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Enhancing 5th graders' science content knowledge and self-efficacy through game-based learning

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A B S T R A C T

Many argue that games can positively impact learning by providing an intrinsically motivating and engaging learning environment for students in ways that traditional school cannot. Recent research demonstrates that games have the potential to impact student learning in STEM content areas and that collaborative gameplay may be of particular importance for learning gains. This study investigated the effects of collaborative and single game player conditions on science content learning and science self-efficacy. Results indicated that there were no differences between the two playing conditions; however, when conditions were collapsed, science content learning and self-efficacy significantly increased. Future research should focus on the composition of collaboration interaction among game players to assess what types of collaborative tasks may yield positive learning gains.

1. Introduction

There is a growing interest among researchers in the transformative potential of game-based learning technologies, especially in STEM education (Prensky, 2001; Spires, 2008; Whitton, 2007). Well-designed educational games have the potential to transform STEM teaching and learning because they can simulate real-world complexity and make learning more connected to students' personal lives outside of the school context (Spires, Rowe, Mott, & Lester, 2011). Further, advocates that support the potential of game-based teaching and learning argue that games can positively impact students' learning by providing an intrinsically motivating and engaging learning environment for students in ways that traditional school cannot (Foster, 2008; Kang & Tan, 2008; Papastergiou, 2009). However, studies that have empirically examined the extent of the teaching effectiveness of game-based learning environments have been slow to emerge; the general picture is still unclear with often times conflicting findings (Hays, 2005; Vogel, Greenwood-Ericksen, Cannon-Bowers, & Bowers, 2006). Taking this landscape into consideration, the first goal of our study was to examine the effectiveness of a game-based learning environment (i.e., Crystal Island) in fostering students' science content learning gains. A second goal of the investigation was to contribute to a larger understanding of what game-based learning environments afford when students play them collaboratively in conjunction with their regular classroom-based curricula.

Another fruitful area for game-based learning research is increasing students' self-esteem as learners in the classroom, specifically in the area of science self-efficacy. Research in this area is important for at least two reasons. First, self-efficacy is an important predictor of students' science performance. Second, it impacts students' desire to choose science related careers in the future. Students in the United States continue to perform more poorly in science than their peers, internationally, and the number of students in the United States who have completed science degrees has declined steadily over recent years compared with other countries (National Science Board, 2006). Improving upon young student' science self-efficacy may increase an overall interest in science education and boost interest in science related careers. Unless students' feelings of science self-efficacy increase, especially from early in their schooling, it is likely that these numbers will remain on the decline (e.g., Ketelhut, 2007). Thus, the potential affordance of game-based learning environments in improving students' science self-efficacy is an area that warrants increasing levels of attention within the research community.

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The following literature review is divided into three areas: (a) effects of gameplay on learning gains, (b) effects of gameplay on science self-efficacy, and (c) effects of collaborative gameplay on learning outcomes. Taken together, the literature provides a rationale for our research question: How does collaborative gameplay affect students' science self-efficacy and science content knowledge?

2. Literature review

2.1. Game-based learning

Several authors have attempted to conduct extensive literature reviews in order to characterize the state of the field, often times painting a rather unclear picture in terms of the overall effectiveness of achieving learning gains through playing educational computer games. For instance, in a literature review based on 32 empirical studies, Vogel, Vogel et al. (2006) reported that interactive games were more effective than traditional classroom instruction on learners' academic learning gains and cognitive skill development. Similarly, Clark, Nelson, Sengupta, and D'Angelo (2009) reviewed studies on science learning through digital games and found that elementary and middle school students showed learning gains in a variety of studies and in a variety of content areas. The authors found that students' biological understanding became more advanced from Pre- to Post-test as a result of playing an infectious disease game. Playing games was also found to contribute to students' science knowledge retention. A study that investigated a version of the Crystal Island game-based learning environment for eighth-grade microbiology found that students' presence, situational interest, and in-game performance were significant predictors of science content learning gains (Rowe, Shores, Mott & Lester, 2010a). A related investigation compared students with high in-game performance to students with low in-game performance in Crystal Island (Rowe, Shores, Mott & Lester, 2010b). The study revealed significant differences in students' science self-efficacy, learning gains, engagement, and gameplay behaviors.

