A Data-driven Methodology for Producing Online Learning System Design Patterns

PAUL SALVADOR INVENTADO, School of Design, Carnegie Mellon University
PETER SCUPELLI, School of Design, Carnegie Mellon University

Online learning systems are complex systems that are frequently updated with new content, upgraded to support new features and extended to support new technologies. Maintaining the quality of the system as it changes to support student learning is a known problem. Design patterns can help the multiple stakeholders involved in using and maintaining an online learning system (e.g., system developers, content creators, learning scientists). Although some design patterns for online learning systems exist, they often focus on one aspect of the system, such as pedagogy. In this paper, we present a new data-driven design pattern production (3D2P) methodology that utilizes data for producing design patterns in collaboration with stakeholders, addresses stakeholders' concerns, and ensures the system's quality as a whole. We present five patterns produced by applying the methodology on the ASSISTments online learning system namely: All Content in One Place, Just Enough Practice, Personalized Problems, Worked Examples, and Consistent Language. We made two changes to the pattern format: added in-text references, and added an evidence section. References situate the design pattern in the literature. The evidence section highlights key findings uncovered from the 3D2P methodology. Three sources of evidence were considered in the pattern format: (a) literature – existing research on the problem or solution, (b) discussion – expert opinions about the problem or solution, and (c) data – measures of the problem's recurrence, or the solution's effectiveness based on collected data. The changes to the format highlight linkages between pattern elements, theory, and empirical evidence. We believe that links mentioned above clarify the theoretical underpinnings of the design patterns, make it easier for multiple stakeholders to understand the logic of the design patterns, and provide known evidence of the patterns' effectiveness.

Categories and Subject Descriptors: **H.2.8 [Information Systems]**: Database Applications—*Data mining*; **H.5.2 [Information Interfaces and Presentation]**: User Interfaces—*Evaluation/methodology*; **H.5.2 [Information Interfaces and Presentation]**: User Interfaces—*User-centered design*; **K.3 [Computers and Education]**: Computer Uses in Education—*Distance learning*;

General Terms: Design, Human Factors

Additional Key Words and Phrases: Design patterns, pattern prospecting, pattern mining, pattern writing, pattern evaluation, online learning systems, ASSISTments, learning analytics

ACM Reference Format:

Inventado, P.S. and Scupelli, P. 2015. A Data-driven Methodology for Producing Online Learning System Design Patterns. HILLSIDE Proc. of Conf. on Pattern Lang. of Prog. 22 (October 2015), 17 pages.

1. INTRODUCTION

Enrollment in online learning systems has grown rapidly. In the Fall of 2007, over 3.9 million students took at least one online course and over 20% of all US higher education students took at least one online course (Allen and Seaman 2008). Massive open online courses (MOOCs) such as Coursera, edX and Udacity have also become popular. Coursera, one of the largest MOOC platforms, has over 11 million users in 941 courses from 118 institutions as of January 2015 (Coursera n.d.). Students and teachers flock to tutoring systems like Cognitive Tutor (Koedinger et al. 1997, Morgan and Ritter 2002, Sarkis 2004) and ASSISTments (Heffern and and Heffernan 2014, Mendicino et al. 2009a). Cognitive Tutor was reported to make over 250 million student observations a year (Carnegie Learning n.d., Sarkis 2004) and ASSISTments has been collecting significant amounts of data since 2003 from close to 50,000 students using the system each year in 48 states of the United States (ASSISTments n.d., Heffernan and Heffernan 2014, Mendicino et al. 2009b).

Designing and maintaining the quality of online learning systems is challenging because it consists of many complex components (e.g., user management, data management, content management), stakeholders with different backgrounds are involved in its development (e.g., system developers, content creators, learning scientists), it is used by a diverse set of users (e.g., students, teachers, parents), and it is often updated to accommodate new technologies (e.g., mobile platforms with different screen sizes).

This material is based upon work supported by the National Science Foundation under Grant No. 1252297.
Author's address: P.S. Inventado, 5000 Forbes Avenue, Pittsburgh PA 15213; email: pinventado@cmu.edu; P. Scupelli, 5000 Forbes Avenue, Pittsburgh PA 15213; email: pgs@andrew.cmu.edu

Design patterns, which are high quality solutions to known problems, can address the development and maintenance challenges of online learning systems by providing stakeholders with a guide for creating content, adding new features, modifying components, and adapting to new technologies. Although design patterns for online learning systems have been developed, they often focus on pedagogy such as strategies for presenting content, activities to promote learning, and methods for providing feedback and evaluation (Anacleto et al. 2009, Derntl 2004, Frizell and Hübscher 2011). They focus on teachers' concerns but not on the concerns of other stakeholders (e.g., system developer, HCI experts) or how pedagogical design patterns affect or are affected by other patterns in the system.

In this paper, we present a methodology that extends the traditional design pattern mining and writing process by using data to guide the production of design patterns (Inventado and Scupelli 2015b). In the methodology, stakeholders involved in the online learning system's development are presented with pattern proposals uncovered from relationships observed in the data. Stakeholders can analyze the proposed patterns using actual data about student behavior in specific contexts. Actual data helps stakeholders communicate and collaborate in refining patterns, and to make design decisions that either satisfies most stakeholders' concerns or strikes a balance between conflicting concerns. The methodology can be used incrementally to ensure the system's design quality as new content is added, new functionalities are incorporated, new technologies are adopted, and more stakeholders engage with the system.

Stakeholders involved in the development of online learning systems often come from diverse backgrounds such as learning sciences, learning analytics, computer science, psychology, interaction design, education, and so forth. The selected pattern format in the paper includes links to theories and empirical evidence to help stakeholders understand patterns better and show how they are grounded in science. A better understanding of the patterns may encourage more stakeholders to collaborate in the pattern production process.

The following section introduces the ASSISTments online learning system, which was used as the mining ground for patterns. This is followed by a discussion on the data-driven design pattern production (3D2P) methodology, which was used to produce design patterns. The next sections contain the design patterns produced using 3D2P, a summary of the work, and future directions.

2. ASSISTMENTS

ASSISTments was developed in 2003 to help students practice mathematics for the Massachusetts Comprehensive Assessment System (MCAS), to help teachers identify students that need support, and to identify topics that need to be discussed and practiced further (Heffernan and Heffernan 2014). It is an online learning system that allows teachers to create exercises with associated questions, solutions, feedback, etc. that they can assign to students and get student performance assessments from (Heffernan and Heffernan 2014). ASSISTments was developed by a multi-disciplinary team consisting of content experts, learning scientists and system developers among others. It was designed and built using architecture and interface development best practices with the help of Math teachers who provided expert advice and content. Figure 1 illustrates a Math problem in ASSISTments, which allows students to view a problem, request hints and attempt to solve it.

