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Using Analytics to Transform a Problem-Based Case Library: An Educational Design Research Approach

Matthew Schmidt (University of Cincinnati) and Andrew Tawfik (University of Memphis)

Abstract

This article describes the iterative design, development, and evaluation of a case-based learning environment focusing on an ill-structured sales management problem. We discuss our processes and situate them within the broader framework of educational design research. The learning environment evolved over the course of three design phases. A semisummative evaluation of student concept maps after the third phase revealed unsatisfactory learning outcomes. This paper focuses on how we investigated design flaws that contributed to poor learning performance. A specific focus of our investigation was the use of Google Analytics data, which uncovered weaknesses in our design. Based on our findings, we used a rapid prototyping process to redesign the learning environment, emphasizing interactive and multimedia-rich elements. Processes and methods are reported along with discussion of implications for case-based reasoning, including relevant design principles. This article will provide insights into resolving design tensions for researchers and practitioners seeking to advance theory and practice in similar domains.

Keywords: problem-based learning, case-based reasoning, analytics, design-based research, educational design research

Introduction and Background

Research suggests that individuals attain higher learning gains from problem-based learning (PBL) than from more didactic, lecture-based approaches to instruction (Lazonder & Harmsen, 2016; Leary & Walker, 2009). In PBL, ill-structured problems are often characterized as having multiple constraints, perspectives, and solutions (Jonassen, 1997; Jonassen & Hung, 2011). Such problems require students to engage in hypothesis generation as they derive solutions using multiple sources of evidence. The contextualized nature of PBL supports higher order learning (Herrington, Reeves, & Oliver, 2014; Lazonder, 2014); however, some researchers argue that learners cannot be expected to solve the complex problems espoused by PBL without support (Kirschner, Clark, & Sweller, 2006; Kirschner & van Merriënboer, 2013; van Merriënboer, 2013). Thus, a great deal of research has focused on how scaffolds can be embedded into instructional contexts to support students and help manage the learning process. One form of such scaffolding is case libraries. Case libraries are databases of cases that detail problems and how others went about solving those problems (Jonassen, 2011). According to case-based reasoning theory (Schank, 1999; Kolodner, 1991), learners can leverage these cases to solve different, but related, problems (Tawfik & Kolodner, 2016; Kolodner et al., 2004).

Research is ongoing regarding the use of case libraries. However, a gap exists in that specific details and optimal designs for cases have not received sufficient attention in the literature. In this article, we describe a longitudinal educational design research project that focuses specifically on the design of cases in a case library. Our research team included the first and second authors of this article, an educational design researcher, and a case-based learning researcher, respectively. Over the course of three design phases, the research team explored aspects of case design related to how various forms of case representation, instructional scaffolding, and assessment impact learning.

We highlight here phase 3 of our design research, during which we encountered evaluation results that were at odds with underlying design conjectures. The purpose of this article

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is to describe how the research team went about elucidating problems that contributed to the unsatisfactory results from phase 3 and how this led to a substantial redesign of our case library. We begin by describing the learning, theoretical, and methodological contexts of the design research project. This is followed by brief synopses of our two prior phases of design research. We then provide an in-depth description of phase 3, summarizing the design, enactment, evaluation, and reflection processes we undertook in this phase. We also discuss how our findings led us to a reconceptualization of our case library representation and how cases within the case library could be accessed. In particular, we discuss how learning analytics provided additional insight into how learners interacted with the case library, which guided our later redesigns of the case library. Our hope is that this article will provide insights into responding to design tensions for researchers and practitioners seeking to advance theory and practice in similar domains.

Learning Context

The Learning Problem

Our case library was designed for implementation in an upper-level, postsecondary Sales Management course at a large Midwestern university, populated primarily with upper-level juniors and seniors. Prior to implementation of the case library, the instructor (who also served as subject matter expert [SME]) reported concern that students lacked the critical thinking skills needed for entering the workforce. Moreover, the SME described how students were faced with the complexity of sales management problems only after they had completed an internship and not during their coursework. The SME lamented that students often focused on finding the "right" answer while meeting the minimum requirements of a given assignment.

The SME previously had included case study discussions and multimedia presentations to promote critical thinking, but was unsatisfied because students failed to consider how key concepts applied to other contexts. The SME explained that students often struggled to account for alternative perspectives or to consider other possible solution paths for a given problem. He believed this was due to students' lack of real-world experience. Because of this, he reasoned, students tended to seek the most expedient path to an acceptable resolution of the problem, which led to students failing to consider other scenarios that might preclude the successful implementation of their constructed solution.

The Solution

To approach these issues, the second author worked with the SME to design an overarching decision-making problem (the primary problem to solve, called "Nick's Dilemma") and a set of related cases (the supporting case library) for the Sales Management course. The case library consisted of multiple sales management hiring cases that served to contextualize relevant sales management concepts presented in the primary problem to solve. The goal of using the case library was to address the SME concerns related to students' lack of experience and their failure to consider alternative solution paths. Specific learning objectives included students (1) increasing their understanding of the different areas of the hiring process, (2) enhancing their awareness of the complexities of the hiring process, and (3) justifying hiring recommendations within a dilemma-type problem.

