Formative Self-Assessment for Customizable Database Visualizations: Checkpoints for Learning

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Abstract

A formative self-assessment opportunity has been added to database visualizations, which are designed to introduce students of many majors to fundamental database concepts. Instructors can customize the example and text within the animations so that database concepts can be presented within the context of their discipline. The formative self-assessment is called a *checkpoint*, which is based on database terminology for checking the state of the database. Checkpoints for learning provide students with the opportunity to check the status of their learning. Using the results of prior research on formative self-assessment, the design of the checkpoints includes true/false and multiple-choice questions targeted to assess the learning objectives of the animations. Feedback to the students on their progress and correctness are visually integrated within the checkpoints. In addition, a preliminary evaluation of the student's perspective of the checkpoints for learning indicates that students find them quite helpful and an important learning component of the animations. This paper also includes a discussion of techniques for using the formative self-assessment as part of a class setting as well as future research directions.

Introduction

The goal of the "Databases for Many Majors" project (Dietrich & Goelman, 2017) is to introduce the fundamental concepts of database technology to students of many majors through the use of animations that provide a visualization of the concepts using an engaging approach. Two animations have been developed. The first animation, referred to as IntroDB, introduces students to relational databases and their similarities/differences with familiar spreadsheets. Important database concepts introduced in this animation include the definition of primary and foreign keys, and how databases use these keys to answer questions, called queries, over the data stored in the database. The second animation, known as QueryDB, provides more depth on queries by introducing students to important operators (e.g., sets, filtering, and joins) for getting information from a database and ultimately, students learn the SQL industry standard query language. The animations were used in various courses and supported by cooperative learning exercises, as encouraged by (Naps et al, 2002). The initial evaluation of the animations (Dietrich et al, 2015) indicates that the animations support student learning.

An important component of the animations is their support for customization. Instructors can change the example and supporting text of the animations for use in their discipline. The initial animations supported customization using raw XML (eXtensible Markup Language) technology, which is not necessarily intuitive to other disciplines. Therefore, the customization of the animations has been revised to be integrated within each animation, allowing the customizer to see the personalized animation as it develops. This customization process still uses XML technology, with the resulting XML file being sent in for curation before posting the customized animation on the project Web site. Currently, there are customizations of the animations for astronomy, computational molecular biology, environmental science/ecology, geographic

information systems, and statistics. The project is ongoing and current efforts include the development of an additional customization tool to assist in the process of designing the database instance.

A major benefit of the animations is their accessibility for learner review even outside the classroom. This is particularly significant in the current pedagogical environments of evidence-based learning, especially when the flipped classroom approach is used. To increase the applicability of the animations to this pedagogy in support of student learning, a formative self-assessment component has been added. Paralleling the definition of a database checkpoint, which logs information about the state of the database, the *checkpoint* feature of the animation provides students with the opportunity to reflect on the state of their learning. The checkpoint includes multiple choice and true/false questions that assess the various learning outcomes of the animation. Students are given feedback on the correctness of their answer and an explanation of the correct answer with an indication of the topic to review in the animation for the assessed concept. Students can return to the checkpoint at any point in their current session to continue their progress through the questions. Although feedback and progress status are given to the students, it is important to note that these checkpoints provide formative self-assessment and are not intended to be a computer-assisted learning system that adjusts to the student's understanding.

The recently introduced checkpoints have been well received both by students and by instructors using the customizable animations. This paper overviews some of the literature on formative assessment and then details the design of the checkpoints for the animations, which was informed by the presented research on formative assessment. The paper also presents a preliminary evaluation of the student's perception of the checkpoints, including a discussion of the context in the use of the animations in the class settings of the evaluation. The paper concludes with a consideration of future work regarding the checkpoints.