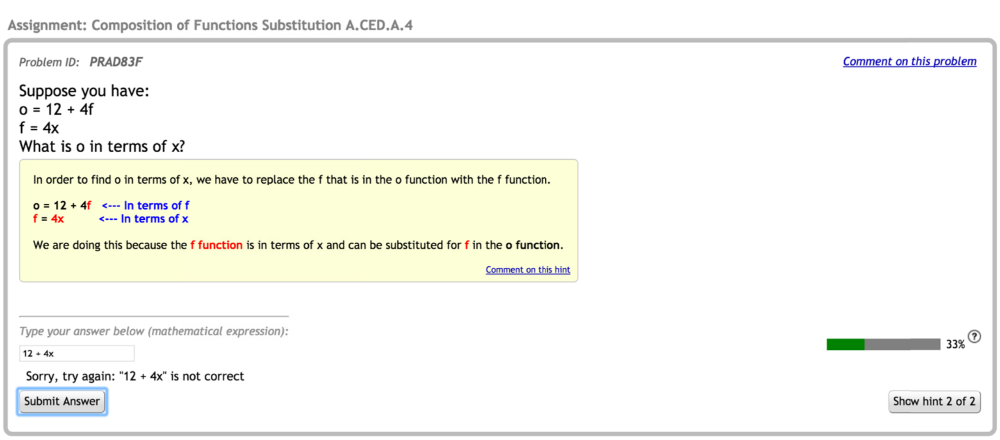


Fig. 1. ASSISTments interface showing an algebra problem. Students can submit their answers, get feedback on their answers, and request hints to help them solve the problem (Image courtesy of ASSISTments http://www.assistments.org).

Initially, Math teachers were asked to provide the content (e.g., problems, answers, hints, feedback) for ASSISTments (Heffernan and Heffernan 2014). Later, questions from Math textbooks were also added and teachers who used the system were allowed to create their own questions or adapt their own versions of existing questions. Over time, ASSISTments underwent many changes to support feature requests (e.g., grading flexibility for teachers, parent access to grades) and improvements (e.g., adding a mastery learning component that required students to master a skill before moving on to the next topic) (Heffernan and Heffernan 2014). It also allowed researchers to run studies and collect student data with options to customize content, feedback, and other elements in a problem (e.g., Broderick et al. (2012), Li et al. (2013), Whorton (2013)).

3. USING DATA TO PRODUCE DESIGN PATTERNS

The data-driven design pattern production (3D2P) methodology illustrated in Figure 2, uses an incremental process of prospecting, mining, writing and evaluating patterns (Inventado and Scupelli 2015b). In pattern prospecting, data collected by the learning system is first cleaned to remove noise and processed to make the data easier to analyze. Background knowledge about the domain and existing literature can help guide the selection of feature values or measures (e.g., answer correctness, number of hint requests, student frustration) that will filter data to find evidence of interesting relationships (e.g., correlation between student frustration and problem difficulty). Patterns can be mined from the filtered data by investigating feature relationships further and framing hypotheses from meaningful relationships uncovered. Literature and expert knowledge is also consulted to strengthen the hypotheses. Resulting hypotheses can be used to write design patterns that are verified and refined in collaboration with multiple stakeholders. The patterns are then evaluated by conducting randomized controlled trials (RCTs) that compare the effectiveness (e.g., increase or decrease of incorrect answers, help requests or student frustration) of the original design and the adapted design (e.g., using textual hints vs. using hints with images). Ineffective design patterns can be refined further while effective design patterns can be shared with stakeholders to help them maintain the system's quality when adding content, incorporating new functionalities, and adopting new technologies.

The design patterns presented in the paper were produced using the 3D2P methodology. More details about using the methodology on ASSISTments data can be found in (Inventado and Scupelli 2015a), and (Inventado and Scupelli 2015b).

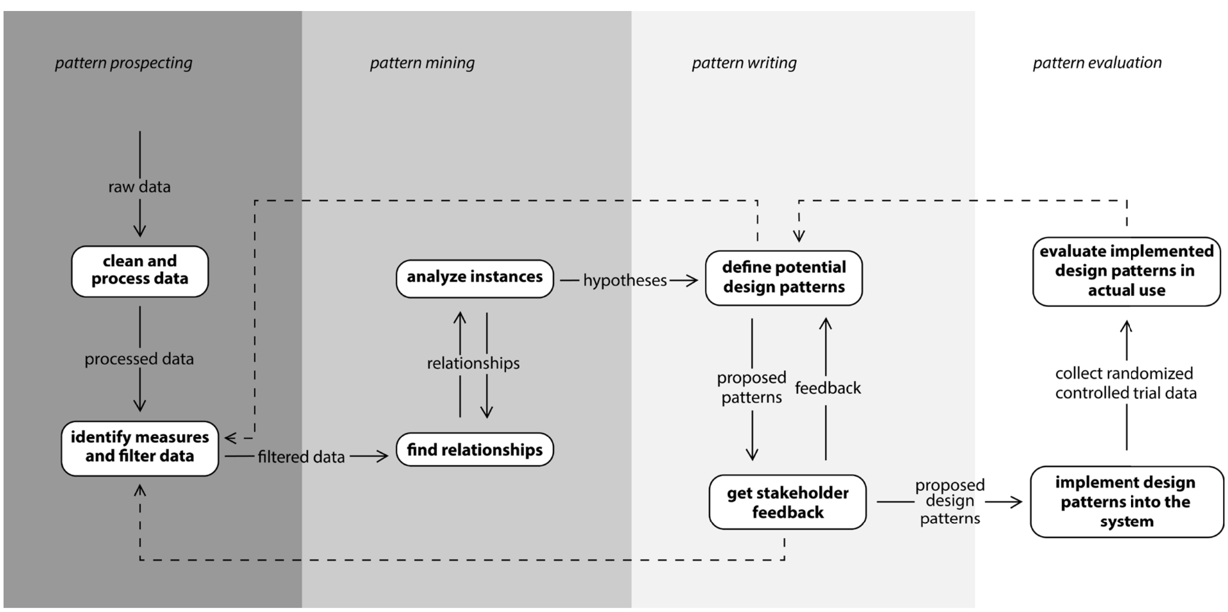


Fig. 2. Data-driven design pattern methodology (Image courtesy of the Learning Environments Lab).

4. DESIGN PATTERNS

The pattern format used in this paper has two major differences from commonly used formats: the addition of in-text citations and the addition of an evidences section. When appropriate, in-text citations link to pre-existing literature. The evidence section was added to highlight key findings uncovered from the 3D2P methodology. These findings justify the recurrence of the problem identified by the pattern or the effectiveness of its solution.

Three sources of evidence were considered in the pattern format: (a) literature – existing research on the problem or solution, (b) discussion – expert opinions about the problem or solution, and (c) data – measures of the problem's recurrence, or the solution's effectiveness based on collected data

We revised patterns based on shepherding process, writer's workshop, and new evidence. Deeply revised patterns are indicated by a version number beside its name, and a short description about the revision below the pattern's diagram.