Nick's Dilemma (the primary problem to solve) confronts students with the complexities involved in making a difficult sales management hiring decision with no clear correct solution. Students are first asked to read Nick's Dilemma and then to read through a series of five associated cases in the case library, each focusing on a different aspect of the hiring process. After this, they make a hiring decision. For instance, students read cases about how management employees should weigh technical and sales acumen when evaluating candidates or how a loyal employee was overlooked for a promotion and the impact of this on morale and workforce retention. The lessons learned, in turn, could be used to generate solutions for Nick's Dilemma. The entire unit can be completed in three weeks.

Theoretical Context

Nick's Dilemma and the associated case library were designed to support PBL using the theoretical construct of case-based reasoning (CBR). Originally, CBR was intended as a way to provide problem-solving experiences to students. This instructional strategy confronts students with problems that are relevant within a given domain. Although CBR research started within the field of medicine, it has since been adopted and implemented in other domains, including preservice teacher education (Ertmer, Schlosser, Clase, & Adedokun, 2014; Hmelo-Silver, Derry, Bitterman, & Hatrak, 2009), and STEM education (Henry, Tawfik, Jonassen, Winholtz, & Khanna, 2012; Jonassen & Cho, 2011). CBR theory (Kolodner, Dorn, Owensby, & Guzdial, 2012; Schank, 1999) aligns with the overall goals PBL because of its emphasis on experience and problem solving. CBR theory argues that when learners are confronted with new problems, they will engage in the following cognitive processes:

1. *Retrieve* the previous case from a repository of cases within memory (one's internal case library),
2. If appropriate, *reuse* the case based on an assessment of the problem and the deemed relevancy of the retrieved case,

3. If the situation is beyond what the case can offer, *revise* the internal case library, and
4. *Retain* the case within the larger database of memories.

CBR thus promotes PBL in important ways. First, it provides a theoretical lens to understand how learners retain the problem they are presented within a PBL module. It also helps to describe how consistent exposure to PBL over time engenders a robust internal case library that can be used for future problem solving.

Theorists argue that CBR could lead to the development of learning systems designed to account for the gaps in experience that novices encounter (Jonassen & Hernandez-Serrano, 2002; Kolodner, Owensby, & Guzdial, 2004). That is, a set of cases could be strategically placed within a PBL module as a just-in-time scaffold. Through related case narratives, novices would be able to learn vicariously from the experiences of others and thus leverage cases similarly to how one might leverage information from a more knowledgeable peer.

Methodological Context

A variety of qualitative studies have attempted to understand how case libraries are used within educational contexts, showing generally positive results. However, questions remain as to how the design of a case library engenders retention of cases and impacts learning outcomes. To explore these issues in our own research, we designed Nick's Dilemma and the associated case library using an educational design research (EDR) approach. Also referred to as design-based research, EDR is an iterative, usage-inspired approach to solving complex educational design problems in a manner that is relevant to process and context, which ultimately focuses on establishing and sustaining the educational impact of an intervention. Proponents of EDR laud the approach for its ability to connect research and practice (Barab & Squire, 2004; Reeves, Herrington, & Oliver, 2005). According to McKenney and Reeves (2012), specific EDR methodologies vary, but share a common element in that they typically progress in an iterative, phase-wise manner. As such, design research is typically reported in phases. Within a given phase, an educational problem is first identified and analyzed, followed by iterative implementation and evaluation of a designed instructional intervention. Iterations are nested and reflexive, and as researchers iterate their designs over time, the impact of those designs grows in terms of both implementation and spread. Outcomes of EDR include practical solutions (in the form of constantly maturing interventions) and improved theoretical understanding (usually in the form of design principles that can be shared with others).

Description of Practice

The process of EDR has been characterized as "notoriously messy" (Kopcha, Schmidt, & McKenney, 2015, p. iii), resulting in unwieldy amounts of data that are often difficult to report. Clarity in EDR research articles is often achieved by reporting specific findings from one or two phases of a larger study, and contextualizing these findings with the larger study (for example, Kopcha et al., 2017; Curwood, Tomitsch, Thompson, & Henry, 2015). We adopt this approach for the current article, focusing specifically on phase 3 of our design research. Research performed during phases 1 and 2 has been reported elsewhere (Tawfik & Jonassen, 2013; Tawfik, 2017); therefore, we provide only brief synopses of those phases here. These synopses present foremost the design of the case library and design differences between phases, along with a brief presentation of findings. Summaries of phases 1–3 are provided in Table 1 (see next page).

Prior Design Phases

Synopsis of Phase 1

The goal of phase 1 was to provide related cases to students so as to overcome potential gaps in experience as they engaged with the primary problem to solve. As mentioned previously, qualitative research has shown how students describe the potential benefits of case libraries. For instance, students often cite how cases help them explicate the complexity of decisions (Bennett, 2010), understand the problem space (Ertmer & Koehler, 2014), and be confronted with various perspectives (Kim & Hannafin, 2011; Kolodner et al., 2003). However, how those narratives should be designed and structured remains unclear. Thus, phase 1 was concerned with understanding how the type of experiences depicted in the cases might influence learning.