Formative Self-Assessment

Formative self-assessment has been an important component in evidence-based pedagogy for some years now. Formal definitions of self-assessment in general and formative self-assessment in particular are provided, for example, by (McMillan & Hearn, 2008) and (Ross, 2006). The former reference considers self-assessment to be "self-monitoring, self-evaluation, and identification and implementation of instructional correctness." Formative self-assessment adds the dimension of feedback during learning (McMillan & Hearn, 2008). The latter, agreeing with (Klenowski, 1995), defines self-assessment as "the evaluation or judgment of 'the worth' of one's performance and the identification of one's strengths and weaknesses with a view to improving one's learning outcomes " (Ross, 2006). It should include students' evaluations of themselves for the sake of improvement. Ross does distinguish between "self-evaluation," where the evaluation actually counts towards the student's grade, and "self-assessment," where it does not.

The literature also contains recommendations for implementation. Although concentrating on mobile environments, (Koorsse, Olivier, & Greyling, 2014) makes several points that would hold in the more general setting as well. For example, it recommends that performance goals be

explicit, that the feedback during assessment be always present and visual, and that there should be a focus on the gap between current knowledge and the desired goal. (McMillan & Hearn, 2008) agrees that correct implementation needs goal orientation. (DePaolo & Wilkinson, 2004) finds that the results are better when self-assessment results actually count towards the student's grade, such as a required quiz.

In terms of assessment instruments, several sources support the proper use of multiple-choice questions ("mcq's"). The checkpoints described in this article consist of *true/false* and more general mcq's. (Ding & Beichner, 2009) proposes five approaches for analyzing mcq data. (Nicol, 2007) addresses the limitations of the approach, which are generally due to the insufficiency of links to a clear pedagogical goal. It further recommends seven feedback principles, supported by research and case studies, which includes high-quality feedback. Practical suggestions and guidelines for mcq's, including a checklist, appear in (Burton, Sudweeks, Merrill, & Wood, 1991).

When formative self-assessment is administered correctly, the research indicates good prospects for success. According to (McMillan & Hearn, 2008) self-assessment "stands alone in its promise." (Black & Wiliam, 1998) states that "there is substantial evidence that appropriate formative assessment activities relate positively to student motivation and achievement." (Schunk, 1989) and (Zimmerman, 1989) have conducted studies that show the benefit of self-reporting. Besides the contributions of (Ross, 2006) mentioned earlier, that paper also cites improvement when students have been guided appropriately; it also indicates when negative results could occur and concludes that, on balance, self-assessment has a positive effect. The (Boud, 2005) book enumerates eight major uses of self-assessment, among them "individual self-monitoring and checking progress" and "learning activity designed to improve professional or academic practices." (Koorsse, Olivier, & Greyling, 2014) recommends self-assessment highly and cites the finding in (DePaolo & Wilkinson, 2014) that it promotes better attendance, participation and performance when it is required and reflects clear goals.

The research on formative assessment has informed the development of the checkpoint feature in the database animations. In particular, the design of the checkpoints includes the proper use of multiple-choice questions and high-quality feedback.

Checkpoint Design

The content of the checkpoint questions is strongly influenced by the existing framework of the pre- and post- tests for the assessment of learning (Dietrich et al, 2015). For both the IntroDB and QueryDB animations, the questions that assess student learning are related to categories of assessed concepts, which are shown in Table 1 for each animation. Questions range from high-level concepts to specific details in identifying data for answering queries or missing parts of an SQL query.

Table 1. Categories of Concepts Assessed in the Two Animations

IntroDB Category	QueryDB Category
Spreadsheet Anomalies	Set Operations
Database Anomalies (None)	Filtering operations
Primary Keys	Join operations
Foreign Keys	SFW Concepts
Data for Queries	SQL Queries

The checkpoint questions are either multiple-choice or true/false. The questions are randomized for presentation to the student, including a randomization of the choices for multiple-choice questions. A progress bar shows the percentage of questions that the student has answered correctly. Initially, this reads 0%. Since there are currently 20 questions in each checkpoint, the progress will increase by 5% for each correct answer. Students are not forced to answer the current question on the screen. There is a Continue button on the bottom right that allows students to progress to the next random question, with or without having answered the current question.

