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Use of physics simulations in whole class and small group settings: Comparative case studies

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ABSTRACT

This study investigates student interactions with simulations, and teacher support of those interactions, within naturalistic high school classroom settings. Two lesson sequences were conducted, one in 11 and one in 8 physics class sections, where roughly half the sections used the simulations in a small group format and matched sections used them in a whole class format. Unexpected pre/post results, previously reported, had raised questions about why whole class students, who had engaged in discussion about the simulations while observing them projected in front of the class, had performed just as well as small group students with hands-on keyboards. The present study addresses these earlier results with case studies (four matched sets of classes) of student and teacher activity during class discussions in one of the lesson sequences. Comparative analyses using classroom videotapes and student written work reveal little evidence for an advantage for the small group students for any of the conceptual and perceptual factors examined; in fact, if anything, there was a slight trend in favor of students in the whole class condition. We infer that the two formats have counter-balancing strengths and weaknesses. We recommend a mixture of the two and suggest several implications for design of instructional simulations.

1. Introduction

The purpose of this study is to investigate student interactions with simulations, and teacher support of those interactions, within naturalistic[1] high school physics classroom settings. We ask what differences there might be between whole class and small group discussions during use of simulations. Constructivist educators have stressed the importance of learning by doing, which, in our experience, has been interpreted by many teachers to mean that students must have their own hands on the keyboards. However, we have noticed that students may misinterpret, or simply miss, important information in a simulation. Because simulations are intended to convey dynamic visual information, teachers may be tempted to believe that simulations are automatically effective in communicating complex models to students. However, research such as Lowe (2003) has shown that comprehension of animations is dependent on appropriate prior knowledge structures. We have observed interesting student reasoning and interesting teacher support moves designed to promote reasoning and comprehension during use of simulations in both whole class and small group contexts; this has led us to look more deeply at what is occurring during these discussions. Our motivating question is, does one format have strengths that the other does not? Though this is a complex question, we can begin to address it by comparing several factors at work in the class discussions.

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[1] We mean 'naturalistic' as opposed to 'in the laboratory.' We tried to interfere with the classroom environment as little as possible because our interest is in what can happen in a real-world classroom.

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We observed classes using simulations in one of two formats, a small group hands-on format or a whole class discussion format during which a single computer was used to project the simulation in front of the class. We will review the pre/post results from Stephens (2012) and then focus on two broad issues: the extent to which students engaged with conceptual issues and the extent to which visual features were recognized, used and supported. Comparative case study analyses of four matched sets of classes identify differences and similarities between the class sections in each matched set, as revealed in classroom videotapes and student written work.[2]

2. Theoretical background

Studies have investigated the effects of *instructional guidance for simulations* when guidance was provided within the learning materials or by the teachers (review by Cook, 2006; Reid, Zhang, & Chen, 2003) and have recommended such actions as providing interpretive support and minimizing cognitive load. The de Jong and van Joolingen (1998) review of simulation use in discovery learning contexts cited the importance of structuring and supporting students' work in ways to prevent difficulties. However, there do not appear to be many studies that address the question of how best to provide instructional guidance for simulations and animations in the context of whole class discussion.

Researchers have studied the use of simulations and other digital tools by *small groups* and by *individual students* (Adams et al., 2008a; Buckley, 2000; Linn, 2003; Williams, Linn, Ammon, & Gearhart, 2004; Windschitl & Andre, 1998; and Zietsman & Hewson, 1986). Among the potential advantages described for these tools are that they can increase engagement, that teachers can use them to “help students make their thinking visible,” and that much of this software provides students the opportunity to customize their own modeling tools. Another potential benefit is that animated graphics can show changes over time (review by Cook, 2006) although these can also produce cognitive overload and actually hinder novice learning (Lowe, 2003; Tversky, Morrisson, & Betrancourt, 2002). Therefore, novices may need to be cued to details of motion in animated graphics (Rieber, 1990).