A central focus of phase 1 was whether students would better apply lessons learned from cases based on narratives of success or failure. A key assumption was that novices would best be able to understand how experts solved problems using narratives of success, and that success cases would serve as better models for students to emulate than failure cases. To test this, a success- and failure-based case library was developed. This case library was largely text based and relied on hypertext to connect the cases (see Figure 1, next page). Hyperlinks to cases were inserted at strategic decision points in the case description of the primary problem to solve based on when knowledge gaps for the student were anticipated. The success cases were designed to model how others solved similar problems and weighed evidence related to the primary problem to solve. Failure-based cases were

Table 1. Overview of EDR phases.

Phase	Primary Intervention	Artifact	Measure of Learning	Design Features
Phase 1	Success vs. failure cases	Two-page argument	Overall holistic scores of two-page student-constructed argument, including: initial claim, counter-claim, rebuttal	Hypertext-based system built in Blogger; links to cases embedded strategically as just-in-time resources
Phase 2	Failure cases only and comparing different question prompts as scaffolds	Two-page argument	Overall holistic scores of two-page student-constructed argument including: initial claim, counter-claim, rebuttal	Wiki-based system built in Wikispaces; links to cases embedded strategically as just-in-time resources; reflection prompts appended to the end of each case
Phase 3	Success vs. failure cases; question prompts as scaffolding	Holistic concept map	Concept map holistic score; number of nodes and connections	Wiki-based system built in Wikispaces; revised reflection prompts appended to the end of each case; incorporation of Google Analytics

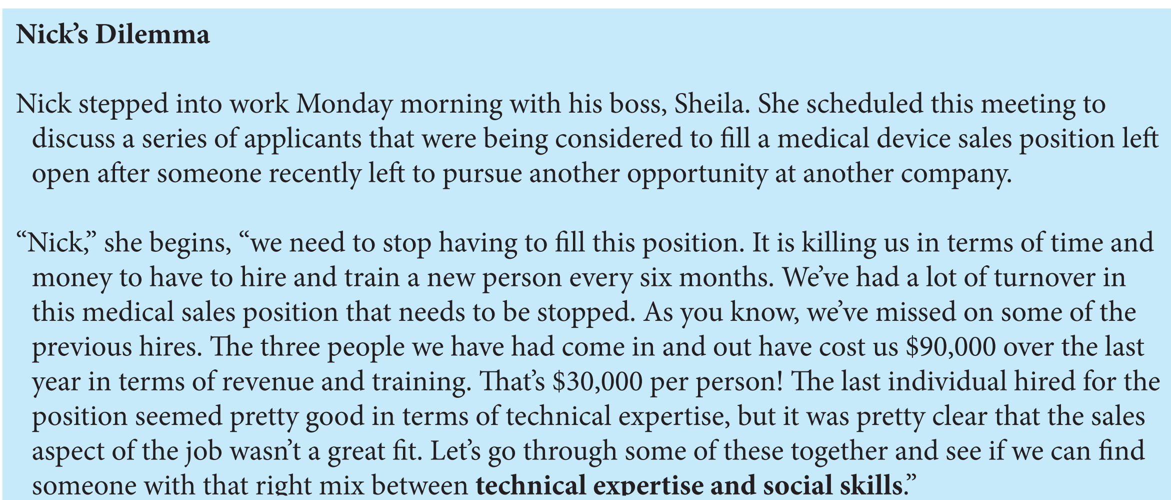

Figure 1. Screenshot of the case library interface from phase 1.

similar in terms of characters and context, but represented erroneous decision making on the part of the characters.

Using the Jonassen and Cho (2011) rubric, it was determined that students with access to failure scenarios were better able to articulate alternative perspectives (counterargument scores) and construct overall better arguments (holistic scores); this suggested that students learned better with failure cases. This was at odds with initial assumptions that novices would need successful models to bridge their experience gap. However, the degree to which students were able to fully understand and apply the specific principles of a given case remained unclear. This became the focus of phase 2.

Synopsis of Phase 2

The goal of phase 2 was to further understand how failure cases support learning and to what degree students were able to fully extract the complexities of those cases. CBR posits that cases are only as beneficial as the individual's ability to define the elements of the case so they can be retrieved and reused when solving new problems (Kolodner, 1991). Given that the case library designed in phase 1 was derived from the experience of an expert, it was unclear if novices could fully understand the nuances of the included cases. This, in turn, could impact their ability to transfer the principles of the case library to the primary problem to solve.

In phase 2, the same failure cases from phase1 were used, but were appended with two different sets of question-based scaffolds as a way to engender additional student inquiry. The first set of question-based scaffolds encouraged the students to consider how the cases in the library were similar based on sales management concepts, for example, "How is Janice's story similar to Holly's story in terms of hiring practices?" These questions were explicitly designed to target specific aspects of sales management (e.g., recruitment, training) and to help students understand how these aspects might manifest in multiple contexts. The second set of scaffold questions were adapted from Ge & Land's (2003) scaffolding framework, which was originally designed based on how practitioners solve problems. The second set differed from the first set in that the questions encouraged students to think more broadly about the problem-solving strategies depicted in the case, rather than the specific sales management concepts. Questions encouraged students to focus on fully understanding a single case, for example, "What are the pros and cons of Holly's solution?" and "What are some alternative perspectives she should consider?"