Figure 1 provides samples of a multiple-choice checkpoint question from IntroDB and a true/false question from QueryDB, illustrating the feedback on a correct and incorrect answer, respectively. Upon answering a question, the animation provides visual feedback of correctness with a green checkmark, if correct, or a red X, if incorrect. In either case, there is an explanation of the correct answer provided as additional feedback along with the location in the animation that this concept appears, which is indicated by a colorful icon of an exclamation mark (!) in order to gain the attention of the student. In Figure 1a, from the IntroDB animation, students are instructed to review the Queries topic from the beginning. In Figure 1b, from QueryDB, the SQL | Where indicates that students should review the animation at the Where discrete step within the SQL topic. The animation is designed to allow the learner to return to the checkpoint by clicking on the Checkpoint topic, after the self-review, to continue working on the questions that they have not yet answered correctly.

The checkpoint questions are also customizable to the discipline example being presented within the animation. As mentioned earlier, the customization process is integrated within the animation and uses XML technology to store the discipline-specific information for customization. The screenshots in Figure 1 illustrate that each customizable checkpoint question has space allocated for the specification of the question, its choices, the feedback to be presented, as well as the location in the animation for reviewing that concept. By integrating the customization in the animation itself, the customizer can see exactly how the question specification and feedback fit within the space allocated. The animation will use scroll bars to present the information if required.

a. IntroDB Multiple-Choice Question answered correctly

b. QueryDB True/False Question answered incorrectly

Figure 1. Samples of Checkpoint Questions and Feedback

Evaluation: Context

Based on teaching assignments at their respective universities, the authors used the checkpoints for learning for the first time in their classes for computer science majors. One author used the animations within an introductory database class; the other author used the animations to quickly review fundamental database concepts within an advanced database class. This section overviews the use of formative self-assessment within these settings.

In the introductory database class, the author did a quick demonstration of each animation at the appropriate point in the curriculum. This included the checkpoint topics, which were recommended as optional, but likely useful, study aids. Furthermore, the IntroDB animation has topics that span two parts of the syllabus: (1) The structure of relational databases, including primary and foreign keys, appears early on. (2) The advantages of relational databases in helping to avoid anomalies, are discussed in detail in the unit on normalization. That animation, along with its checkpoint questions, was therefore recommended as part of the study guide for the later unit as well.

In the advanced database class, the animations presented the opportunity for students to review the expected knowledge from the prerequisite class. The class has a participation component that includes attendance, punctuality, and exercises. In the first week of the semester, each of the animations was assigned as a review exercise where students self-reported their score by submitting a screen capture of their checkpoint progress from the animation. The exercise rubric was a total of 4 points, allowing for ranges of participation points based on the score submitted. The use of a performance goal is strongly recommended for formative assessment to promote class attendance and participation (Koorsse, Olivier & Greyling, 2014). In addition, the literature ((Schunk, 1989) and (Zimmerman, 1989)) suggests that self-reporting learning can improve student performance.

Another recommendation from the research study in (Koorsse, Olivier & Greyling, 2014) for a formative assessment is to make sure that the solutions and feedback for assessment should always be present and visual. If these components are optional or user-selected, some students did not take advantage of the information. In the checkpoint feature of the animations, the detailed feedback of the solution to the question is always presented to the learner in conjunction with a visual clue regarding the correctness of their selected answer. The visual clue, the green checkmark or red X, is also an important feedback component as studied in (Kumar, 2015).

Evaluation: Results

The classes were given a simple survey that included one Likert scale question and an open-ended question. Since the authors taught only database classes to computer science majors, the results represent the use of the animations to introduce database concepts before delving more deeply in a first database course as well as a review of the database concepts for an advanced course on database systems.