Other individual studies have reported that game playing resulted in improved academic learning achievement in student participants (i.e., Gillispie, Martin, & Parker, 2009; Hickey, Ingram-Goble, & Jameson, 2009; Kang & Tan, 2008; Papastergiou, 2009). For example, in two game-based learning studies with sixth graders, Hickey et al. (2009) found that students who received the science curriculum demonstrated greater learning gains in both understanding of scientific concepts and in achievement than did students in a control group (using expository text). The authors also reported that formative feedback provided by the game further contributed to improving students' content area achievement. Findings from some other studies also supported this conclusion. In another study by Tuzun, Yilmaz-Soylu, Inal, and Kizilkaya (2009), the authors found that fourth and fifth graders' made significant learning gains (geography) from the serious game environment. Similar results were found in another study by Gillispie et al. (2009), which reported that playing 3-D digital games positively impacted students' math (pre-Algebra and Algebra) learning attitudes and achievement.

However, the above-mentioned educational benefits afforded by such game-based learning environments have not consistently been supported empirically (e.g., Gao, Yang, & Chen, 2009; Wrzesien & Raya, 2010). For instance, some researchers have reported that extensive reviews of the literature have failed to support the claim that instructional games were a more effective method than traditional classroom-based instruction, in that it was not possible to identify a clear causal relationship between academic performance and computer gameplay (e.g., Harris, 2001; Hays, 2005). O'Neil, Wainess, and Baker (2005) further articulated that educational games are not sufficient for learning, asserting that individual differences should be taken into account if educational games are to be used as a method to enhance learning. For example, Wrzesien and Raya (2010) found sixth graders reported higher motivation and engagement levels as a result of playing a science-based game; however, there was no evidence to show that the game led to significant learning advancements over the traditional class. Individual difference factors such as perceived academic ability and interest in educational content both in the game and in the classroom should therefore be taken into account in an effort to fully understand the impact of game-based learning environments on academic achievement. Since a clear consensus has yet to be achieved regarding the effects of instructional games on learning, more empirical studies are needed to validate the claimed effects of game-based learning.

2.2. Self-efficacy and learning

Academic self-efficacy has been found to be an important mediator of students' learning behaviors. More specifically, many research studies have reported that academic self-efficacy impacts students' choice of learning activities and the amount of effort they attribute to learning both in the classroom and while playing educational video games (Mikropolous & Natsis, 2011), with self-efficacious students more likely to undertake more challenging learning tasks and to persevere in difficult situations (e.g., Ketelhut, 2007; Zimmerman, 2000). Academic self-efficacy has also been found to be one of the most important predictors of students' academic achievement (e.g., Jinks & Lorsbach, 2003; McPherson & McCormick, 2006; Nelson & Ketelhut, 2008). For instance, in a study by Nelson and Ketelhut (2008), ninety-six middle school students learned science related content in a multi-user virtual environment, noting that students with lower levels of self-efficacy did not perform as well as students with higher-levels of self-efficacy. Academic self-efficacy has also been found to impact students' career choices and career-related goals (Cordero, Porter, Israel, & Brown, 2010; Gainor, 2006; Lindley, 2006). Gainor (2006) pointed out that this is because people are more likely to consider careers in areas in which they believe they are capable of doing well.

A few researchers have recently begun to examine the effectiveness of using game-based learning to improve upon students' self-efficacy in different subject areas (including science and math). These few studies have demonstrated that playing educational games serves to improve students' self-efficacy in several areas. For example, Ketelhut (2007) examined seventh graders' data gathering behaviors in a virtual game environment and found that the game-based learning environment improved students' science self-efficacy and that high self-efficacy students demonstrated better data gathering behaviors. Researchers have also found the playfulness that students experience while playing games helps to encourage academic self-efficacy (Potosky, 2002, as cited in Hong, Lin, Huang, Chen & Li, 2009). Emerging research on game-based learning environments and associated improvements in self-efficacy is promising. More studies are needed in this area in order to validate the seeming potential of using educational games to improve students' academic self-efficacy, especially in science related areas.