Findings from phase 2 suggested that that when students were provided question-based scaffolds based on the Ge and Land (2003) framework, they were better able to construct alternative perspectives (Tawfik, 2017). Using argumentation as the unit of assessment, the study found that participants with access to the question scaffolds derived from Ge and Land (2003) had statistically significant higher counterargument scores when compared with those that had access only to scaffolds that compared and contrasted narratives in the case library. This provided additional evidence that the design of the case played a role in students' ability to solve Nick's Dilemma. These findings provided additional insights into case library design, but raised additional questions about the degree to which the regularity of students accessing cases impacted their learning. In addition, there were questions about additional forms of assessment. The previous studies depicted above employed argumentation, but it was unclear if differences in the design of the case library would be maintained across other approaches to assessing problem solving.

Phase 3

In the following sections, we present the processes of design and inquiry within phase 3. Design researchers represent specific processes within design research phases differently. For example, McKenney and Reeves (2012) represent within-phase processes as micro-cycles of analysis and exploration, design and construction, and evaluation and reflection. In contrast, Cobb and colleagues (2003) represent within-phase processes as design, enactment, evaluation, reflection, and revision. While there is substantial overlap in both approaches, Cobb and colleagues' (2013) model represents revision as a final within-phase process, whereas McKenney and Reeves' (2012) model considers revision as part of an initial micro-cycle in a new phase. We adopt Cobb and colleagues' (2003) approach as a model for reporting phase 3, primarily because our revision efforts were conducted as concluding process of the current phase and not as a process starting a new design phase.

Design and Enactment

Phase 3 sought to investigate the use of alternate assessments. While written argumentation had been used in the two prior design phases, we selected concept maps for phase 3. Although argumentation is a viable way to assess student problem solving, using alternative forms of assessment provided a means to contribute further support to case-based reasoning theory and case library design. According to Jonassen (2011), concept maps are beneficial because they are "spatial representations of concepts and their interrelationships (propositions) that are intended to represent the knowledge structures that human store in memory" (p. 313). This aligns with the critical importance of indices (labels) in CBR theory. For instance, a case such as "Janice's Story," a case about a woman who is passed over for an internal promotion in favor of a man, might be indexed using a label like "retention," but could also be assigned indices such as "morale," "salary compensation," and "equity." Such indices could serve as descriptive and meaningful nodes on a concept map. Further, given that a case library database is meant to replicate networked memories, the nodes and connections of concept maps potentially could serve as a proxy representation of the desired interconnectedness of indices and memories described by CBR. Prior research has also demonstrated the connection between using concept maps to assess differences in case library design (Fitzgerald et al., 2009, 2011).

In addition to concept maps, we were interested in exploring further how learners interact with related cases. While the argumentation essays used in prior design phases had allowed us to measure learning gains, usage behavior patterns and how learners accessed cases while engaging with the primary to solve remained unknown. Given that case libraries have been theorized as a just-in-time scaffold, it was important to collect data about when and how cases were referenced during problem solving. By exploring user behavior, we hoped to gain additional insight into the how a case library is accessed and used by students over time.

Since findings from phase 2 suggested increased learning outcomes for students who accessed cases that incorporated the Ge and Land (2003) scaffolds, we supplemented cases in phase 3 with the same questions we used in phase 2. We anticipated that applying the multilevel scaffolding strategy in our learning environment would better facilitate indexing of cases so students could better retrieve them upon transfer. Beyond the introduction of question prompts and the use of concept maps instead of written arguments, the design of the learning environment for the current version remained largely unchanged over what was used in prior phases. That is, the primary case problem to solve, Nick's Dilemma, served as a starting point for students, with other narratives in this collection of cases hyperlinked from the primary case.

A noteworthy addition in phase 3 was the inclusion of Google Analytics to investigate how users interacted with the learning environment. Google Analytics is a platform that allows for tracking users' behaviors as they interact with a website. It is able to capture information such as which pages visitors view, how long they remain on a page, and their path through the website. We were interested in using Google Analytics because we wanted to be able to draw connections between our design and our research findings. For example, if students who were exposed to question prompts created better concept maps, we wanted to be able to see if they exhibited different usage patterns than students who were not exposed to question prompts.

Evaluation

We conducted a semisummative evaluation on the case library during phase 3 with a group of upper-level undergraduate students (n = 39) at a large Midwestern university. The term "semisummative evaluation" is largely synonymous with summative evaluation; however, because EDR phases are reciprocal and tend to result in recommendations for improvement in future phases, the term "semisummative" is used (Plomp, 2013). The final deliverable for the unit was a concept map that illustrated students' understanding of the overarching sales management problem. Because we were trying to extend beyond just post-hoc analysis of learner artifacts (e.g., argumentation essays), our evaluation focused on learning more about how students actually used and experienced the case library and the extent to which this might shape students' understanding of underlying concepts. To this end, we evaluated both students' concept maps and reviewed Google Analytics data. Based on our findings we also performed a post-hoc readability analysis of all cases in the case library.

Concept Map Quality Scores

As the final assignment in the Nick's Dilemma unit, students created a concept map that represented their conception of the overarching sales management problem. The first and second author assessed students' final concept maps using Fitzgerald and colleagues' (2009) Concept Map Quality Scoring Rubric and Protocol. We coded the concept maps and met regularly to normalize our coding processes. We also established inter-rater reliability using Cohen's Kappa (κ = 0.7), which indicated substantial agreement (Cohen, 1968).

