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Designing an Educational Game (Heroes of Math Island): An Exploratory Study of Emotion and Learning

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Abstract

In response to the need for more empirical research with respect to emotion and learning, this study provided an empirical investigation of the students' interaction with an educational game, *Heroes of Math Island*, specifically designed for this study. The purpose of this study was to explore learners' emotional states triggered during gameplay with the goal of providing critical information needed for the design of advanced learning technologies (ALTs) and intelligent tutoring systems (ITSs). The study used the design-based research (DBR) paradigm by combining exploration with design, and mixed methodologies including: pretest, intervention (gameplay), posttest, post-questionnaire, and interview. Fifteen students (seven boys and eight girls) from grades six and seven participated in this study. Findings report on heuristics of educational technology design, emotion, and learning.

1. Objectives

Educational technologies like advanced learning technologies (ALTs) and intelligent tutoring systems (ITSs) enhance teaching and learning by adapting to the learners' needs and by providing individualized support and guidance. According to Aleven, Beal, and Graesser (2013), advanced learning technologies (ALTs) are:

> [1] created by designers who have a substantial theoretical and empirical understanding of learners, learning, and the targeted subject matter… [2] provide a high degree of

> interactivity, reflecting a view of learning as a complex, constructive activity on the part of learners that can be enhanced with detailed, adaptive guidance… [3] capable of assessing learners while they use the system along different psychological dimensions, such as mastery of the targeted domain knowledge, application of learning strategies, and experiences of affective states (pp. 929–930).

This research study involved the design and implementation of an educational game (*Heroes of Math Island*) and an exploration of the students' interaction, focusing on emotions experienced during gameplay. In this current implementation, the *Heroes of Math Island* game meets many of the criteria for an ALT device. Results from this study will be used for extending the game by including adaptive guidance, and recognition and response to the cognitive and emotional needs of learners.

The DBR methodology used in this study is suitable for studies of ALTs and ITSs in that it blends "empirical research with the theory-driven design of learning environments" and helps educational researchers understand "how, when, and why educational innovations work in practice" (Design-Based Research Collective, 2003, p. 5).

Understanding emotional reactions and responses with respect to ALTs and ITSs is extremely timely and relevant for teaching and learning in digital or virtual (e.g., gaming) environments taking in consideration that technology is now ubiquitous in schools and in students' lives. As Petrina argued, teachers should recognize the importance of technology in the classroom as well as the feelings and values of students: "Our task [as instructional designers and teachers] is to validate, direct, and transform the emotion in our students' experiences" (Petrina, 2007, p. 59). Similarly, designers of educational technologies should recognize the importance of learners' emotions because of the strong interrelation between cognition, emotion, learning, and motivation.

2. Theoretical Framework

Three theoretical frameworks are most relevant to this dissertation: emotion theory, emotion and learning, and affective computing. In this paper, the terms "affect," "affective state," and "emotion" are used interchangeably.

Many contemporary scientists and theorists define emotion in the context of cognition and motivation (LeDoux, 1995; Ortony & Turner, 1990; Plutchik, 1984; Rolls, 1995). Cognitive processes are complemented by motivational systems responsible for identifying needs and setting goals, and by emotional systems enabling relationships with the world, perception of surroundings, responses to stimuli, and communication. Amygdalae, areas of the brain that process emotions, are also concerned with learning (LeDoux, 1995). LeDoux (1995) is Socratic or Platonic when noting that cognition "historically has been thought of as part of a trilogy of mind that also includes emotion and will (motivation) rather than as an all-encompassing description of mind" (p. 226), and Ortony and Turner (1990) argued that emotion has cognitive representation and is "causally related" to motivation (p. 318). According to LeDoux (1996), "once emotions occur they become powerful motivators of future behaviors. They chart the course of moment-to-moment action as well as set the sails toward long-term achievements" (p. 20).

To what extent does a specific emotion affect learning? Memorization, judgment, and choice are key aspects of learning processes and are also heavily influenced by emotion. For example, we know that emotion is beneficial because it drives attention, which in turn drives memorization.

Confidence creates a disposition to learn as opposed to negative emotions such as anxiety, grief, and dejection, which can prevent learning, leading to inactivity and isolation (Ingleton, 2000). Frustration can lead to a "vicious circle" resulting in boredom and a disengagement from learning (D'Mello, Taylor, & Graesser, 2007).

