic. The ticket itself serves as a record of attendance, as a probe of the student's preparation for each class, and as a litmus to determine the questions that students have about the material.

Entry Ticket Entry ticket questions are designed to encourage students to think about the assigned reading for the day, reinforcing the principle of an inverted classroom. An example question would be, "Describe the initial data set and attributes that the researchers used in BallotMaps. How did they **derive** new data for analysis?" This question refers to one of the assigned readings, a paper on voter data analysis [16], and asks the students to discuss the reading in the terms used within the chapter assigned from the textbook on Task Abstraction [11]. Students can be given an option to answer one of several questions, and the choice for response as well as the accuracy of response can be an excellent indicator for understanding of the material. These questions are also useful for determining exam questions if one is to be administered.

Design Notes Students are encouraged to take notes on the blank side of the index card during the design game as they work through the problem, even if the design game itself calls for the design to be completed on a separate piece of paper. The notes are meant to serve as a record of the approaches that were attempted during the design game, a method to keep score if students are competing, or to make notes of interesting insights revealed during the presentations of other students. They also serve as an indication to the instructor that a student participated in the lecture, and can be used to help create a more nuanced participation grade for the day.

Exit Ticket Exit ticket questions are designed to encourage reflection on the activity attempted during the design game, the material that has been discussed in the course, or on the structure of the course itself. For example, students could be asked to name a concept in the previous lectures they are struggling with, so that upcoming classes could take a new approach to explaining concepts that many students are struggling with. Similarly, students could be asked to consider what domain they would be most interested in pursuing for the group project, or whether they are receiving enough explicit feedback on homework assignments.

3.2 Flipped Classroom

Traditional lecture presentation is kept to a minimum or in equal measure to design games. Students are expected to come to class having completed the assigned reading, which is typically a chapter from the textbook required for the course and one additional influential visualization paper related to the chapter. For example, for the chapter in Munzner's book on Color [11], the assigned external paper explores methods for numerically representing colors and their psychophysical basis [15]. Lectures are provided to spur discussion between students rather than to explain all of the concepts that are described in the texts. This *flipped classroom* places the instructor in the role of a mentor who guides discussion during the class rather than delivering a lecture. Consequently, several additional topics outside of the reading are used to explore the topics in a new light, such as the affect of language on color perception in Homer's Odyssey [9] or the social media phenomenon of the dress color illusion [10]. As a policy, it is recommended that students are not allowed to use electronic devices during class (e.g., laptops, tablets, phones) unless a design game requires it. This prevents students from distracting themselves or each other from fully participating in the discussion [7].

3.3 Learning by Teaching: Ignite Talks

This strategy encourages students to become familiar with individual topics and share that information with the other students during class. Students give short, fast-paced presentations designed to quickly convey the most important aspects of a published paper to the other students without devoting too much of the in-class time to a one-sided presentation. The format for this style of presentation is the Ignite Talk style popularized in tech meetups, in which presenters give a five-minute presentation of 20 slides with the presentation software auto-advancing to the next slide every 15 seconds [6]. Students are provided with a list of published papers that are relevant to the scheduled class topics but not on the assigned readings. Each student chooses a paper, then gives their Ignite talk on the day with the lesson that is most relevant to the chosen paper. Students who are not giving a talk are encouraged to ask the speaker questions afterward and to make additional comments or constructive criticisms on the entry & exit tickets.

3.4 Group Project

Each student participates in a group project in small teams of 3–4 students over the course of the semester. Early design games are focused on getting students thinking about dataset types and domains that are interesting to them so that they can begin thinking about the type of project that they want to work on as early as possible. Each student then *pitches* an idea for a project in a two-minute lightning session near the beginning of the semester so that students with similar interests can find each other and choose a topic. Design games later in the semester separate the teams and pair them up with students from other teams so that they can critique the progress that has been made so far and the plans for the rest of each project. The projects were graded through a sequence of milestones in which groups presented increasingly refined plans and prototypes for the finished product that culminated in a final presentation in front of the class. Students were also given a form through which they rated themselves and teammates on level of participation in the project and specific contributions to the result.

4 Discussion

The design strategies discussed in this paper were implemented for a 12-week course in the summer of 2015. 19 students were enrolled in the course throughout the summer. In-class meetings consisted of an initial 30 minutes of lecture followed by a 45 minute period for design games. Each period, 30 minutes were set aside for Ignite talks, completion of the entry & exit tickets, and general class discussion. Through the entry & exit tickets collected throughout the semester I was able to obtain a detailed record of individual student participation. Of the 19 possible class dates that a student could attend, students on average missed only two lectures *(M=2.26, SD=2.05)*.