In general, findings revealed low concept map quality scores, with 49% of concept maps representing a minimal level of concept development, 33% representing a fair level, 12% representing a great deal, and just 7% representing all parts of the concept. The majority of students' concept maps were sparse, with little detail or extrapolation of ideas presented in the cases. Most concept maps only included one or two main concepts and failed to include important information from the case library. In Figure 2 (see next page), a typical concept map with underdeveloped concepts is juxtaposed with a less common but more developed concept map. In the figure, the less developed concept map has fewer nodes and lines than the more developed concept map. The less developed map also has no interconnections between nodes, whereas the more advanced concept map has many more nodes and lines, including interconnecting lines between nodes.

Google Analytics Usage Trends

In addition to evaluation of students' concept maps, we used Google Analytics to inform our EDR evaluation efforts in phase 3. Again, our focus was on how students actually used and experienced the case library. To begin, we investigated the behavior flow section of Google Analytics. Behavior flow can lend insight into patterns of how users are interacting with a site, such as at which page they start, the path they take when exploring the site, and whether any pages are skipped. In our analysis, nodes represented single pages that were visited, lines represented the path from one node to another, and red lines with only one connecting point represented users exiting the site. An example behavior flow diagram is provided in Figure 3 (see "Reflection" section).

Our analysis of behavior flow indicated that students typically started by navigating back and forth a few times between the homepage and the primary problem to solve (Nick's Dilemma), after which they exited the site. Navigating back and forth is expected web interaction behavior at the beginning of an activity, as students work to gain an understanding of expectations. However, after this initial back-and-forth between the primary problem to solve and the homepage, the majority of users exited the website, which was unexpected behavior. Expected behavior was that students would continue on to read the supporting cases in the case library. This led us to investigate the Google Analytics data more closely to better understand this usage pattern.

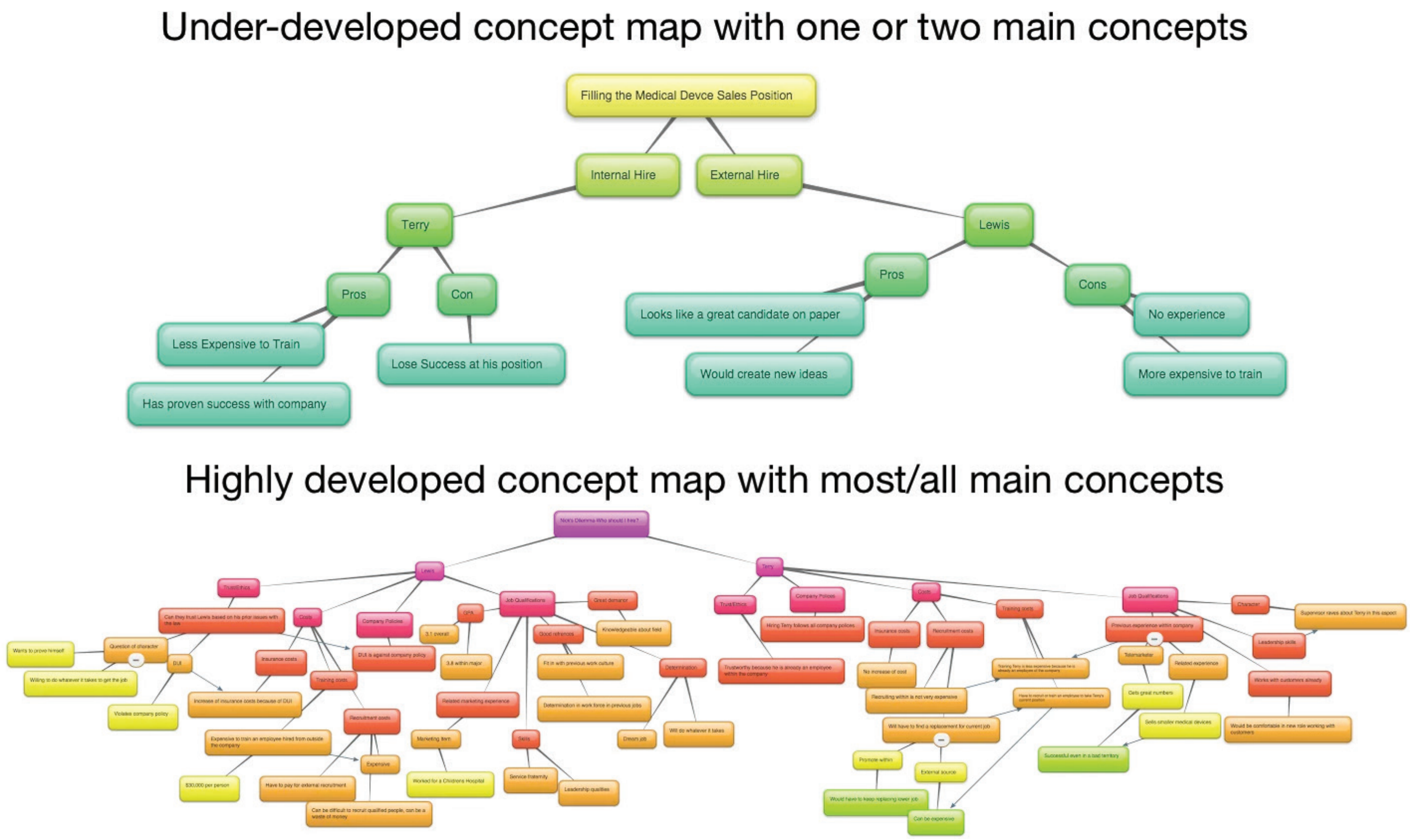

Figure 2. Concept maps illustrating minimal development of concepts (top) and more advanced development of concepts (bottom).