The relationship between emotion and learning is documented in educational literature. Astleitner (2000) empirically validated his theoretical instructional design approach employing five emotions—fear, envy, anger, sympathy, pleasure (FEASP)—and demonstrated the existence of a significant correlation between sympathy and pleasure-related instructional strategies and corresponding emotions. Ingleton (2000) analyzed interactions that give rise to emotions of pride or shame. "Accompanying these emotions are positions of solidarity or distance, attendant with confidence or fear. Together these are the basis of decision making, conscious or unconscious, about immediate or future action" (p. 88). The mood-congruence hypothesis, proposed by Bower, (1981) is based on the idea of cognitive networks and predicts that mood congruence affects cognitive processes: information with a positive content (e.g., feedback from a successful exam) is easily recalled when one is in a positive mood. Similarly, negative information is recalled when one is in a negative mood. Hascher (2010) also stated that a positive environment is an "optimal precondition for holistic and creative thinking as it does not force the learner to cope with the situation but enables open-mindedness" (p. 15). However, this is a simplistic approach and the "valence of a mood or an emotion (being positive or negative) is only one aspect of its quality" (Hascher, 2010, p. 16).

Overall, educational research lacks empirical and theoretical studies of emotion and learning (Astleitner, 2000; Ingleton, 2000; Hascher, 2010). Criticizing this situation, Hascher (2010) argued that "there are a handful of limited but very interesting theories but we need more empirical evidence about them, we need to investigate the effects of different emotion qualities, and we need to figure out the range of their validity" (p. 16).

Past research related to intelligent tutoring systems (ITSs), addressed cognitive tutors and privileged cognitive over affective needs, observing learning as information processing and "marginalizing affect" (Woolf, et al., 2009, p. 129). However, more attention has been recently given to emotion. Studies of emotion in the context of interaction with ITSs have been employed by several research groups (Baker, D'Mello, Rodrigo, & Graesser, 2010; Conati & Maclaren, 2009; Derbali, Ghali, & Frasson, 2013; D'Mello, Taylor, & Graesser, 2007; Rodrigo, et al., 2012).

3. Methodology and Procedure

Following the DBR paradigm, this study combined exploration with design and employed triangulation mixed methodology (Gay, Mills, & Airasian, 2006) consisting of (1) a quasi-experimental study (pretest, intervention, posttest, followed by post-questionnaire and interview) and (2) affect analysis (emotion-labeling process and video annotations) performed by two trained judges. This paper focuses on the quasi-experimental study; the methodology and the findings related to affect analysis were presented in details in Gutica & Conati (2013).

3.1. Design-Based Research and Game Design

DBR is characterized by theory-driven pedagogical intervention and instructional design implemented and evaluated in real-world situations (Joseph, 2004). Sometimes called design experimentation, DBR "simultaneously pursues the goals of developing effective learning environments and using such environments as natural laboratories to study learning and teaching" (Sandoval & Bell, 2004; p. 200). Sandoval and Bell (2004) noted that on the design side, researchers draw from the “fields of computer science, curriculum theory, instructional design, and teacher education” and on the research side, they draw from multiple disciplines, including “developmental psychology, cognitive science, learning sciences, anthropology, and sociology” (p. 200). Converging experiments with design is an important characteristic of DBR.

The mathematics game *Heroes of Math Island* is intended for students in grades five through seven. Based on my observation and classroom practice, this age group is suitable because, at this stage, students start learning more complex concepts and also enjoy playing games. Several other studies with similar games also targeted this age group (Conati & Maclaren, 2009; Conati & Manske, 2009; Rodrigo, et al., 2008; Rodrigo, et al., 2012). *Heroes of Math Island* was implemented on the XNA professional gaming platform (a runtime environment provided by Microsoft for game development) that allowed for implementation of rich game mechanics. Players’ interaction in *Heroes of Math Island* is rich, comparable to that of commercial video games, including to Crystal Island, the game used by McQuiggan, Robinson, and Lester (2008). *Heroes of Math Island* also has aspects inspired from *Prime Climb*, an educational game for number factorization (Conati, 2002; Conati & Maclaren, 2009; Conati & Manske, 2009).