2.3. Collaboration and game-based learning

There is also evidence to suggest that playing educational video games in collaboration with other students, as well as with other in-game avatars, can positively impact learning gains (see Mikropolous & Natsis, 2011). In addition to the contributions of game-based learning environments in general on students' achievement and also on students' self-efficacy, there is also emerging evidence that collaborative gameplay may have differential effects in comparison to playing educational video games as a single-player (e.g., Foko & Amory, 2008; Shih, Shih, Shih, Su, & Chuang, 2010). One reason that collaboration may be an effective means of enhancing learning outcomes through playing educational video games in the classroom is that such games may influence discussion, such as that pertaining to the content received through the game. Furthermore, it is also likely that collaboration may have an effect on the quality of information that children receive from playing such games, in that students may learn from each other while playing the game, a benefit that cannot be afforded when playing individually (Mikropolous & Natsis, 2011). Howard, Morgan, and Ellis (2006) did in fact report that students highly valued the usefulness of discussion with their peers while playing the game. This discussion may therefore have an effect on other game-related outcomes. Foko and Amory (2008) found, for example, that playing in pairs was more effective than playing individually and that collaboration helped students overcome their misconceptions about content. The authors also reported that students' visualization, logic, and numeric skills improved after playing the educational video game in their study in pairs as opposed to individually (Foko & Amory, 2008). In another study, Shih et al. (2010) reported that collaboration could be more influential in terms of learning than playing individually, however the effects of collaboration were highly dependent on the specific model and strategies that were being used, at least in their investigation. Finally, in a review of the virtual reality literature, Mikropolous and Natsis (2011) reported that several studies have indicated that collaboration has many beneficial effects on the learning process, such as increasing reflective thinking and more effective problem solving. However, the direct effects of various forms of collaboration and various collaborative settings remain incompletely understood, warranting more research to understand the relationships between the effects of collaboration while playing educational video games on students' learning outcomes.

3. Materials and methods

3.1. Participants and research context

The study took place at a public magnet school serving elementary-age (K-5) students located in a large school district in the south-eastern part of the United States. The surrounding area is both suburban and urban and is relatively diverse in terms of socioeconomic status. This particular school serves students that represent the surrounding community, 35% of whom receive free or reduced lunches. Participants were 100 fifth graders, with 45 boys and 55 girls. Approximately 19% of the participants were African American, 7% Asian, 44% Caucasian, 18% Latino, and 12% other. Across the six classes, students were randomly assigned to either a single-player or a collaborative gameplay condition.

Students played the Crystal Island (see Figs. 1 and 2) game after they had exposure to the curriculum landforms that related to the North Carolina standard course of study for fifth grade science. Crystal Island is an online computer game consisting of an immersive, 3-dimensional intelligent learning environment with a cast of characters situated on an island within a storyworld. It is in its third year of development as a NSF-funded, multidisciplinary project. For a virtual walkthrough of the game see http://www.intellimedia.ncsu.edu/videos/CI5-yearTwo-video.html. This version features an expansive island setting that has rivers, a delta, a dam, a plateau, a lake, several waterfalls, and a beach. Throughout gameplay, students have the opportunity to interact with characters (e.g., town mayor, citizens of the island) to learn about science related concepts and to obtain advice and guidance pertaining to game scenario completion. The Crystal Island content curriculum was generated from FOSS (Full Option Science System) and the NC standard course of study on landforms and ecosystems. One theoretical underpinning for Crystal Island is narrative-centered learning. Mott, Callaway, Zettlemoyer, Lee, and Lester (1999) introduced the theory of narrative-centered learning to virtual worlds by building on Gerrig's (1993) two principles of cognitive processes in narrative

Fig. 1. Image taken of interaction between student avatar and character from Crystal Island.

Fig. 2. Image taken of student avatar learning about models in Crystal Island.

comprehension. First, readers are transported; they are somehow taken to another place and time in a manner that is so compelling it seems real. Second, they perform the narrative. Simulating actors in a play, readers actively draw inferences and experience emotions prompted from interactions with the narrative text. Students learn content as they experience the narrative.

3.2. Instruments and assessment measures

3.2.1. Pre- and Post-test assessments

The research presented here is part of a larger study examining the effects of Crystal Island on several outcome variables, measured through Pre- and Post-test assessments. Of the variables included in those assessments, this study focused on gains in students' science self-efficacy science and content knowledge only. The questions designed to assess students' science self-efficacy required them to indicate how much they found each item to be "like" them. The content knowledge questions included in the present study consisted of a series of 14 multiple-choice questions that measured STEM content knowledge about topics that were covered in the game.