Deeper analysis of Google Analytics' data indicated that, on average, users accessed 5.2 pages per session. These were not necessarily unique pages, but the total number of times separate pages were accessed. That is, if students accessed the same page twice, this would be calculated as two pages accessed. Analysis also revealed that the average amount of time per session was 00:10:47, or about 50 seconds per page. This finding caused us to reflect on how quickly students would have to have read each page. Hence, we calculated reading rate in words per minute to estimate how quickly a student would need to read to complete a case (811 words on average) in just 50 seconds. Results indicate 960 words per minute. Given that adults read, on average, around 200 words per minute (Noyes & Garland, 2008), students would have had to read nearly five times faster than average to complete the average case in just 50 seconds. This provided additional evidence that students were not reading and reflecting on the cases as they were originally intended.

Readability Assessment

Findings from analysis of Google Analytics data led us to question whether the reading level of cases might be too high. Given that the cases had been developed by a university professor, it seemed reasonable that they might be overly academic, therefore potentially leading to students becoming frustrated and quitting. We assessed reading levels using the Flesch-Kincaid grade level tool. Results indicated the highest level was 10.1 and the lowest was 6.8, with an average of 7.85, thereby suggesting an average reading level of between seventh and eighth grade for all cases. Although no general rules have been established for target reading levels for case libraries, general web guidelines suggest using a sixth-grade reading level for homepages and an eighth-grade reading level for other pages (Nielsen, 2005). These same guidelines suggest that higher reading levels can be used for appropriate audiences. Given that students were juniors and seniors taking a university class, the average reading level of 7.85 seemed to be well within their reading ability. Hence, the reading level of the cases did not appear to be a barrier to students' use of the cases.

Reflection

The interaction patterns uncovered using Google Analytics suggested that the majority of students were not engaging deeply with materials provided in the case library. It followed, therefore, that this lack of depth would be reflected in