Table 1 provides a summary of the patterns presented in this paper and Table 2 provides a summary of the patterns that were referenced. This is followed by the online learning system design patterns.

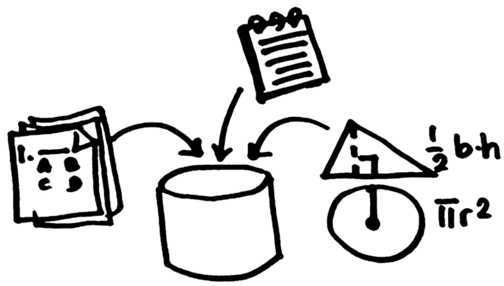
Table 1. Problem Solving Feedback Patterns

Design Pattern	Summary
All Content in One Place	Embed all content such as images, animations, videos, or text into the problem instead of asking students to switch between various sources.
Just Enough Practice	Allow students to practice a skill until they master it then switch to another skill in order to avoid over practice.
Personalized Problems	Assign appropriate problem-solving activities to a student's skill level.
Worked Examples	Provide students with an example similar to the problem they are asked to solve so they understand how to solve the problem without revealing the answer.
Consistent Language	Use terms, images, notations, and other problem elements consistently throughout the learning activity.

Table 2. Referenced Patterns

Referenced Design Patterns	Summary
Build and Maintain Confidence (Bergin et al. 2012)	Give students problem-solving activities with appropriate feedback, so they apply what they learned, discover there are multiple solutions, and realize they can implement solutions themselves.
Different Exercise Levels (Bergin et al. 2012)	Provide students with exercises that differ in difficulty levels, approaches, topics, etc. and assign to each student whichever is most appropriate to their skill level.
Differentiated Feedback (Bergin et al. 2012)	Provide students personalized feedback instead of generic feedback.
Familiar Language (Van Duyne et al. 2007)	Use terms consistently so readers understand what you mean.
Just Enough Practice (Inventado and Scupelli 2015b)	Allow students to practice a skill until they master it then switch to another skill in order to avoid over practice.
Keep It Simple (Cunningham and Cunningham 2014)	Designs should be kept as simple as possible while ensuring it still achieves its purpose.
One Concept – Several Implementations (Bergin et al. 2012)	Present and compare several implementations of an abstract concept so learners understand its essence and not just associate it with a single implementation.
Try It Yourself (Bergin et al. 2012)	Ask students to answer exercises that will give them a better understanding of the topic.
Worked Examples (Inventado and Scupelli 2015a)	Provide students with an example similar to the problem they are asked to solve so they understand how to solve the problem without revealing the answer.

All Content in One Place



Context: Content creators create problem-solving activities in an online learning system so students can practice solving problems. The **All Content in One Place** design pattern described below is the result of an implementation of the **Try It Yourself** design pattern in an online learning system (Bergin et al. 2012).

Problem: Content creators may find it easier to provide links to existing content (e.g., exercises in the textbook, images, videos, animations, websites) instead of copying the content of the problem into the online learning system, but scattering problem content across multiple locations makes the learning task more difficult for learners.

Forces:
1. **Permission.** Some content cannot be copied directly into the online learning system because of copyright rules (e.g., text, images).
2. **Replication difficulty**. Some content are difficult or time consuming to replicate in an online learning system (e.g., copying text, images, video).
3. **Accessibility.** Students may be unable to access the necessary content that is referenced in the problem (e.g., no textbook, no permission to access content, limited internet access).
4. **Split-attention effect.** Students need to integrate information across multiple locations when they switch between different content sources (e.g., textbook, handouts, external website). This increases cognitive load, which impairs performance and unnecessarily complicates the learning task at hand (Sweller 2004).
5. **Affect.** Students can get annoyed by repeatedly going back and forth between content sources to solve a problem. Negative emotions might hurt learning (e.g., frustration, disengagement) and often result in failure to complete assigned problem sets (D'Mello and Graesser 2012).

Solution: *Therefore, gain access to the content and embed it into the online learning system instead of asking students to switch to a different resource (e.g., looking for a problem in the textbook, opening a new browser window, downloading content).*

Consequences:

Benefits:
1. Third-party content can be used after getting permission to use it.
2. It takes less effort to embed content instead of copying it.
3. Students do not need to worry about integrating content across multiple locations because the content is in the system.
4. Students focus on an integrated content source instead of switching between multiple locations.
5. Students are less likely to experience negative emotions when they can focus on the learning activity and are not subjected to unnecessary cognitive load.

Liability:
1. Teachers have no choice but to build new content if they lack permission to use copyrighted content or cannot find alternative open-source learning content.
2. Some online learning systems have limited or lack support to embed external content. Teachers will need to manually add the content into the online learning system in this case.

3. Neither the content creator nor the online learning system has control over external content. Unless the system automatically replicates content, access to the content may be lost if the owner discontinues support for it.

Evidence:

- *Literature:* Several studies have shown that split-attention increases cognitive load and have negative effects on learning in various settings such as: instructional manual usage while learning to use computer software (Cerpa et al. 1996), split-attention worked examples for geometry (Sweller et al. 1990), and split-attention worked examples in math word problems (Mwangi and Sweller 1998).
- *Discussion:* Shepherds, writing workshop participants, and learning system stakeholders (i.e., data mining experts, learning scientists, and educators) agreed that the problem recurs in online learning systems and the solution could properly address the problem.
- *Data:* According to ASSISTments' math online learning system data, boredom and gaming behavior correlated with problems that referred students to content in their textbook (Inventado et al. in preparation).

Examples:

Most online learning systems either use their own content or embed existing content (e.g., Cognitive Tutor (Aleven et al. 2006), SQL-Tutor (Mitrovic 2012), ASSISTments (Heffernan and Heffernan 2014)). When content is copyrighted, access may be requested from the owner or alternative non-copyrighted content may be used. In the case of the ASSISTments online learning system, some of its Math exercises are copied from publicly available textbooks, such as EngageNY. Content may be embedded into the system using iframes that contain external websites or loaded directly into the page (e.g., external images, animations, videos, text). For example, videos used in the problem content or feedback are embedded into the system so students do not need to view them in separate browser windows.

Figure 3a illustrates a particular case wherein a teacher provided instructions to access a math problem from the textbook instead of copying the content directly into the online learning system. Figure 3b illustrates the same math problem, but with the content embedded into the system.

