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The positive effect of in-class clicker questions on later exams depends on initial student performance level but not question format

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ABSTRACT

Active learning strategies have been increasingly adopted in higher education across many science, technology, engineering, and math (STEM) disciplines. Audience response systems, or clickers, are useful tools that allow instructors to incorporate active learning into large-enrollment courses. Clickers engage students during class and provide real-time feedback that can allow both students and the instructor to identify and correct misconceptions. Many instructors that implement clickers also implement peer instruction, where students vote individually, discuss the question with their peers, and then revote. While this strategy has been shown to improve conceptual understanding, the effects of specific factors, such as question format and student performance level, on learning gains remains unclear. We designed a study in which students in an introductory biology course engaged in clickers with peer discussion during class. We incorporated a treatment in which one section of the course answered a given clicker question in a multiple-choice (MC) format and another section of the same course answered the same question in a multiple-true-false (MTF) format. Students subsequently answered an isomorphic exam question 1–3 weeks later. We observed that both clicker question formats had similar effects on later exam performance. While clickers had an overall positive effect on student exam performance, we found that this effect was significantly greater in higher-performing students, with lower-performing students showing little-to-no benefit. We also found that the initial response rates within peer discussion groups influenced whether students changed to the correct answer. These findings demonstrate that students interact with and benefit from clicker questions in different ways and highlights the importance of considering how different students might be affected by active learning strategies.

1. Introduction

A fundamental goal of discipline-based education research (DBER) is to determine which teaching strategies are effective at improving student engagement, understanding, and achievement (National Research Council, 2012). The growing interest in this field is largely driven by national calls to transform instructional practices in science, technology, engineering, and math (STEM) disciplines in order to help grow the scientific workforce (American Association for the Advancement of Science, 2009; National Research Council, 2012; President's Council of Advisors on Science and Technology, 2012). From this research, active learning and

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other student-centered pedagogies have emerged as effective remedies to the various challenges faced by higher education in STEM fields. For example, many studies have shown that adopting active learning strategies yields positive effects related to engagement, learning, reduced failure rates, and retention within STEM majors (Armbruster, Patel, Johnson, & Weiss, 2009; Ebert-May, Brewer, & Allred, 1997; Freeman et al., 2014, 2007; Haak, HilleRisLambers, Pitre, & Freeman, 2011; Michael, 2006; Prince, 2004). Consequently, active learning strategies have been increasingly implemented in higher education (DeAngelo, Hurtado, Pryor, Kelly, & Santos, 2009; Eagan et al., 2012; Hurtado, Eagan, Pryor, Whang, & Tran, 2012). In addition to the overall positive impacts on students, recent "second-generation research" studies have focused on understanding how active learning pedagogies affect particular groups, such as disadvantaged students (Haak et al., 2011), under-represented minority (URM) and female students (Preszler, 2009), and black students (Eddy & Hogan, 2014). These studies serve as signals of the broader need to understand how specific features of an active learning assignment affect student learning as well as the extent to which all students receive similar benefits.

Clickers and other audience polling systems are popular active learning tools used in many STEM classrooms, particularly those teaching large-enrollment courses (100 + students), as they allow instructors to engage students and provide real-time feedback on conceptual understanding (Chien, Chang, & Chang, 2016; Hunsu, Adesope, & Bayly, 2016; Kay & LeSage, 2009). Thus, students can use results formatively to adjust their thinking when they realize a gap in their understanding, and instructors can modify their teaching when a common point of confusion is revealed (Black & Wiliam, 2009; Krumsvik & Ludvigsen, 2012; Ludvigsen, Krumsvik, & Furnes, 2015). In addition to providing formative feedback on conceptual questions, clickers can be used for a variety of reasons in classrooms. For example, many published case studies and teaching resources use clickers to check understanding and help students move through activities (e.g., National Center for Case Study Teaching in Science, CourseSource). Finally, clickers have proven to be a valuable tool allowing researchers to track student performance and make inferences about learning across time and among different groups.