Participation grades for the course included a component for in-class participation, which included attendance and entry & exit ticket performance, as well as a component for participation in the group project as reported by their peers. There was a significant correlation between participation grades and final grades *(r=0.80,*

$p<.01$), indicating that the students who tended to get full marks for participating in the class discussions also received higher grades. Without direct comparison to an equivalent control course consisting primarily of lecture-based classes, I cannot state conclusively that participation and high grades can be solely attributed to the design games used to facilitate active learning.

Student comments were collected as part of a course and instructor evaluation. I have chosen some of the most representative positive and negative comments for discussion. For example, many students enjoyed the diverse strategies applied within the course, and the mix of traditional homework assignments with design games and peer review.

> 1. Excellent split between learning basics, exploring topical current research, software implementation, design problems, and team-based project work. The course awakens you to all the things that are possible with CS.
>
> 2. The assignments were interesting and neat. The peer reviewing the assignments were also very helpful to learning. It was a heavy crash course into the world of infoviz and I really enjoyed it. There were aspects of programming, designing, and implementing and I got to learn a lot working through the assignments.

Some students, however, pointed out that this does create perhaps too many moving parts for a single course. While each individual deliverable was relatively small, combined they create a significant burden in trying to keep track of them all. This burden could be lessened if certain elements were removed or diminished, for example, by reducing the number of group project milestones or the number of individual homework assignments. This should be done carefully, however, so as not to upset the support that the design games receive from the additional strategies. The effect of this burden may also be lessened during a lengthier full semester in the fall or spring.

> 3. I think the course could have fewer homeworks and readings. I understand the need to test students' grasp of content, but in this class we had 7 homeworks, a very large 5-part-project, multiple presentations, in class participation, a chapter of reading almost every class, a research paper to read for almost every class, a midterm, and a final. This much in 12 weeks made this course overly time consuming.

One of the most surprising criticisms of the course pointed out an area where it exhibited the exact behavior it was designed to avoid, that is, lecturing verbatim from the textbook. Several early classes used the lecture time preceding the design game to review the textbook material. Several of the helpful diagrams from earlier chapters of the text were projected to serve as a reference during discussion. While this was kept to a minimum within the course, students felt it was still too much!

> 4. Taking diagrams straight from the textbook for use on presentation slides is unhelpful at best. Having required reading before class and then going over the same exact information during lecture is useless and discourages people from attending lecture.

One of the most challenging aspects for conducting a course of this nature is the manner in which the burden shifts for the instructor from delivering material during a lecture to facilitating discussion. For students who come prepared to lecture, surprising questions and unusual ideas can be challenging for even an instructor who is well-versed in the material. Personality, enthusiasm, and speaking style may also play a significant role in the success of this course, as an instructor who is unwilling to deviate from a rigid lesson plan or is more comfortable with a lengthy slide deck may have difficulty keeping the rapid pace of discussion going. At other times, the instructor also has to be comfortable stepping back almost entirely to allow the students to work on the design games, intervening only to offer constructive criticism or to force the students to articulate the rationale for a decision.

It should also be stated that there is a significant burden in creating the design games in the first place. There are few resources for obtaining existing design games within the domain of information visualization, apart from the course described in this paper. While future instructors are welcome to adapt the design games established for this course or adopt them as they are, variations in emphasis for certain aspects of information visualization will often require that an instructor add or remove lessons as necessary. This will, in turn, require the design of fresh, engaging design games that keep the experience relevant to the goals of the lesson while still providing the students with room to find novel designs.

As discussed for Student Comment 3, there are also quite a lot of moving parts for this course, which adds to the burden of conducting it for the instructor. The design game approach worked well for a course of 19 students with a teaching assistant on hand to assist in grading homework assignments, milestone deliverables, and exams. For larger courses, the number of components could potentially become overwhelming without significant support from teaching assistants or co-instructors. The entry & exit ticket alone are created at each in-class meeting for each student, and require time to translate into the nuanced participation score that far exceeds that of a simple sign-in sheet. By removing the tickets, however, an instructor reduces the impetus for students to come prepared to each lecture beforehand. This risks lowering the quality of the group discussions and the value of the design game approach overall.

5 Conclusion and Future Work

In this paper, an approach was presented to teaching an introductory course in Information Visualization using design games to encourage active learning. Student participation was thoroughly measured, and was strongly correlated in the course to final grades. Several opportunities remain for future work in this area, notably, a controlled comparison with a secondary section of the course that does not utilize an active learning approach or incorporate design games. Conclusions about the benefits of the proposed approach would also be improved if the course were to be repeated across subsequent semesters with new students and alternative instructors to separate the effects of the learning environment.

Design games represent a promising and novel approach for information visualization to encourage student engagement and improve performance. The author plans to make the full set of design games utilized for this course available to other instructors seeking to adopt these strategies on their own.

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