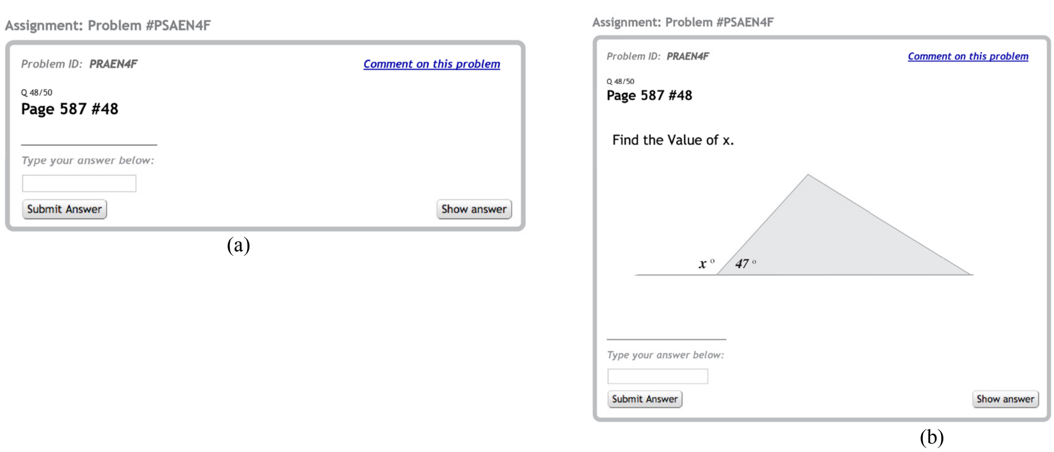
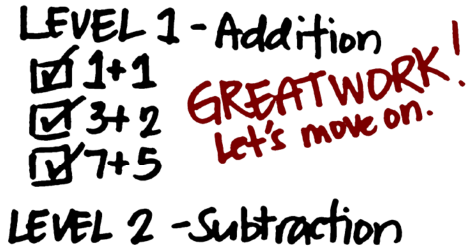


Fig. 3. (a) A problem that references content from a textbook. (b) A problem that consolidates external content into the system (Image courtesy of ASSISTments http://www.assistments.org).

Related Patterns: The **All Content in One Place** design pattern implements the **Keep It Simple** design pattern by removing extraneous tasks that do not help students learn (Cunningham and Cunningham 2014). Implement the **All Content in One Place** design pattern whenever students are asked to perform learning activities such as those implemented in the **Try It Yourself**, **Build and Maintain Confidence**, or **One Concept – Several Implementations** design patterns (Bergin et al. 2012).

Just Enough Practice (v.2)



This is a revision and extension of ***Just Enough Practice****.*

Context: Content creators for *Skill Builders* design problem-solving activities that facilitate student mastery of a particular skill. *Skill Builder* problem sets require a student to achieve three correct answers consecutively in order to move on to new assignments while continuing to provide struggling students with extended practice.

Problem: Students cannot maximize their learning time if they are asked to practice skills they already mastered.

Forces:
1. **Diminishing returns**. Students learn more when they initially practice a skill, but eventually learn less as they master the skill through continued practice (Rohrer and Taylor 2006, Sweller 2004).
2. **Over practice.** Students' learning gains are almost the same when they either stop practicing a skill after mastery or over practice it (Cen et al. 2007).
3. **Limited resources.** Student attention and patience is limited so they may switch to other tasks if they feel they are no longer learning from an activity (Arnold et al. 2005, Bloom 1974).

Solution: *Therefore, give students problems to practice a skill until they master it then give them new problems to practice a different skill*. There are different ways to assess mastery such as students' performance on a skill-mastery test, or a statistical model's prediction of student mastery (Yudelson et al. 2013).

Consequences:

Benefits:
1. Students get enough practice to master a skill.
2. Students do not spend unnecessary time over-practicing a skill when it does not contribute to learning gains.
3. Students make better use of their time by learning more skills in the allotted time.

Liability:
1. The online learning system needs to support the measurement of skill mastery before the pattern can be applied.
2. If skill mastery is incorrectly predicted, the learning system can cause over-practice on a skill or worse, prevent students from practicing a skill enough before mastery.
3. Aside from creating problems to practice a particular skill, content creators will also need to prepare problems that target other skills students are asked to learn.

Evidence:
- *Literature:* An experiment conducted by Cen and colleagues (2007) revealed that students had similar learning gains regardless if they over-practiced a skill or stopped practice after mastery. However, it took less time when students stopped practice after mastery. They suggest that students should switch to learning new skills instead of over practicing already mastered skills.
- *Discussion:* Shepherds, writing workshop participants, and learning system stakeholders (i.e., data mining experts, learning scientists, and educators) agreed that over-practice could be common among online learning systems, and adapting problems to student mastery could address this problem.

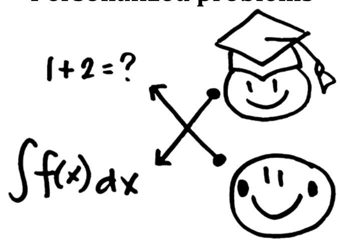
- *Data:* According to ASSISTments math online learning system data, frustration correlated with students repeatedly answering problems they already mastered.

Examples:
Some online learning systems measure students' skill mastery to help control the amount of practice provided. For example, Cognitive Tutor Algebra and Cognitive Tutor Geometry are both online learning systems that track student mastery on a particular skill and provide students with problems that help them master that skill (Aleven et al. 2006, Koedinger and Aleven 2007). After the system detects that the student mastered a skill, it selects a different skill for the student to practice. The ASSISTments online learning system provides an IF-THEN-ELSE functionality that allows content creators to control the problems assigned to a student according to student performance (Donnelly 2015). This functionality allows students to be assigned problems that practice a particular skill and switch to another problem set after mastering the prior skill.

A concrete example of applying the pattern would be a teacher designing homework for her class. She can design a problem set that helps students practice decimal addition and another set for decimal subtraction. When students answer these problems, an online learning system may track the number of problems the student answers correctly. When a student answers three problems right in a row for example, then the student can advance to decimal subtraction problems. Otherwise, the student continues practicing decimal addition problems.

Related Patterns: Make sure the system implements the **Just Enough Practice** design pattern when students are asked to use the **Try It Yourself** or **Build and Maintain Confidence** design patterns (Bergin et al. 2012). When implementing the **Just Enough Practice** design pattern, move on to more challenging problems after mastery using the **Personalized Problems** design pattern. The **Differentiated Feedback** or **Worked Examples** design patterns may be used to facilitate learning (Bergin et al. 2012).

Personalized problems



Context: Content creators design problems for students to solve to better understand the concepts taught.

Problem: Students become bored or disengage from an activity if they are asked to solve problems that are either too easy or too difficult.

Forces:

1. **Prior knowledge.** Students cannot solve a problem if they lack the necessary skills (Sweller 2004).
2. **Desirable difficulty.** Activities that are too easy or do not challenge learners' understanding of a concept require less mental processing and often, result in less learning (Bjork 1994, Piaget 1952).
3. **Learning rate.** Student learning rates vary because of differences in prior knowledge, learning experiences, and quality of instruction received (Bloom 1974).
4. **Persistence.** Students may disengage from a learning activity if they get stuck too long while trying to solve it (Arnold et al. 2005, D'Mello and Graesser 2012).