Numerous studies have demonstrated the positive effects that clickers can have on diverse student outcomes. At the most basic level, clickers improve attendance (Caldwell, 2007; Hunsu et al., 2016; Trees & Jackson, 2007; Zhu, 2007), which likely translates to improved performance through increased exposure and interaction with course content. For example, students in a genetics course that used clickers to ask application problems showed improved problem-solving skills on exams, seemingly resulting from the increased practice (Levesque, 2011). Studies frequently report overall higher exam scores for courses using clickers compared to courses not using clickers (Chien et al., 2016; Crossgrove & Curran, 2008; Hunsu et al., 2016; Reimer et al., 2016). In one case where no overall difference was found between clicker and non-clicker sections, researchers noted the more subtle finding that relatively more students performed at the top level (scoring between 91 and 100% on a composite exam) with clickers, suggesting that clickers may have selective effects on certain groups (Addison, Wright, & Milner, 2009). When using clickers, researchers and instructors report higher student engagement demonstrated through participation in class discussions and activities (Hunsu et al., 2016; Stowell & Nelson, 2007; Wood, 2004). Clickers have also been shown to influence student perceptions as seen in a survey in which business students indicated that using clickers improved their self-efficacy and perceived academic control (Buil, Catalán, & Martínez, 2016) as well as through other studies that demonstrated improved perceptions of courses overall (Crossgrove & Curran, 2008; Han, 2014; Stowell & Nelson, 2007).

Clicker questions are often paired with a peer instruction pedagogy in which students initially answer the question independently, discuss their reasoning with a partner or group, and then re-vote, potentially revising their original answer based on the conversation with their peers (Crouch & Mazur, 2001; Mazur, 1997). When implementing this pedagogy, instructors have been commonly advised to only engage in peer discussion and a re-vote if less than 70% of students initially answer correctly (Crouch & Mazur, 2001; Mazur, 1997; Vickrey, Rosploch, Rahmanian, Pilarz, & Stains, 2015). Across disciplines, studies of peer instruction have demonstrated that more students answer correctly on the second vote after discussion (Lasry, Charles, & Whittaker, 2016; Porter, Bailey Lee, Simon, & Zingaro, 2011; Smith, Wood, Krauter, & Knight, 2011; Smith et al., 2009). Additionally, this active learning strategy often yields higher course grades (Crouch & Mazur, 2001; Levesque, 2011; Porter, Bailey-lee, & Simon, 2013) and improved student engagement (Han & Finkelstein, 2013), with a recent meta-analysis finding a large positive effect of peer instruction on learning gains (Balta, Michinov, Balyimez, & Ayaz, 2017).

The improved performance that occurs after peer discussion suggests that peer instruction results in learning, and studies specifically aimed at testing alternative explanations for these gains have come to the same conclusion. For example, a qualitative analysis of the peer discussions of middle school students revealed that students were not simply getting the correct answer from their peers, but rather that their conversations involved the co-construction of knowledge (Barth-Cohen et al., 2016). Moreover, students report that they can arrive at the correct answer despite no one in their group knowing it at the time of the first vote (Porter et al., 2011, p. 45; Smith et al., 2009). Another alternative explanation for improved performance on the second vote is that peer discussion provides students with additional time to think about their answer, but substituting peer discussion with additional time for individual-reflection yielded comparatively lower learning gains (Lasry et al., 2009). Some of the most convincing evidence for the positive effect of peer instruction comes from studies that explicitly test for conceptual understanding following peer discussion (e.g., Porter et al., 2011, p. 45; Smith et al., 2009). In these studies, students were asked a clicker question using the peer instruction pedagogy and, as expected, performance after peer discussion was higher. Subsequently, students were asked an isomorphic question (defined as a question that addresses the same concept, but asked in a different context), and individual performance remained significantly higher than on the original question (Barth-Cohen et al., 2016; Porter et al., 2011, p. 45; Smith et al., 2009, 2011). These findings suggest that the improvements seen after peer discussion can be recapitulated on an isomorphic question, but additional research is needed to determine whether these learning gains persist beyond a single class period and how they vary across student performance level.

In addition to examining persistence of learning gains, identifying factors that might influence those gains will provide instructors