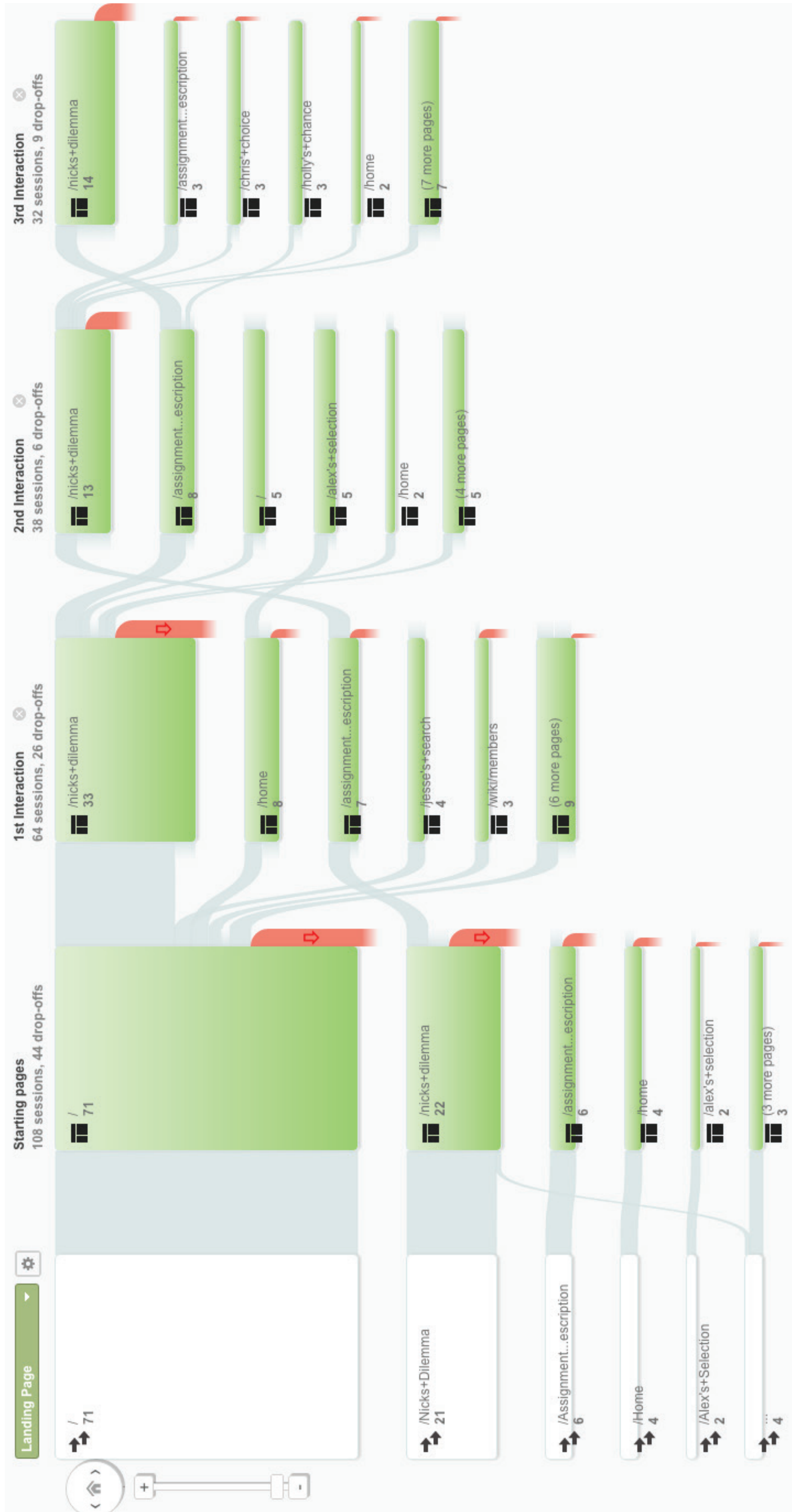

Figure 3. Sample behavior flow diagram.

the quality of students' concept maps, that is, students who only accessed the primary problem to solve created underdeveloped concept maps. Hence, our reflection focused on identifying design principles that might lead to greater quality in students' concept maps (and therefore indicate deeper understanding of the underlying problem). Our design conjecture rested on the assumption that exposure to all cases was required if students were to develop sufficient depth of understanding. Related to this were the assumptions (1) that students would be more likely to access cases if they were given a clear motive for accessing the cases, and (2) that students would be more likely to access the cases if the cases were written for maximum readability.

Design Principle 1: Motives to Access Related Cases Should Be Explicit

The way that related cases were presented in the case library emerged as a design flaw during our reflection. While all students accessed the primary problem to solve (Nick's Dilemma), few students continued on to read the supporting narratives in the case library. This behavior was unexpected, as the learning environment had been designed so that students would follow embedded hyperlinks to related cases. While the supporting cases were intended to be accessed via hyperlinks in the primary problem to solve, it was not made clear what information students would encounter when they clicked a link, nor was it made clear why a student should click on a link. Further, our design did not sufficiently make it clear that students were required to visit the cases linked from the main problem.

From a CBR perspective, we assert the indices (as indicated by hyperlinks in the primary case) might have been insufficient to prompt case retrieval. Students might ignore hyperlinks when it is not clear that they lead to supporting cases that include important information related to the primary problem to solve. And even if it is made clear that that hyperlinks lead to supporting cases, students might not access those links if the utility of the information provided in the linked cases is not explicitly made clear. Therefore, we reasoned, motive must be provided by making explicit the purpose and utility of related cases.

Design Principle 2: Cases Should Be Written for Maximum Readability

Data from Google Analytics suggested that students spent an average of 50 seconds on each page, which is far too little time to read each page, let alone comprehend and reflect on what was read. Students would have had to read nearly five times faster than an average adult to complete a page in just 50 seconds. We were unable to find any specific guidelines for case length in the CBR literature; however, some research suggests that case length can impact case retrieval in general (Aha, McSherry, & Yang, 2005; McSherry, 2001). In terms of our design, we concluded that cases should be developed such that they minimize "the user's burden in terms of resources such as time, information cost, and cognitive load" (Branting, Lester, & Mott, 2004, p. 1).

In addition, Nielsen (2006) reports that users read web content largely in an F-shaped pattern, that is, they do not read web content from left to right and from top to bottom, but rather, they skim information. The first two paragraphs will be read the closest, and subsequent paragraphs will be quickly skimmed or not read at all. Hence, the design of the first two paragraphs in a web-based interface is of great importance. In our learning environment, each case was a set of long paragraphs. With the average case being 811 words, it is likely that cases were not amenable to a skimming pattern. Cases might have appeared to users as a "wall of text" with no visual breaks. Given that case presentation can impact case retrieval, it follows that web-based reading patterns and best practices for hypertext design should factor prominently into the design of web-based case libraries.

Revision

Our reflection process resulted in identification and acknowledgment of flaws in our design, as well as reflective discussions on design decisions that led to these issues. One flaw that we discovered was a tacit assumption that if students were presented with a collection of cases, they would use it as designers intended. Continued discussions revealed that many early design decisions (phase 1, phase 2) were focused more on advancing theoretical understanding of case-based reasoning than on improving the case library intervention. Phase 3 our EDR process led us to understand the importance of how cases were presented to students, a finding supported by research which suggests that differing the design of a case can positively impact learning outcomes (Gartmeier et al., 2015; Lin-Siegler, Shaenfield, & Elder, 2015). Reflection led to two key focus areas for improvement: (1) making explicit the motives to access related cases, and (2) designing cases for maximum readability online. Potential solutions were informed by case-based reasoning and multimedia literature, as well as our own expertise and perceptions.