Solution: *Therefore, assign problems that are appropriate for a student's skill level.* A student's capability to solve a problem can be identified using assessments of their knowledge on pre-requisite skills, or model-based predictors (Koedinger and Aleven 2007).

Consequences:

Benefits:

1. Students are asked to answer problems that they are capable of solving themselves, or with some assistance (Vygotsky 1962).
2. The problem challenges students because it requires skills that students may not have mastered yet.
3. Each student is assigned to a different problem that is appropriate for his/her skill level.
4. Students may continue to solve a challenging problem if they have enough prerequisite knowledge.

Liability:

1. Content writers will need to provide different content for each skill level.
2. The system needs to keep track of pre-requisite and post-requisite skills, as well as problems associated with those skills so they can be assigned appropriately.
3. The system needs to be capable of measuring students' skill level and selecting problems dynamically.
4. If students' skill level is incorrectly identified, the system can still give students problems that are too easy or too difficult.

Evidence:

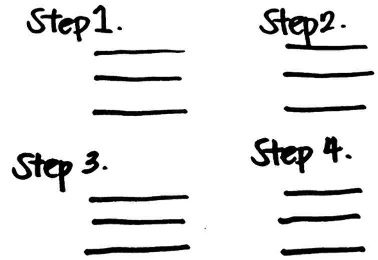
- *Literature:* Research showed that personalizing content according to students' skill level resulted in similar learning gains as non-personalized content, but took a shorter amount of time. This was observed in various domains such as simulated air traffic control (Salden et al. 2004), Algebra (Cen et al. 2007), Geometry (Salden et al. 2010), and health sciences (Corbalan et al. 2008).
- *Discussion:* Shepherds, writing workshop participants, and learning system stakeholders (i.e., data mining experts, learning scientists, and educators) agreed that the design pattern's solution could address the identified problem.
- *Data:* According to ASSISTments math online learning system data, boredom and gaming behavior correlated with problem difficulty (i.e., evidenced by answer correctness and number of hint requests).

Example:
Many online learning systems were designed to adapt to students' skill level. For example, SQL-Tutor provides students with problems on SQL programming that are appropriate to their level of knowledge (Mitrovic and Martin 2004). Cognitive Tutor Algebra is another learning system that tracks student mastery on a particular knowledge component and provides them with algebra problems that are appropriate to their skill level (Koeding and Aleven 2007). The ASSISTments online learning system provides an IF-THEN-ELSE functionality that allows teachers to control the problem sets assigned to students based on their performance (Donnelly 2015). This can be used to identify students' skill level and to assign the appropriate problem set.

A concrete example for applying this pattern is a teacher that encodes multiple math problem sets with varying levels of difficulty into an online learning system (e.g., single-digit subtraction, multiple-digit subtraction, subtraction by regrouping). As students answer questions in their homework, the online learning system would keep track of students' progress to identify their skill level such as low (i.e., student makes mistakes ≥ 60% of the time), medium (i.e., student makes mistakes < 60% and ≥ 40% of the time) or high (i.e., student makes mistakes < 40% of the time). Based on students' performance, the online learning system would provide the appropriate problem set so that it is more likely for students to receive questions that are fit for their skill level.

Related Patterns: The **Personalized Problems** design pattern is an implementation of the **Different Exercise Levels** design pattern in online learning systems (Bergin et al. 2012). The system should use the **Just Enough Practice** design pattern so that students reach mastery before switching to a more challenging problem set. The **Differentiated Feedback** or **Worked examples** design patterns may be used to facilitate learning (Bergin et al. 2012).

Worked examples (v. 2)



This is a rewriting and extension of ***Worked examples****.*

Context: Students are answering problem-solving activities on an online learning system to get practice with a particular type of skill. Students are implementing the design pattern **Try It Yourself** (Bergin et al., 2012).

Problem: Some students may be motivated to solve a problem, but do not know where to begin, and do not want to muddle their way through hints without an overview of the problem solving process first.

Forces:
1. **Prior knowledge.** Students may be unable to solve a problem if they forget key facts, concepts, and processes (Hume et al., 1996).
2. **Randomness.** When students do not know how to solve a problem, they may randomly combine elements to form a solution that may not solve the problem or even confuse themselves further (Sweller 2004).
3. **Affective entry.** When students are unable to achieve their learning goals, they may become frustrated, discouraged of their abilities, and dislike the subject (Bloom 1974).
4. **Limited Resources.** Students may eventually give up if they are unable to solve the problem (D'Mello and Graesser 2012).

Solution: *Therefore, provide a worked example so that students can have an overview of the procedures to follow.* Worked examples show a step-by-step process of solving a problem similar to the type of problem the student is currently asked to solve. Students may request for a worked example themselves, or the system could show the worked example automatically when a given condition is satisfied (e.g., too many incorrect attempts, too many hint requests, student's answer is very different from the expected answer).

Consequences:

Benefits:
1. Worked examples help students form new knowledge, which they can use to solve the current problem and similar problems in the future.
2. Students can pattern their solution on the worked example instead of finding solutions on their own.
3. Students will be more confident in their abilities and develop interest in the subject when they successfully apply the solution.
4. Worked examples may help guide students to solve the problem that they were not able to solve themselves (Vygotsky 1962).

Liability:
1. Teachers and content experts will also need to provide worked examples for the problems they create.
2. The worked example may give away too much information (e.g., student would have already remembered the process if only two out of five steps were presented).
3. The online learning system will need to identify when to provide the worked example. Showing it too soon may take away possible learning opportunities, but showing it too late may no longer be helpful.

Evidence:

- *Literature*: Expert guidance can help students achieve difficult tasks within the Zone of Proximal Development, which they are unable to do on their own (Vygotsky, 1962). Worked examples are one way of guiding student learning. It gives a step-by-step demonstration of how to perform a task or solve a problem. It helps novice learners form basic knowledge structures, which they can use to acquire new knowledge and skills through practice (Clark and Mayer 2011).
- *Discussion*: Shepherds, writing workshop participants, and learning system stakeholders (i.e., data mining experts, learning scientists, and educators) agreed that the design pattern's solution could address the identified problem.
- *Data*: ASSISTments online learning system data showed that students rapidly requested for all available hints when they did not know how to solve the problem (i.e., based on hint request and answer correctness features). Students could have used hints as a proxy for worked examples, which showed them the entire procedure for solving the problem.

Example:

Worked examples are common strategies used in online learning systems to support student learning. Both Cognitive Tutor Algebra and Cognitive Tutor Geometry provide a button that students can click to request for a worked example (Aleven et al. 2006, Koedinger and Aleven 2007). The ASSISTments online learning system also supports the creation of worked examples for problem solving activities (Weitz et al. 2010). It gives content creators the flexibility in controlling where to attach the worked example and when to show it (e.g., hint, scaffold, scaffold on incorrect response).