3.2.1.1. Self-efficacy. For the current study, students' science self-efficacy was measured by adapting items from the Sources of Science Self-Efficacy scale (SSSE) (Britner & Pajares, 2006) and from the Self-Efficacy for Self-Regulated Learning Scale (Bandura, 2001). To assess the consistency of results across responses to the science self-efficacy items on the Pre- and Post-test assessments, reliability analyses were conducted and the items were found to be quite reliable, with alpha coefficients of .80 and .78, respectively.

3.2.1.2. Science content knowledge. Students' science content knowledge, specifically for landforms and ecosystems, was measured through identical Pre- and Post-test assessments developed to align with the North Carolina Standard Course of Study. Content knowledge items were constructed for this study based upon the FOSS (Full Option Science System) informative assessments and the 5th grade EOG (End of Grade) questions. These items collectively assessed both basic, low-level recognition knowledge and mid-level application knowledge. To assess the consistency of results across responses to the content knowledge items on the Pre- and Post-test assessments, reliability analyses were conducted and the items were found to be modestly reliable, with alpha coefficients of .65 and .78, respectively.

3.3. Data collection

Students participated in the present study in sessions that took place once a day across a series of four days. On Day 1, students individually completed the pre-test assessment. Next, each student completed a 20-min, online Crystal Island tutorial in order to familiarize them with the controls and character movements within the gaming environment. On Day 2 at the school, each student was randomly assigned to one of two playing conditions (i.e., single-player or collaborative) as follows. First, each student was assigned to either the single-player condition (student plays alone) or the collaborative playing condition (2 students play together). To do this, students from each class first drew a token from a hat. Two-thirds of the tokens were labeled as Cougars (i.e., collaborative condition) and one-third were labeled as Sharks (i.e., single-player condition). Those in the Shark (single-player) condition proceeded to the single-player room. Each time a student drew a Cougar (collaborative) token, that student waited until the next Cougar token was selected and then proceeded to their respective collaboration room with another student, as a pair. In the event that an odd number of Cougar tokens were drawn and students did not have another student to collaborate with because there were no longer any students to draw from the hat, students were switched to the Shark (single-player) condition and were sent to the single-player room. On each day thereafter students remained in their assigned collaborative.

On Day 2 the designated amount of gameplay time across playing conditions was 50 min. Students in the single-player condition played independently for the entire 50 min. However, in the collaborative condition, the total amount of gameplay time for each individual child was 25 min (i.e., half of the total amount of time in the session). This was achieved by having the first member of each pair in the collaborative condition play for 25 min and then having students alternate with the other member of the pair halfway through the gameplay session. The second student then played the game for the remaining 25 min.

Gameplay sessions on the following two days followed approximately the same procedures as described above. Procedures differed in that on Day 3, the overall amount of designated gameplay time in both conditions was shortened to 40 min to allow for students to complete a motivation survey (part of the larger investigation and not examined in the present study). On Day 4 the designated amount of gameplay time was shortened to 30 min to allow students to complete the Post-test assessment.

4. Results

4.1. Data coding

Science self-efficacy was coded according to procedures similar to those used in Lent, Lopez, and Bieschke (1991). Students responded to self-efficacy questions by providing their level of agreement with how much each of 8 statements related to them about the ability to learn and perform in science (e.g., I am sure that I can learn science.), with answers ranging from "nothing", "somewhat", or "a great deal" like them. Of the 8 self-efficacy questions, 2 were negatively worded and were therefore reverse-coded. A total science self-efficacy score was then calculated for each student by adding the students' points for each question. Higher scores reflected stronger science self-efficacy.

Students' responses to content knowledge items were coded as either being correct (1) or incorrect (0). Since there were 14 items the highest possible score that students could receive was 14. A total score was calculated for each student.

4.2. Data analysis

Of the 100 students, 70 students completed all 4 of the experimental sessions (males, $n = 30$). Only students who completed all sessions of gameplay and completed all items on both the Pre- and Post-tests were included in the analyses. After removing those participants that did not meet the aforementioned requirements, the final sample consisted of 66 participants (males, $n = 30$). In the single-player condition, there were a total of 27 participants (males, $n = 14$) and in the collaborative condition there were a total of 39 participants (males, $n = 16$). Preliminary analyses indicated that there were no differences across males and females in terms of responses to science self-efficacy and content knowledge questions; therefore the following analyses are collapsed across males and females.