With these new insights and their implications, we adopted a rapid prototyping (RP) approach for advancing our design. RP seemed appropriate due to its usefulness in complex situations that make predictions difficult, situations that have not produced satisfactory results using other methods, and "new situations where there is not an abundance of experience from which to draw" (Tripp & Bichelmeyer, 1990, p. 9). Based on analytics data, we strongly suspected that students were not reading cases because the cases were

Nick's Dilemma

Nick stepped into work Monday morning with his boss, Sheila. She scheduled this meeting to discuss a series of applicants that were being considered to fill a medical device sales position left open after someone recently left to pursue another opportunity at another company.

"Nick," she begins, "We need to stop having to fill this position. It is hurting us in terms of time and money to have to hire and train a new person every six months. We've had a lot of turnover in this medical sales position that needs to be stopped. As you know, we've missed on some of the previous hires. The three people we have had come in and out have cost us $90,000 over the last year in terms of revenue and training. That's $30,000 per person! The last individual hired for the position seemed pretty good in terms of technical expertise, but it was pretty clear that the sales aspect of the job wasn't a great fit. Let's go through some of these together and see if we can find someone with that right mix between technical expertise and social skills."

What is the right mix between technical expertise and social skills **Holly's Chance**?

You step into work Monday morning with your boss, Sheila. She scheduled this meeting to discuss a series of applicants that were being considered to fill a medical device sales position left open after someone recently left to pursue another opportunity at another company.

What's up, Sheila?

How was your weekend, Sheila?

Figure 4. Rapid prototypes developed in Twine, with text-based version on the left and multimedia version on the right.

text heavy and lacked multimedia and interactive elements. For design inspiration, we looked to the medium of comics and graphic novels, as we felt these media were uniquely suited to catch and hold students' interest (Harackiewicz, Barron, Tauer, Carter, & Elliot, 2000). Using a tool for creating non-linear hypertexts called Twine (http://twinery.org), we rapidly prototyped a single case from the case library. Each author prototyped the case independently, resulting in two initial prototypes (Figure 4).

To approach the design principle of making the motives for accessing related cases explicit, we considered ways to make hyperlinks more descriptive both in terms of why a student should access the case and what kind of information she or he would encounter after clicking the hyperlink. These questions have replaced the hyperlinks that were embedded in prior versions of the learning environment. Because the associated case narrative contextualizes these questions, they naturally make explicit the motives for selecting them. Students select a question with their mouse and are then taken to a page where that question is answered. We considered pop-up text descriptions that would appear when students hovered their mouse over a hyperlink, but found these descriptions to be easily ignored in prototypes. Using text descriptions also conflicted with our design principle of maximizing readability (see Figure 4). To approach the design principle of maximizing readability, we experimented with splitting up a case on the same page or across pages to accommodate web-based reading patterns as well as some of the cognitive load challenges of reading (Mayer & Moreno, 2003). Ultimately, we were pleased with the prototype that had a graphic novel feel due to how it addresses design flaws of case-length and visual presentation, as well as how its presentation requires students to access necessary information using embedded questions, similar to an ASK system (Ferguson, Bareiss, Birnbaum, & Osgood, 1992; Schank, 1999). Future phases of our design research will investigate this design related to issues of case design and user interaction discussed in the following section.

Conclusion

In this article, we have described and interpreted our iterative processes of design and development, and situated these processes within the broader framework of EDR. We have presented our work as a design case spanning one iteration of design, enactment, evaluation, reflection, and revision. A highlight of this work was a focus on how we encountered a design problem and used analytics data to help answer important questions during a critical phase of our EDR cycle. The reflexive nature of EDR allowed us to critically consider design flaws and to develop new principles to guide our design.

By using analytics and EDR to guide our design, our latest design iteration embodies principles of (1) making explicit the motives to access related cases, and (2) designing cases for maximum readability online. However, concerns and questions remain. While our redesigned case library reduces the amount of text on each page and arguably improves visual presentation, it also has human factors implications. For example, this approach requires students to click through multiple pages to complete a single case. While we assert this could sustain engagement, we must also consider if this also might lead to issues with navigation and cognitive load. Additionally, in phases 1 and 2 students were given question prompts that were intended to stimulate thinking. However, further investigation is needed to determine if those prompts have an impact on learning or indeed if students even pay attention to them. In the redesigned learning environment, we have continued the tradition of using questions, but now represent them as interactive, hyperlinked questions at the bottom of each page. This is intended to make questioning and decision making more salient for students, but it remains unclear the degree to which these embedded hyperlinks-as-questions will promote students accessing necessary information. This design approach also requires a nonlinear approach to navigating to the case library, which could lead to challenges with navigation and staying aware of one's progress. Further evaluation and design iterations are needed as we further apply EDR to CBR.

In conclusion, design problems are notoriously difficult because they are ill structured, do not have a single correct solution, and typically lack a clear solution path (Jonassen, 2011), as is evident in the example we have described here. We have explained how using analytics data in conjunction with the EDR approach led us to uncover flaws in the design of a case-based learning environment and how this led to the development of new design principles. Using a rapid prototyping approach, we were able to incorporate these design principles into a new case library design, which has led to new directions for inquiry. Our hope is that our experiences and the design principles that emerged from our work will inform other researchers seeking to advance theory and practice related to the design of problem-based learning environments and case-based learning environments.

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