Components of the game’s development have been funded through Dr. Petrina’s SSHRC SRGs at the University of British Columbia (UBC) and the VP Research Seed Fund at British Columbia Institute of Technology (BCIT). As well, a group of BCIT students participated (under supervision) in designing and programming this game. The game design and implementation had several prototypes and iterations that were evaluated in presentations and brainstorming sessions with graduate students from UBC and students from BCIT. A graphics artist was hired to create the game graphics and animations. Game design started in June 2010, and the game was ready for data collection in March 2012.

Design was based on several principles of game design: avatars, non-player characters (monkey, queen, king, etc.), content (a narrative accompanying each task), control (players use the keyboard and the mouse to navigate through the game), repetition (a player repeats a set of actions for mastering a task), and levels of difficulty (the game's level of difficulty increases over time) (Salen & Zimmerman, 2004). Several instructional design principles employed in classroom practice were used in the game's design: defining learning objectives, planning learning activities, assessment and evaluation, and knowledge construction.

Heroes of Math Island was designed with five possible challenges or "quests": forest, mine, mountain, seashore, and swamp (Figure 1). Each quest is intended to have a set of activities. For this version of the game, only the mine quest was designed and implemented. The mine quest was constructed based on learning outcomes involving prime numbers and factorization in accordance with British Columbia Ministry of Education Guidelines for grades five through seven (Ministry of Education Curriculum, 2011). Three activities were implemented: divisibility, prime numbers, and decomposition.

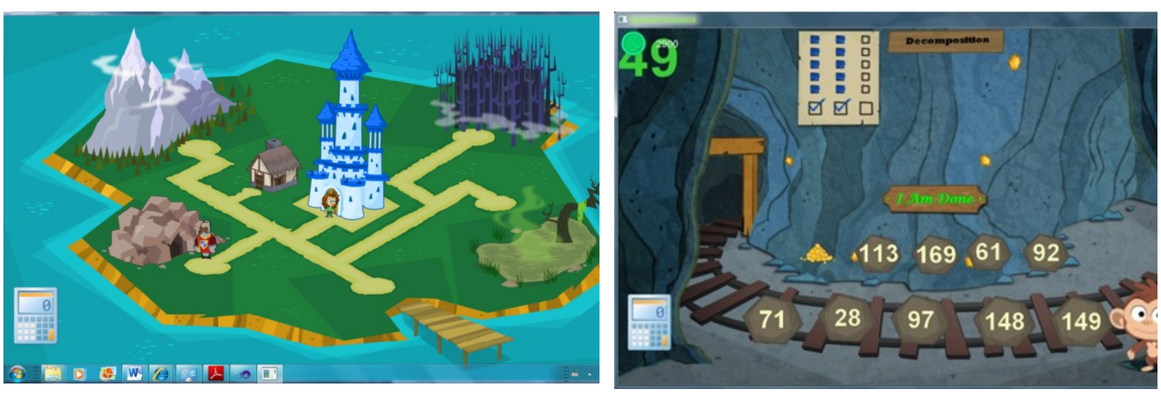

Figure 1: Heroes of Math Island

Mathematics content for the game was chosen for various reasons, including my background in teaching mathematics. The game was designed based on usability studies involving one grade six student, one mathematics teacher for grade six (two studies), and two instructional designers.

The metaphor used for the mine quest is that miners are sick and need help. Rocks represent numbers: prime numbers are hard rocks that cannot be broken and should be separated. Composite numbers can be broken with picks.

The game includes an emotional agent, represented by a monkey character (see Figure 1). The monkey uses emotional expressions to respond to the student's performance in the game. For this study, the monkey displays a neutral state, two positive (happy and confident) emotional states, and two negative (sad and frustrated) emotional states. Happy and sad indicated a small change in the student's performance, while frustration or confidence indicated a more persistent situation. The emotional state displayed by the monkey is based on the student's score.

3.2. Quasi-Experimental Study

The quasi-experimental study consisted of pretest, intervention, posttest, followed by post-questionnaire and interview. Fifteen grade six and seven students (seven boys and eight girls) participated in this study. The mean age was 11.4 and the median age was 11.