Hands-on activity afforded by small group work would appear to offer students a more *active learning experience* with simulations than would a whole class format. In the context of think-aloud interviews, for example, Adams et al. (2008a), indicate that simulations can be highly effective, but only if the student's interaction is directed by the student's own questioning. This kind of self-directed interaction with a simulation would seem to require individual or small group work with hands-on-keyboard opportunities. Considering this, and the fact that the teachers in our study have stated they prefer to allow students to work with simulations in small groups and feel experienced teaching in that format, it might be expected that the small group format would work better for them than would a whole class format. On the other hand, studies have reported a variety of issues concerning the effective use of small group discussions in science classes (some of which used simulations), including that students can exhibit a low level of engagement with tasks (Bennett, Hogarth, Lubben, Campbell, & Robinson, 2010), in contrast to findings cited above.

Good practices for teacher response in *whole class discussion* have been and continue to be informed by the work of Chin (2006), Hammer (1995), Hogan and Pressley (1997), and McNeill and Pimentel (2009) among others. In general, these recommend that the teacher play a role in 1) drawing out student reasoning and 2) scaffolding certain kinds of reasoning where students have difficulty. However, these studies did not focus on use of interactive simulations (but see Raghavan, Sartoris, & Glaser, 1998, for a counterexample). What kinds of teacher responses are optimal during class discussion may be affected by use of an interactive simulation that has been designed to provide feedback and to serve as an expert voice. Some believe we know very little about how to use animation effectively in instruction (Jones, Jordan, & Stillings, 2001). Principles suggested by theory and by laboratory work with students using simulations (Lowe, 2003; Mayer & Moreno, 2002) would appear to need further validation in science classroom contexts (Cook, 2006), and may well have to be modified to be usable by teachers employing available simulations with available, frequently limited, classroom hardware.

The present study is of classrooms engaged in *model-based learning* in science. Studies of expert scientists and of science students conclude that the ability to generate and evaluate mental models appears to be a crucial aspect of scientists' thinking (Clement, 2008; Darden, 1991; Nersessian, 1995) and of student thinking (Clement & Ramirez, 2008; Gentner & Gentner, 1983; Nunez-Oviedo & Clement, 2008). The pedagogical approach of the teachers in this study can best be characterized as *guided inquiry* (Bell, Smetana, & Binns, 2005; Hammer, 1995), in which students are supported by the teacher in lessons that are neither pure inquiry nor pure lecture but somewhere in between. Studies of model-based instruction (Hestenes, 1987; Krajcik, McNeill, & Reiser, 2008; and Schwarz et al., 2009) emphasize that complex scientific models can be constructed using prior knowledge ideas and reasoning resources of students, but that this usually requires scaffolding from external supports of various kinds. Minstrell and Kraus (2005), Williams and Clement (2015), and Windschitl, Thompson, Braaten, and Stroupe (2012) have recently identified many interesting strategies for teachers to use in dealing with conceptual difficulties encountered during the learning of complex models in science. Findings from social constructivism (Hogan & Pressley, 1997) have led to a belief that classroom discussion that includes teacher-student or student–student exchanges can be an important and helpful component of model-based learning; we note that these can occur in either small group or whole class contexts.

Little work has been done comparing *small group vs. whole class formats*. Wu and Huang (2007) compared a single teacher-centered and a single student-centered class using physics simulations where the classroom formats were similar to the whole class and small group formats we describe. They found no overall difference in pre/post conceptual gains between the two groups, although they found qualitative differences in cognitive and behavioral engagement. The present study takes a somewhat different tack; rather than focusing on engagement, we focus on students' ability to make use of the visuals in order to address certain difficult concepts and the extent to which discussions dealt with this. Smetana & Bell (2009) compared the use of chemistry simulations in a single small group class and a single whole class discussion and found no significant difference in pre/post gains; they suggest that future research involving more varied populations and additional teachers and classrooms is needed. The present study, along with a related study of a second lesson sequence (Stephens, 2012), aims to contribute to that goal and to investigate more deeply some of the underlying factors at work in the two modes.

[2] Levels of physics courses included in this study, from least to greatest difficulty: CP = College Preparatory, HP = Honors, AP = Advanced Placement.