Figure 4 illustrates an example of a geometry problem and an associated worked example. It shows a step-by-step process of solving for the angle *x*, but uses a different problem so as not to give away the answer.

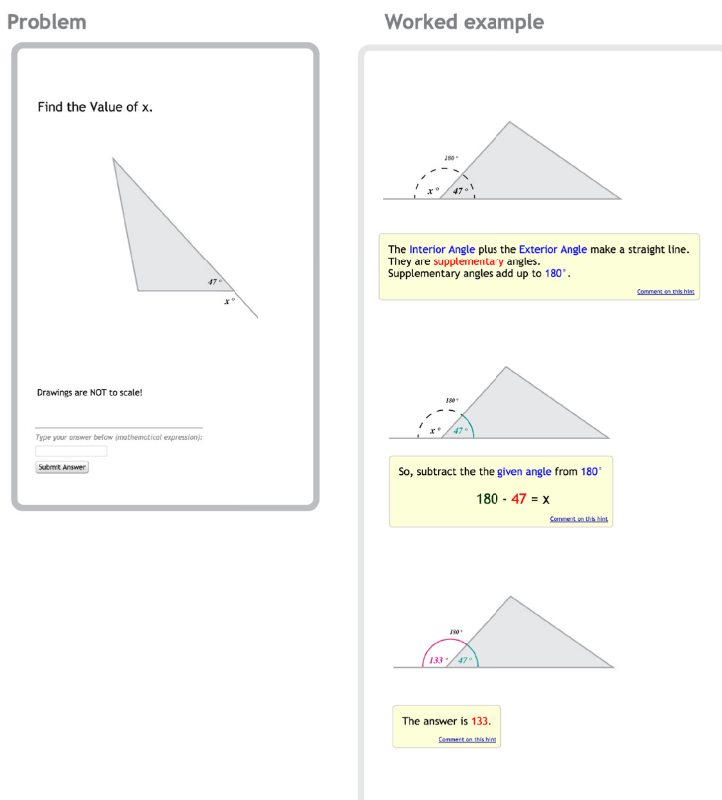
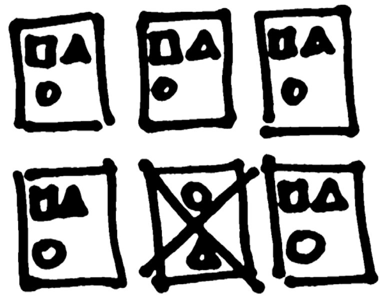


Fig. 4. A geometry problem with a corresponding worked example (Image courtesy of ASSISTments http://www.assistments.org).

Related Patterns: The **Worked examples** design pattern can be used to support student learning when they implement the **Try It Yourself**, **Different Exercise Levels**, or **Build and Maintain Confidence** design patterns (Bergin et al. 2012).

Consistent Language



Context: Students are asked to answer problem-solving activities on an online learning system to practice a skill. They are practicing problems with the **Try It Yourself** design pattern (Bergin et al. 2012). The system also provides students with support through feedback such as **Differentiated Feedback** (Bergin et al. 2012), **Worked Examples** (Inventado and Scupelli 2015a), and others.

Problem: Students are easily confused when terms, figures, or other elements of the problem or hint are used inconsistently.

Forces:
1. **Working memory.** Working memory can only hold a limited amount of information. Adding extraneous information unnecessarily increases cognitive load required to store information (Sweller, 2004). For example, using the × and • symbols interchangeably to indicate multiplication will require students to remember both symbols (Polya, 2014).
2. **Split-attention effect.** Unnecessary processing of information adds cognitive load that interferes with learning (Sweller 2004). For example, two different figures are used in the problem statement and in the hint, but they mean the same thing. This requires the student to compare and contrast the figures before using them to make inferences.
3. **Limited resources.** Student attention and patience is a limited resource (Arnold et al. 2005, Bloom 1974). Students may give up if they are overwhelmed by too many extraneous tasks they need to manage while learning.

Solution: *Therefore, use the same language throughout the problem.* The term "language" is used broadly to include different elements of the problem such as term usage, text formatting, color usage, notations, visual representations, and so forth.

Consequences:

Benefits:
1. Students need to keep track of less information in working memory.
2. Students do not need to spend unnecessary effort to discover the relationship between different representations used in the problem.
3. Straightforward tasks are easier to manage and are less likely to cause students to feel overwhelmed.

Liabilities:
1. There are some cases when inconsistent problem elements are needed to introduce desirable difficulty (Bjork 1994). For example, using a different figure in a **Worked Example**.
2. Students may not learn other representations if they are exposed to the same ones every time.
3. It is more difficult to reuse existing content because it needs to be modified to ensure that it uses a language consistent to the problem.

Evidence:
- *Literature:* Peterson and Peterson (1959) found that unfamiliar combinations of letters could only be held in memory for a few seconds. In a different study, Miller (1956) indicated that working memory could only

hold five to nine chunks of unfamiliar information at a time. Learners are more likely to perform better when working memory is not overloaded by unnecessary information (Sweller 2004).

- *Discussion:* Shepherds, writing workshop participants, and learning system stakeholders (i.e., data mining experts, learning scientists, and educators) agreed that the problem recurs in online learning systems and the solution could properly address the problem.
- *Data:* According to ASSISTments math online learning system data, frustration correlated with problems that used its elements inconsistently. For example, a math problem dealing with angles used the degree notation inconsistently – "Subtract the given angle from 180°. 180 - 47 = 133."

Example:

Most online learning systems adhere to instructional designs, specifically using a **Consistent Language**. Three notable online learning systems, which were also reported to lead to significantly better student learning, are Cognitive Tutor Algebra (Koedinger and Aleven 2007), Cognitive Tutor Geometry (Aleven et al. 2006) and ASSISTMents (Heffernan and Heffernan 2014).

Figure 5a shows an example of a problem and its corresponding hints with an inconsistent language. The hint uses a different figure, orientation, and color to represent the angle. Students will need to analyze the hint and relate it to the problem before it can be used to make inferences. Figure 5b shows an example of a problem and its corresponding hints that uses a consistent figure. It will probably take students less time to process, understand, and utilize these hints to make inferences.