I conducted the experiments together with three other observers (BCIT students working as research assistants who were knowledgeable of this study and involved in the design and implementation of the game). They observed the experiments and participated in the emotion-labeling process and video annotations as judges. The protocol used for experiments included a short tutorial given by one of the observers to bring participating students to the same level of mathematical knowledge, followed by the experiment: pretest, gameplay, posttest, post-questionnaire, and interview. Total time for an experiment was 1-½ to 2-½ hours, and the time used for gameplay was 15 to 48 min (M = 32.3 min; SD = 10.3 min). The game interaction was videotaped (one video camera recorded the student's face and one recorded the computer screen). The pre- and posttests were similar but not identical and contained 23 questions (12 divisibility, 5 prime numbers, and 6 number decompositions). When students had questions, they asked the observers.

The post-questionnaire was adapted from one used in *Prime Climb* studies (Conati & Maclaren, 2009; Conati & Manske, 2009). The adapted post-questionnaire was composed of 48 Likert-scale and five open-ended questions regarding emotions, the general game experience, and learning.

4. Findings

Based on affect analysis described in details in Gutica & Conati (2013), twelve emotions were observed in videos of 15 study participants and were classified by two judges from the team of observers. These twelve emotions were boredom, confidence, confusion/hesitancy, curiosity, delight/pleasure, disappointment/displeasure, engaged concentration, excitement, frustration, pride, shame, and surprise. Several conclusions resulted from affect analysis (percentage values refer to average between the two judges): students were merely engaged: engaged concentration was observed 79% of the time, confidence 37% of the time, confusion/hesitancy 26% of the time, frustration 5% of the time, and boredom only 1.5% of the time (Gutica & Conati, 2013).

4.1. Game Mechanics

In order to evaluate the students' reaction to the design of the game, I computed a summative histogram, with results from five questions related to game mechanics (e.g., aspects of the game related to the avatar; castle; ending the quest and rocks' animations). The analysis concluded that only a small percentage of responses were not favorable: 68% of responses to the five statements from 15 students indicated that students agreed or strongly agreed (18.7% strongly agreed and 49.3% agreed); 26.7% were neutral; and only 5.3% disagreed or strongly disagreed (4% disagreed and 1.3% strongly disagreed). These results are optimistic, indicating that the game mechanics currently implemented in the game are adequate and attractive for this age group (see Figure 2).

Figure 2: Summative game mechanics

Students were asked in interviews what improvement would they suggest. Their suggestions were toward adding more content to the game (quests), and including awards and leaderboards. Suggestions were also related to game mechanics that are characteristics to video games targeting this age group, like collecting items and "dressing their avatar."

A majority of students, 78.6%, considered this game to be more interesting than other mathematics games; however, they did not find the game more interesting than video games. Even if the perception of students was that the game is not more interesting than a video game, it was satisfying to learn that it was considered better than other mathematics games.

4.2. Attitude Towards the Game

Two questions intended to investigate the students' interest in the game: "I would like to play the game again" and "This game is boring" complemented each other. Interestingly, these questions were responded to symmetrically, with a similar majority of 73.3% supportive responses (see Figure 3). The two students who were neutral to the question related to playing the game again disagreed with the statement that the game was boring. I concluded that their lack of interest in future play was caused by something other than boredom. One student, who strongly agreed with the statement that the game was boring was completely non-interested in any mathematical game; however, observers indicated that she demonstrated a high level of engagement and also her test score improved by 4.3% (from 78.3% in pretest to 82.6% in posttest).

Figure 3. “This game is boring.” / “I would like to play again.”

The response to the statement “I would like to see more quests” was almost unanimously positive. All but one student agreed or strongly agreed that they would like to see more quests (see Figure 4).

Figure 4. “I would like to see more quests.”

This almost-unanimous response supports my conclusion that students found value in playing the game and would like to see more topics included.

4.3. Learning

An important inquiry of this study is related to the attitude towards the mathematics content of the game and the students’ achievements. The pre- and posttests consisted of problems related to the three game’s activities: divisibility, prime numbers, and decomposition. Students reported different levels of previous knowledge with respect to the three topics. More students reported a good grasp of divisibility than of prime numbers and decomposition.

I rejected the null hypothesis of no difference between the pretest and posttest. One student did not write the posttest because he was too tired; therefore I computed the pre- and posttest scores for 14 students only. For these 14 students, there was a significant improvement from pretest (M = 77.7%; SD = 9.3%) to posttest (M = 83.5%; SD = 8.7%), $t(14) = 2.2$; two-tailed $p < 0.007$), which suggests that students likely learned from their interaction with *Heroes of Math Island*.