4.2.1. Science self-efficacy

To examine changes from Pre- to Post-test across playing conditions (single-player, collaborative) in terms of science self-efficacy, a Session (2: Pre-, Post) × Condition (2: Single-player, Collaborative) repeated measures ANOVA was conducted with session as the within-subjects factor and condition as the between subjects factor. The analyses failed to reveal a significant Session × Condition interaction, thereby indicating that the students did not differ in terms of changes in science self-efficacy as a function of their playing condition. However, a significant main effect of Session was revealed across groups indicating that participants made significant increases in science self-efficacy from Pre- ($M = 12.27$, $SD = 1.33$) to Post-test assessment ($M = 13.33$, $SD = 2.51$), $F(1, 64) = 11.08$, $p < .01$, eta squared = .15 (see Fig. 3). Therefore, regardless of playing condition, participants demonstrated increases in science self-efficacy after playing Crystal Island.

4.2.2. Content knowledge items

To examine changes from Pre- to Post-test across playing conditions in terms of responses to the content knowledge items, a Session (2: Pre-, Post) × Condition (2: Single-player, Collaborative) repeated measures ANOVA was conducted with session as the within-subjects factor and condition as the between subjects factor. The analyses failed to reveal a significant Session × Condition interaction, thereby indicating

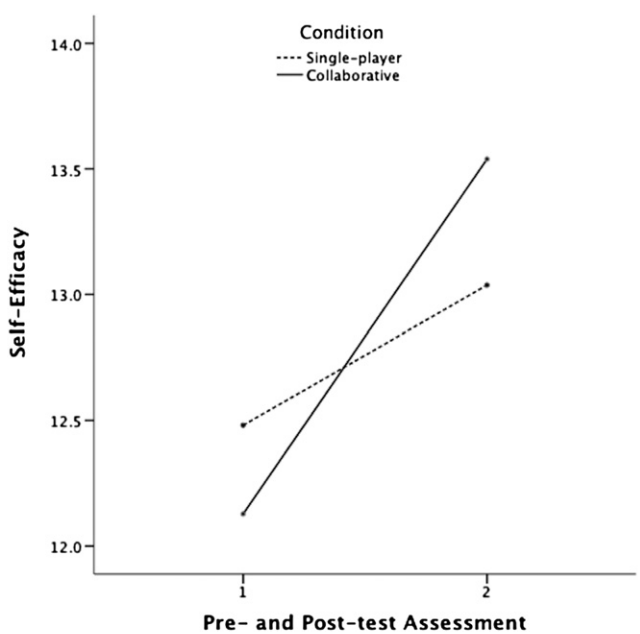

Fig. 3. Changes in students' self-reported science self-efficacy from the Pre-/Post-test assessment.

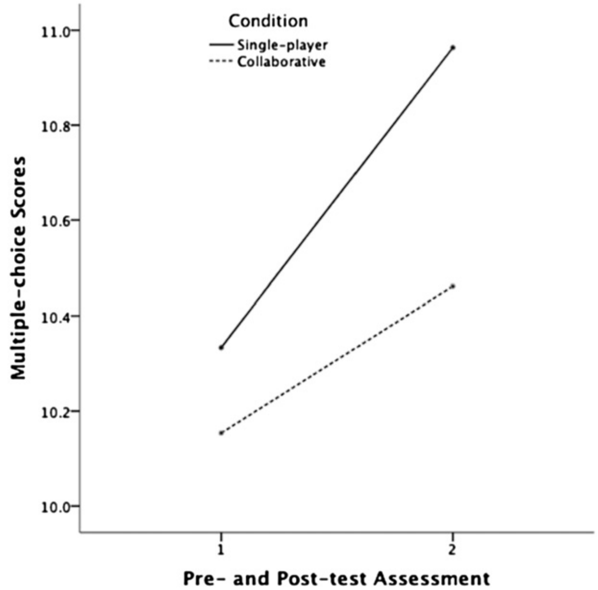

Fig. 4. Changes in students' correct responses to multiple-choice items in the Pre-/Post-test assessment.

that students did not differ in terms of gains in content knowledge as evidenced by their responses to items on the Pre- and Post-test assessments as a function of their playing condition. However, a significant main effect of Session was revealed across groups, indicating that participants made significant learning gains from Pre- ($M = 10.23$, $SD = 2.48$) to Post-test assessment ($M = 10.67$, $SD = 2.91$), $F(1, 64) = 4.47$, $p < .05$, eta squared = .07 (see Fig. 4). Therefore, regardless of playing condition, participants demonstrated increases in content knowledge, as evidenced by increases in correct responses to the content knowledge items from Pre- to Post-test assessment after playing Crystal Island.