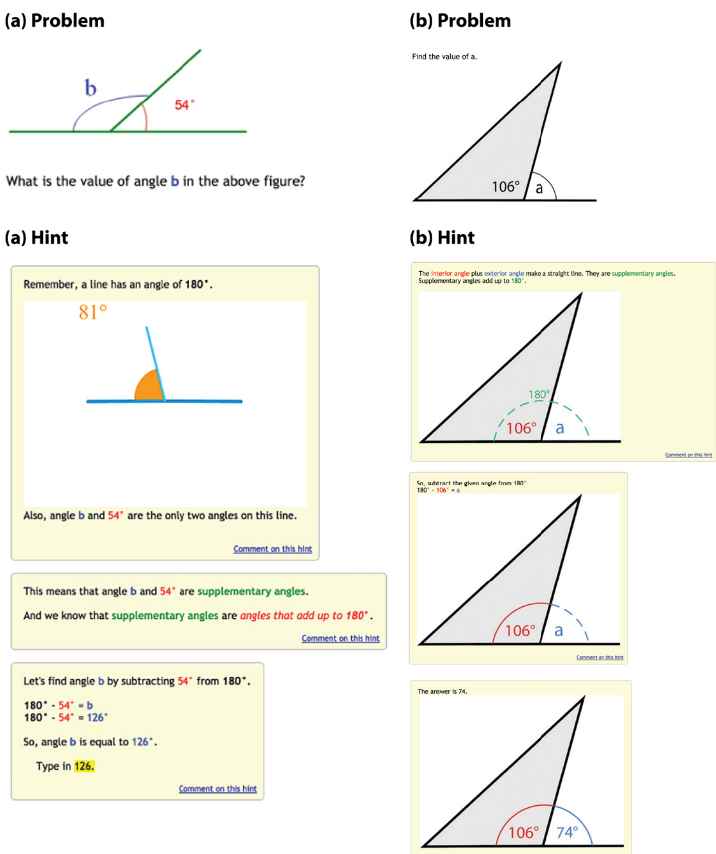


Fig. 5. (a) A problem that uses inconsistent images in the hints. (b) A problem that uses images consistently (Image courtesy of ASSISTments http://www.assistments.org).

Related Patterns: Use the **Familiar Language** design pattern when selecting the representation for creating a **Consistent Language** to facilitate understanding . It is good practice to use a **Consistent Language** to develop any type of content in an online learning system.

5. DISCUSSION

The 3D2P methodology differs from traditional design pattern mining and writing processes by producing design patterns from collected data. The methodology can address issues in maintaining the quality of online learning systems such as ASSISTments, which are complex, designed and developed by multiple stakeholders, used by diverse users, and rapidly changing as new technologies become available. Specifically, it supports prospecting, mining, writing, and evaluating patterns through data, provides concrete scenarios that stakeholders can use to collaborate in refining patterns, allows design patterns to be tested, and helps verify the quality of design patterns in actual use (see Section 3, Figure 2).

The pattern format used in the paper differs from commonly used formats by highlighting links to theory and empirical evidence. We believe such links promote better understanding of the problem, as well as how and why the solution works. It can promote interest and collaboration between stakeholders and pattern authors because it allows them to contribute to the pattern production process without being pattern experts themselves. For example, learning analytics experts can uncover recurring problems and effective design solutions from online learning system data. Pattern authors can use results from the data analysis to create design patterns. Teachers can then test the effectiveness of the design patterns in their classes.

The design patterns presented in the paper were primarily developed for the ASSISTments online learning system. However, the patterns were written so they can be used in other online learning systems as well. Specifically, the five patterns we present in this paper can guide teachers and content writers in ensuring the quality of online learning systems when they create new content or refine existing content.

6. SUMMARY AND NEXT STEPS

The paper discusses the application of 3D2P methodology in the production of online learning system design patterns. The resulting patterns can guide the development and maintenance of quality online learning systems. The selected pattern format contains links to theory and empirical evidence that could encourage stakeholders from different backgrounds to collaborate in the production and refinement of design patterns.

More design patterns are being developed with the 3D2P methodology on ASSISTments data. However, the complex and rapidly changing nature of online learning systems will result in the production of a large amount of design patterns that cannot be handled by a small team. There is a need for community effort in producing patterns. The authors are currently developing an open pattern repository that can facilitate collaboration between interested stakeholders in the production of online learning system design patterns (Inventado and Scupelli 2015a).

7. ACKNOWLEDGEMENTS

This material is based upon work supported by the National Science Foundation under Grant No. 1252297. We would like to thank David West, Christian Köppe, and Thomas Erickson for their invaluable advice and feedback in the development of our work. We would also like to thank Ryan Baker, Neil Heffernan, and their teams at Teachers College Columbia University and Worcester Polytechnic Institute for helping us analyze the data and gain insights on the methodology. We thank members of the Learning Environments Lab: Alexandra Merski for her help exploring the existing math problems, design of revised math problems, and help setting up the randomized control trials; and Rachael Chang for her help with the randomized control trials and visualization of the 3D2P process. We thank the Learning Environments Lab for providing all the design pattern images.

REFERENCES

Allen, E. and Seaman, J. 2008. Staying the course: Online education in the United States. Sloan Consortium, Needham, MA.

Aleven, V., Mclaren, B., Roll, I., and Koedinger, K. 2006. Toward meta-cognitive tutoring: A model of help seeking with a Cognitive Tutor. International Journal of Artificial Intelligence in Education, 16(2), 101-128

Anacleto J.C., Neto, A.T., and de Almeida Néris, V.P. 2009. Cog-Learn: An e-Learning Pattern Language for Web-based Learning Design. eLearn Magazine, 8, ACM, New York, NY.

Arnold, A., Scheines, R., Beck, J.E., and Jerome, B. 2005. Time and attention: Students, sessions, and tasks. In Proceedings of the AAAI 2005 Workshop Educational Data Mining (pp. 62-66).

ASSISTments. n.d. Retrieved February 1, 2015 from https://www.assistments.org/

Bergin, J., Eckstein, J., Völter, M., Sipos, M., Wallingford, E., Marquardt, K., Chandler, J., Sharp, H., and Manns, M.L. 2012. Pedagogical patterns: advice for educators. Joseph Bergin Software Tools.

Bjork, R.A. 1994. Memory and metamemory considerations in the training of human beings. In J. Metcalfe and A. Shimamura (Eds.), Metacognition: Knowing about knowing. (pp.185-205). Cambridge, MA: MIT Press.