From the group of 15 students, only one student responded neutral to the question "I learned math when I played the game," and 93.3% of students agree or strongly agreed to the statement: of the 14 students, 6 agreed and 8 strongly agreed (see Figure 5).

The student who responded neutrally was completely uninterested in mathematics. When asked how she would feel about the game if it were improved, she responded that the game would not interest her unless the mathematical content were removed and replaced with "more fun learning material."

During the game, when observers noted that students were tired or struggled too much, they advised them to stop or replay the easier divisibility activity. It was interesting to note that students were determined to finish the quest. None of the students in this group stopped before finishing the quest. Observers agreed that two students in particular were very tired during the gameplay, but did not want to stop and managed to finish the quest.

I generated a histogram of all statements from the learning category. It is remarkable and reassuring, given the intention of the game, to observe that frequencies are concentrated on the right towards "agree" and "strongly agree." Learning from hints is concentrated towards neutral, a finding that will be investigated in future research and will be taken into consideration in the next implementation of the game. Figure 5 summarizes the following findings:

Figure 5. Learning: Detailed histogram

4.4. Emotion and Learning

It is interesting to observe that when students were asked what emotions they experienced during the gameplay, the most reported state was happiness or a related state of "fun." Judges involved in video annotations did not report too many instances of "enjoyment" (reported by judges as pleasure/delight): only 5% by Judge 1 and 3.8% by Judge 2 (Gutica & Conati, 2013); however the most reported state by students was happiness. Instead, observers noted that engaged concentration was the main emotional state that students experienced. This observation is consistent with the results of the affect analysis, as engaged concentration was reported 79% of the time (Gutica & Conati, 2013), the learning gains (the improvement from pre- to posttest) and the positive responses students gave to post-questionnaire questions related to learning.

In interviews, participants in this study reported high engagement, some of them complaining that some elements of the game (i.e., the monkey emotional character) bothered them and disturbed their focus. One of the students indicated a sense of accomplishment, and other students described their experience with words like "interesting" and "effective," but the main words used by students were "happy" and "fun." I believe that engagement, focus, and completion of work provide satisfaction that is perceived as joy and reported by participants as happiness and fun.

The most observed emotional state was engaged concentration, also called flow and characterized by immersion, focus, and concentration on the system, with the appearance of positive engagement. Overall, all students were engaged and motivated to do well. Many of them explained in interviews their state of focus. Even the student who reported that a game with mathematics content didn't interest her was highly engaged.

The second most important affective state observed during gameplay was confidence. Confidence needs special attention because of its close relationship to disposition to learn. I agree with Barbalet (1998) that confidence is a particular emotion because it "is the only emotion that has time as its object" (p. 88). Confidence provides motivation for future actions: e.g., the subject evaluates her/his perception with respect of a learning topic and, feeling confident, apprehends the future as possible and takes the decision to continue to study. Confidence was reported during affect analysis an average 37% of the time (Gutica & Conati, 2013) and was observed often, especially at the beginning of the game and when difficult tasks (i.e., identifying larger prime numbers) were mastered.

The third most frequently reported state was confusion/hesitancy. The two states, confusion and hesitancy were treated together because it was too difficult to distinguish between them. Confusion is a normal step in learning that occurs each time learners reach a stage where new topics are presented or new skills are needed. Confusion/hesitancy was reported during affect analysis 26% of the time (Gutica & Conati, 2013). The frequency of confusion in this study is higher than other similar studies [e.g., 13% of the time in Baker et al. (2010)]; however, confusion is not considered a negative emotion in learning because deep comprehension can happen in moments of confusion ((D'Mello, Taylor, & Graesser, 2007; Graesser, et al., 2006; Kort & Reilly, 2002).

Even if a good percentage of students (40%) responded in the questionnaire that their curiosity was increased by the gameplay, the same percentage (40%) neither agreed nor disagreed. One student strongly disagreed and two students disagreed. Interviews offered clarification. One student indicated that anticipation of what would be next (curiosity) motivated him to continue to play the game.