The students were asked the following question with the response on a Likert scale of Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree: *The checkpoints in the animations are an important learning component of the animations*. Table 2 shows the results broken down by class and as a total of both classes. Overall, the results illustrate a positive response to the checkpoints within the animations; 21/25 or 84% of the students Agree or Strongly Agree with the statement and only 4/25 or 16% were Neutral. None disagreed with the statement.

Table 2. Likert question on Checkpoints

Question	*The checkpoints in the animations are an important learning component of the animations*.				
Class	**Strongly Agree**	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**
Introductory Database	2	9	4	-	-
Advanced Database	8	2	-	-	-
Totals	10	11	4	0	0

An open-ended question was also included in the simple survey: *Please provide feedback on the checkpoint component of the animations*. There were some interesting student responses from the introductory database class, emphasizing the importance of the formative assessment from the student's perspective.

- I need to be asked questions to see what I understand by myself, the checkpoints were very helpful for this. It's easy to go through it quickly and think "yea, I get it" but the checkpoints make you prove to yourself that you do. I think they are very important.
- The checkpoints provide great opportunities for students to quiz themselves on what they observed. In addition, the text provided after a student answers is also very helpful, as it reinforces what the student learns (if answered correctly) or explains the error that was made (if answered incorrectly).

The advanced database class had not been exposed to the animations before using them for review and shared their perspective:

- The questions in the checkpoint assessment were difficult enough that I had to reiterate what I learned by going back to through the animated course but not too difficult that I could not arrive at an answer. The animations were extremely helpful, had I had these animations when I first started learning databases it might have enabled me to come to a better understanding of the material quicker. I learned in a similar way last semester by printing out the tables in the db we were working on and marking them similar to the animations. Overall, the animations provide a great way to learn the material.
- I appreciated this for a review. I found it to be resourceful and wanted to work on it more after completion.

Figure 2 provides a qualitative content analysis of the open-ended responses by two coders using an inductive, data-driven approach. There are 3 major categories resulting from the coding of the
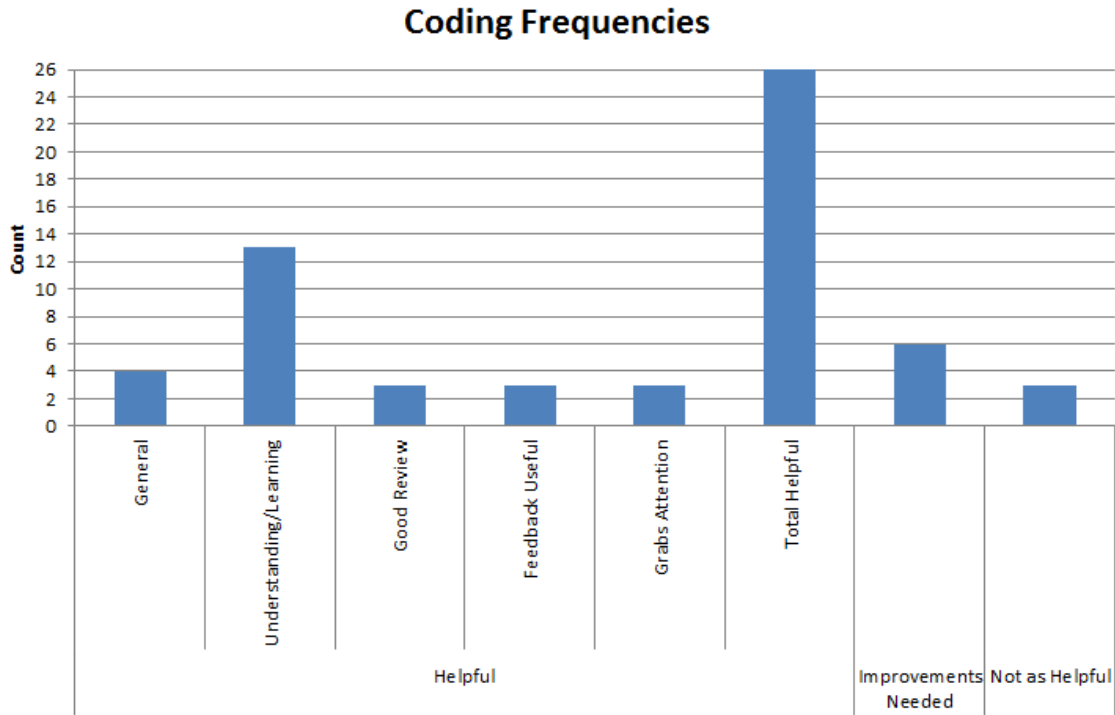
Figure 2. Qualitative Content Analysis of User Responses to Checkpoints