5. Conclusion

This study investigated the effects of collaborative and single game player conditions on science content learning and science self-efficacy. Results indicated that there were no differences between the two playing conditions; however, when conditions were collapsed, science content learning and self-efficacy significantly increased. It is possible that the collaborative group did not outperform the single-player group due to the lack of specificity of the actions that the collaborative players engaged in Shih et al. (2010). For example, if each player was directed to perform a certain role (e.g., be the driver of the controls), it is possible that results might have been different. As mentioned previously, Shih et al. (2010) found that collaboration could be effective in some circumstances but was highly dependent on the specific model and strategies that were being used. As Howard et al. (2006) reported, students valued the usefulness of discussion with their peers while playing games, indicating that it is important to continue investigations that center around understanding the effects of collaborative gameplay. In our own future studies, we intend to define roles for the collaborative condition and conduct discourse analyses of the communication between paired players.

Crystal Island has the potential to be a powerful addition to 5th grade science curriculum. Most of the game-based learning research to date has focused on content learning gains at a basic level (acquisition of facts, etc.) and has not fully incorporated higher-level assessments. Future iterations of the game will incorporate higher-level activities to assess whether the game has the potential to teach children how to apply what they learn in more complex ways, as well as whether self-efficacy can be increased above and beyond the results in the present study. Additionally, future research will focus on the composition of collaboration interaction among game players to assess what types of collaborative tasks may yield positive learning gains. As members of the 2006 National Summit on Educational Games suggested, game-based learning research needs to continue to focus on what works with whom and in which context. When the research community adequately addresses this concern, games will become more compatible with school learning contexts and potentially have a greater impact on the development of students' 21st century skills.

Appendix A

*Self-Efficacy Items**

Instructions: These questions are designed to help us better understand what areas cause students difficulty in science classes. Please indicate how much the following statements are like you. (Possible responses to select from: Nothing, Somewhat, A great deal)

1. I am sure that I can learn science.
2. I can get a good grade in science.
3. I am sure I could do middle school science.

4. I have a lot of self-confidence when it comes to science.
5. I am not the type to do well in science.
6. It takes me a long time to learn new things in science.
7. Even before I begin a new topic in science, I feel confident I will be able to understand it.
8. I think I have good skills and strategies to learn science.

*Adapted from Nietfeld et al. (2006).

Appendix B

Content Items

1. Which of the following is not a model?
   a A globe
   b A doll
   c A waterfall
   d A map
2. Which of the following is a person who makes maps
   a Geographer
   b Surveyor
   c Cartographer
   d Volcanologist

Use this map (Note: Map not included for space purposes) to answer the following questions.

3. When hiking in a park, what is the BEST reference material to use?
   a A globe of the world
   b A map of the area showing elevation
   c A road map of the state
   d An atlas of the country
4. Where is the Police Station located on the map?
   a 3-F
   b 4-J
   c 2-F
   d G-H
5. If you start at the Bus Station on Washington Street and walk West for 0.2 miles, what building are you closest to?
   a Fire Station
   b Elementary School
   c Middle School
   d High School

In the box next to each definition, select the word that best fits that definition. (Word list provided: Lake, Mouth, Meander, Plateau, Sediments, Valley, Waterfall)

6. A low area between hills and mountains where a river often flows.
7. A large, nearly level area that has been lifted above the surrounding area.
8. Where a river enters another body of water.
9. A sharp curve or loop in a river
10. An inland body of water, small to moderately large
11. A steep to vertical descent of water in a stream.

Use the illustration below (Note: illustration not included for space purposes) to answer the following questions.

12. In which location has a delta formed?
    a A
    b B
    c C
    d D
    e E
13. Where is a tributary shown in the illustration?
    a A
    b B
    c C
    d D
    e E

14. The box to the right shows a map of a cafeteria including tables, chairs and a food station. Which of the following is a possible key to this map? Enter your answer below. (Note: images not included for space purposes)
    a A
    b B
    c C
    d D

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