Bloom, B.S. 1974. Time and learning. American psychologist, 29(9), 682.
Broderick, Z., O'Connor, C., Mulcahy, C. Heffernan, N., and Heffernan, C. 2012. Increasing parent engagement in student learning using an intelligent tutoring system. Journal of Interactive Learning Research 22, 4 (2012), Association for the Advancement of Computing in Education, Chesapeake, VA, 523--550.
Carnegie Learning. n.d. Retrieved February 1, 2015 from http://www.carnegielearning.com/
Cen, H., Koedinger, K. R., and Junker, B. 2007. Is Over Practice Necessary?-Improving Learning Efficiency with the Cognitive Tutor through Educational Data Mining. Frontiers in Artificial Intelligence and Applications, 158, 511.
Cerpa, N., Chandler, P., and Sweller, J. 1996. Some conditions under which integrated computer-based training software can facilitate learning. Journal of Educational Computing Research, 15, 345-368.
Clark, R. C. and Mayer, R. E. 2011. E-learning and the science of instruction: Proven guidelines for consumers and designers of multimedia learning. John Wiley & Sons.
Coursera - Free Online Courses From Top Universities. n.d. Retrieved February 1, 2015 from https://www.coursera.org/
Corbalan, G., Kester, L., and van Merrieonboer, J.J.G. 2008. Selecting learning tasks: Effects of adaptation and shared control on learning efficiency and task involvement. Contemporary Educational Psycholoy, 33, 733--756.
Cunningham and Cunningham Inc. 2014. Keep it Simple. Retrieved from http://c2.com/cgi/wiki?KeepItSimple.
Derntl, M. 2004. The Person-Centered e-Learning pattern repository: Design for reuse and extensibility. In World Conference on Educational Multimedia, Hypermedia and Telecommunications, Association for the Advancement of Computing in Education, Lugano, Switzerland, 3856--3861.
D'Mello, S., and Graesser, A. 2012. Dynamics of affective states during complex learning. Learning and Instruction, 22(2), 145-157.
Donnelly, C. J. 2015. Enhancing Personalization Within ASSISTments (Doctoral dissertation). Retrieved from: https://www.wpi.edu/Pubs/ETD/Available/etd-042315-135723/unrestricted/cdonnelly_thesis.pdf.
Frizell, S. and Hübscher, R. 2011. Using Design Patterns to Support E-Learning Design. In Instructional Design: Concepts, Methodologies, Tools and Applications, pages 114-134, Hershey, PA. USA. IGI-Global.
Heffernan, N.T. and Heffernan, C.L. 2014. The ASSISTments Ecosystem: Building a Platform that Brings Scientists and Teachers Together for Minimally Invasive Research on Human Learning and Teaching. International Journal of Artificial Intelligence in Education 24, 4 (2014), 470--497.
Hume, G., Michael, J., Rovick, A., and Evens, M. 1996. Hinting as a tactic in one-on-one tutoring. The Journal of the Learning Sciences, 5(1), 23-47.
Inventado, P.S. and Scupelli, P. 2015a. Towards an open, collaborative repository for online learning system design patterns. eLearning Papers, 42(Design Patterns for Open Online Teaching):14-27.
Inventado, P.S. and Scupelli, P. 2015b. Producing design patterns from big data in the ASSISTments online learning system. In Proceedings of the 20th European Conference on Pattern Languages of Programs. ACM, New York, NY.
Inventado, P.S., Scupelli, P., Van Inwegen, E., Ostrow, K., Heffernan, N., Baker, R., Slater, S., and Ocumpaugh, J. in preparation. Design Subtleties Driving Differential Attrition.
Koedinger, K. R., and Aleven, V. 2007. Exploring the assistance dilemma in experiments with cognitive tutors. Educational Psychology Review, 19(3), 239-264.
Koedinger, K. R., Anderson, J.R., Hadley, W.H., and Mark, M.A. 1997. Intelligent tutoring goes to school in the big city. International Journal of Artificial Intelligence in Education, 8, 30--43.
Li, S., Xiong, X., and Beck, J. 2013. Modeling student retention in an environment with delayed testing. Educational Data Mining 2013. International Educational Data Mining Society, 328--329.
Mendicino, M., Razzaq, L., and Heffernan, N.T. 2009a. Improving learning from homework using intelligent tutoring systems. Journal of Research on Technology in Education, 331--346.
Mendicino, M., Razzaq, L., and Heffernan, N.T. 2009b. A comparison of traditional homework to computer-supported homework. Journal of Research on Technology in Education (JRTE), 41, 3, 331--359.
Miller, G.A. 1956. The magical number seven, plus or minus two: Some limits on our capacity for processing information, Psychological Review 63: 81–97.
Mitrovic, A. 2012. Fifteen years of constraint-based tutors: what we have achieved and where we are going. User Modeling and User-Adapted Interaction, 22(1-2), 39-72.
Mitrovic, A., and Martin, B. 2004. Evaluating adaptive problem selection. In Adaptive hypermedia and adaptive web-based systems (pp. 185-194). Springer Berlin Heidelberg.
Morgan, P. and Ritter, S. 2002. An experimental study of the effects of Cognitive Tutor® Algebra I on student knowledge and attitude. Carnegie Learning, Inc., Pittsburgh, PA.
Mwangi, W. and Sweller, J. 1998. Learning to solve compare word problems: The effect of example format and generating self-explanations. Cognition and instruction, 16(2), 173-199.
Peterson, L. and Peterson, M. 1959. Short-term retention of individual verbal items, Journal of Experimental Psychology 58: 193–198.
Piaget, J. 1952. The origins of intelligence. New York: International University Press.
Polya, G. 2014. How to Solve It: A New Aspect of Mathematical Method: A New Aspect of Mathematical Method. Princeton university press.
Rohrer, D. and Taylor, K. 2006. The effects of over-learning and distributed practice on the retention of mathematics knowledge. Applied Cognitive Psychology, 20, 1209--1224.
Salden, R.J.C.M., Aleven, V., Schwonke, R., and Renkl, A. 2010. The expertise reversal effect and worked examples in tutored problem solving. Instructional Sicience, 38, 289--307.
Salden, R. J., Paas, F., Broers, N. J., and Van Merriënboer, J. J. 2004. Mental effort and performance as determinants for the dynamic selection of learning tasks in air traffic control training. Instructional science, 32(1-2), 153-172.
Sarkis, H. 2004. Cognitive Tutor Algebra 1 Program Evaluation: Miami-Dade County Public Schools. The Reliability Group , Lighthouse Point, FL.
Sweller, J. 2004. Instructional design consequences of an analogy between evolution by natural selection and human cognitive architecture. Instructional science, 32(1-2), 9-31.

Sweller, J., Chandler, P., Tierney, P., and Cooper, M. 1990. Cognitive load as a factor in the structuring of technical material. Journal of Experimental Psychology: General, 119(2), 176.

Van Duyne, D.K., Landay, J.A. and Hong, J.I. 2007. The Design of Sites. Prentice Hall, Upper Saddle River, NJ.

Vygotsky, L. S. 1962. Language and thought. Massachusetts Institute of Technology Press, Ontario, Canada

Weitz, R., Salden, R. J. C. M., Kim, R. S., and Heffernan, N. T. 2010. Comparing worked examples and tutored problem solving: Pure vs. mixed approaches. In Proceedings of the Thirty-Second Annual Meeting of the Cognitive Science Society (pp. 2876-2881).

Whorton, S. 2013. Can a computer adaptive assessment system determine, better than traditional methods, whether students know mathematics skills? Master's thesis, Computer Science Department, Worcester Polytechnic Institute.

Yudelson, M. V., Koedinger, K. R., and Gordon, G. J. 2013. Individualized bayesian knowledge tracing models. In Artificial Intelligence in Education (pp. 171-180). Springer Berlin Heidelberg.