questions: Helpful, Not Too Helpful, and Needs Improvement. Subcategories are introduced for the Helpful category, recording how the student thought that the checkpoints are helpful: understanding/learning, feedback useful, good review, grabs attention. There are 3 responses that are categorized as Not Too Helpful, which included the following phrases "better than nothing," "did not use," and "not my style of learning." In particular, there were several students who specifically provided input that were categorized as Needs Improvement:

- The checkpoints are helpful in testing and reinforcing the concepts learned. One additional feature that would be helpful is to add pictures of the visual schema for the respective problems to aid in the memory of the tables and their relations. This would also better reflect the understanding of the user. Overall, great resource and a fine way to first approach learning about relational databases.
- They are good exercises but I think we need to see the RDB schema to solve them, I personally could not remember it for some questions.
- If you got one wrong it obviously made you review the information in your head and it re-asked it again later on as you went through them. My only problem was when it referred to information previously shown but was not available on the screen and I could not remember it. It would have been good to have a pop up window to look at the information the checkpoint component was referring to.

This student feedback has already been incorporated into the animations available on the project Web site. In the checkpoints, there is a Show button that pops up the necessary information. In the IntroDB animation, the Show Tables button shows the tables, including their data, with the

indications of primary and foreign keys. In the QueryDB animation, the Show Schema button shows the abstraction of the database without data, including table and attribute names along with the primary and foreign keys. Another change that has been incorporated into the animations based on initial feedback from this study is the ability to click on the topic indicator next to the exclamation mark, which will directly take the student to that location in the animation for review of that concept.

Conclusions

The research literature strongly indicates the benefits of formative assessment activities with respect to stronger student motivation and higher achievement ((McMillan & Hearn, 2008) and (Black & Wiliam, 1998)). Instructors and students are partners in the learning endeavor. Instructors are responsible for designing appropriate learning and formative assessment activities, and students are responsible for conscientiously taking advantage of these opportunities.

The additions of the checkpoints for learning in the visual animations for database concepts are formative assessment opportunities that both students and instructors appreciate. The preliminary evaluation of the checkpoints presented in this paper were based on a student's perspective of their usefulness. The anticipation is that the checkpoint feature will support evidence-based pedagogy, such as a flipped classroom. Future research plans also include the evaluation of pre- and post- assessment data to further examine the effect of the checkpoints on student learning.

As stated earlier, this project is ongoing. Since the study presented in this paper, a third animation, DesignDB, has been released. This animation introduces students to the conceptual modeling of data and how that visual design can be mapped to a relational schema for the storage and querying of data. Customization has also been integrated within this animation as well as the checkpoint feature.

The checkpoints are designed for formative assessment so that students can adjust their understanding of their learning during the animation. In informal discussions with instructors, there have been requests for more information being able to be self-reported by students. From the instructor viewpoint, they want to know what concepts the students are finding difficult to understand so that they can tailor their coverage in class to address those fuzzy points. Further research will hopefully illuminate a path that can balance the goal of formative assessment with the instructor's request for additional information beyond a simple score.

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