> Interviewer: When I asked if you wanted to have fun when playing the game, you were indifferent. And when I asked if you wanted to learn math by playing the game, you were also indifferent. What was your motivation to play the game?
>
> Student: My motivation . . . I think for me it wasn't "I wanted to have fun or I wanted to learn." I just did it hmmmm . . . not that I wanted to learn, but because I wanted to see what it was.

Another student indicated that she was not interested in this game because of the mathematical content. She responded that other topics interest her, especially writing, and no improvement of the game would give her motivation to play as long as the game had the current content. More effort should be spent in the future to understand what should be done to increase curiosity and address issues of lack of interest in the subject matter.

Disappointment/displeasure (again two emotions that were evaluated together because of difficulty to distinguish between them) was rarely observed. The only student who strongly expressed displeasure was the one who disliked mathematics.

Frustration is a negative emotion which can hinder learning. Frustration was observed to a lesser extent (only 5% of the time) during affect analysis (Gutica & Conati, 2013). Students reported frustration in relationship to learning (harder questions and making mistakes) and game mechanics, especially an element of design commonly used in game design: the player was sent to the beginning of the activity if the player made a certain number of mistakes.

A positive outcome is that boredom, another emotion that is considered detrimental to learning (D'Mello, Taylor, & Graesser, 2007; Graesser, et al., 2006), was rarely observed in this study; it was reported only 1.5% of the time in affect analysis (Gutica & Conati, 2013). Students did not report or complain of boredom, except for the same student who disliked the game because of the mathematical content, who strongly agreed to the statement “This game is boring.” The low level of boredom observed and reported in this study provides assurance that the game can be a useful learning technology to augment teaching numeracy in grades five through seven.

From the set of twelve emotions identified in affect analysis, the emotions of excitement, pride, surprise, and shame were very seldom observed by judges (Gutica & Conati, 2013) or reported by students; therefore, even if these emotions are important to learning (e.g., pride and shame), they were not significant for this study.

4.5. Emotional Agent

Interesting results were obtained with regard to the emotional agent: the monkey. I started from the assumption that the monkey character would be attractive and appreciated by students. However, not all students liked the monkey: only 53.3% of students disagreed or strongly disagreed; 26.6% of students were neutral and 20% of students strongly agreed that the monkey was annoying.

Students had mixed feelings regarding the monkey character. Some students complained in post-questionnaires and interviews of being distracted by the monkey’s animations and would like to have the choice to turn her off. Another group of students indicated that they did not even notice the monkey. One student considered that showing emotions is beneficial and offered advice for future design: “I think the emotions are good and maybe even a voice too, like if you are doing good, then he feels those emotions: he could say like good job or keep trying, keep it up". Other students suggested that the monkey can participate in the game by offering hints.

5. Conclusion

In response to the need for more empirical research with respect to emotion and learning, this study provided an empirical investigation of the students' interaction with an educational game designed specifically for the purpose of this study. Exploration of gameplay with a focus on emotions, a current goal for now, is paving the road to a more long-term goal of responding to students' cognitive and emotional needs in promoting better learning with educational technologies.

In the context of this investigation, the most relevant emotions were: boredom, confidence, confusion/hesitancy, curiosity, delight/pleasure, disappointment/displeasure, engaged concentration, and frustration. I recommend that these emotions should to be considered when designing adaptive guidance, and emotion detection and response for ALTs and ITSs.

The design heuristics included in this game (quest, monkey, island, castle, activities in a mine, and metaphors related to prime numbers being rocks that do not break) were appropriate for the age group and provided engagement and enjoyment. I believe that the design lessons learned in this study can be extrapolated to designing ALTs and ITSs for other school subjects.

Generally, students found the game enjoyable and indicated that they would like to play the game again. I found that in this study students, even tired, were highly motivated to accomplish the tasks and finish quests. Designing educational games to employ aspects of video games, such as quests that motivate students to finish, ought to be considered among the heuristics of educational game design.

Empirical research is needed for agents and game companions, such as the monkey character utilized in this research: what effect would a less intrusive, more useful companion have (offering advice, cues, hints, help)?

The high degree of engagement and confidence, the low occurrence of boredom, the students' responses, and the learning gains indicate that *Heroes of Math Island* is an adequate technology for learning that should be evaluated in future longitudinal studies and in schools.

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