The Influence of Tablet PCs on Students' Use of Multiple Representations in Lab Reports

Clarisa Bercovich Guelman, Charles De Leone, and Edward Price

Department of Physics, California State University San Marcos, San Marcos, CA 92096

Abstract. This study examined how different tools influenced students' use of representations in the Physics laboratory. In one section of a lab course, every student had a Tablet PC that served as a digital-ink based lab notebook. Students could seamlessly create hand-drawn graphics and equations, and write lab reports on the same computer used for data acquisition, simulation, and analysis. In another lab section, students used traditional printed lab guides, kept paper notebooks, and then wrote lab reports on regular laptops. Analysis of the lab reports showed differences between the sections' use of multiple representations, including an increased use of diagrams and equations by the Tablet users.

Keywords: Physics lab, Tablets, multiple representations, tools, activity theory.
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INTRODUCTION

Physics education researchers have created and popularized many instructional innovations. In thinking about innovations and how they affect the classroom, it is useful to distinguish between practices and material tools. Practices are what we do; for instance, Peer Instruction is a practice consisting of students answering a question individually and then discussing the question with their peers before answering again. Tools are used in carrying out practices; examples of material tools include flashcards and clickers. According to Activity Theory, human activity is mediated by tools [1]. Tools shape the way human beings interact with reality. They influence the nature, not only of external behavior, but also of the mental functioning of individuals. Our goal was to analyze how the use of a specific tool, Tablet PCs, influenced students' use of multiple representations (MRs) in the physics lab generally, and in their lab reports in particular.

MOTIVATION

Physicists – and physics students – use MRs in their work. An external representation is something that depicts, symbolizes or represents objects and/or processes. Representations used in physics include mathematical equations, diagrams and sketches. Research has shown that MRs help students learn concepts and skills and assist them in problem solving [2,3]. MRs can help students better understand complex physical concepts by supporting visualization and by linking and organizing separate ideas.

The introductory physics lab is a natural place for using MRs. Students use equations and force diagrams while constructing explanations, diagrams while designing experiments, tables or graphs while analyzing data, and graphical representations of data and phenomena while using Microcomputer Based Laboratories (MBLs) and computer simulations. The goals and activities of the introductory physics lab have changed in recent years in response to the findings of research on students' learning and to technological developments (for a detailed discussion of lab goals see Ref. 4)). The use of computer-based data acquisition, simulation, and analysis (use of Excel or statistical programs) has become predominant. There is wide consensus that one of the main goals of the labs is for the students to develop expertise in clear reporting of experimental design, observations, analysis, and conclusions in a variety of formats ranging from informal discussion to formal laboratory reports. Communication of scientific results is therefore another use of MRs in the lab.

In the context of introductory science lab courses, research on MRs has centered on the use of MRs in MBLs and in computer simulations as a way to improve students' understanding [5,6]. Some research has examined students' use of MRs to communicate. Kozma [7] examined the differences between expert chemists and chemistry students in their representational skills and in their use of representations in science laboratories. He found that scientists coordinate features within and across MRs to reason about their research and negotiate shared understanding based on underlying principles and concepts. Students, on the other hand, have difficulty moving across or connecting MRs, so their understanding and discourse are constrained by the surface features of individual representations.

If we want students' lab activities to model the process of physical inquiry and the way scientists communicate with each other, then students should practice using MRs to construct shared understanding and communicate. The lab report plays an important role in this process, and the instructor's assessment of the lab report constitutes an explicit and implicit message to students about aspects of the lab that are meaningful.

Students' lab reports reflect their abilities as well as what they feel is important, expected, and useful. Students' use of MRs in the report also depends on the ease with which they can create them. In some cases these lab reports are submitted electronically, which is very practical not only because it relieves the teacher from handling and returning paper, but also because it allows easy submission of data collected electronically during the lab. Yet graphical and symbolic representations cannot be created quickly and intuitively on a computer. In this paper we explore how the tool students use to keep a lab notebook and generate a lab report influences their use of MRs.

DESIGN AND IMPLEMENTATION

We explored how students' use of MRs varied depending on the tools they used in the lab. Specifically, we focused on whether or not students created MRs, without considering quality or correctness. Though quality matters, students must create MRs before they can create *quality* MRs. The research was conducted in Phys 201, an introductory mechanics course with a weekly, three-hour lab. Students worked in groups to perform 14 different inquiry labs focused on experimental design and conceptual understanding, and wrote individual lab reports in class after completing the experiments.

Students were divided by course section into Tablet and Control groups. While performing experiments, the control group used printed versions of the lab guides, kept paper lab notebooks, and used regular computers to collect and analyze data. They used computers to type their lab reports. In the Tablet group, every student had a Tablet PC. The instructor provided a Microsoft OneNote workbook containing the same instructions as the printed version of the lab. In OneNote, students can use digital-ink to draw or write by hand (i.e. sketch their apparatus or write formulas). Students can also type text and "clip" images; that is, take a snapshot of an area of a screen produced by a different program (*i.e*. data collected with computer-interfaced sensors, graphs made in Excel, or images of a simulator), and have it automatically pasted in the OneNote workbook. They can then add digital-ink annotations to these images. Students used the Tablets as digital lab notebooks, and to collect and analyze data. The Tablets were also used to prepare lab reports. Students in both groups were surveyed at semester's end about their lab experience.

RESULTS AND DISCUSSION

Students' reports and some of their notes were collected and analyzed to determine how often students used various representations. The frequency of formulas, drawings or force diagrams was similar in both groups' *notebooks*, whether paper (control group) or digital (Tablet group). Table 1 shows how many students in each group used different representations in their notebooks and the significance levels based on chi-square tests. The number of students in each section varies through the different labs according to attendance variations.

The findings were different for the lab reports. Both groups were given the same prompts for writing lab reports. For the Roller Coaster, Craters, and Newton's 2nd Law labs, the prompts were quite general such as, "Describe your procedure in detail." For the other labs, to assure that students consider all possible MRs, the prompts included explicit choices

TABLE 1. Number (%) of students using one or more formulas, drawings, or force diagrams in their notebook.

Representation	Group	Mobile lab	Friction lab	Projectile motion lab
Formulas	Control	15/15 (100%)	18/18 (100%)	19/19 (100%)
	Tablet	26/26 (100%)	25/25 (100%)	25/25 (100%)
	χ^2, p	undefined, p=1	undefined, p=1	undefined, p=1
Drawings	Control	9/15 (60%)	17/18 (94%)	14/19 (74%)
	Tablet	15/26 (58%)	23/25 (92%)	20/25 (80%)
	χ^2, p	0.021, p>0.88	0.096, p>0.76	0. 245, p>0.62
Force diagrams	Control	1/15 (7%)	17/18 (94%)	
	Tablet	2/26 (8%)	25/25 (100%)	
	χ^2, p	0.015, p>0.9	1. 422, p>0.23	

TABLE 2. Number (%) of students using one or more formulas, drawings, or force diagrams in their lab reports.

MRs	Group	Roller Coaster	Craters lab	Newton's II law	Mobiles	Circular Motion	Projectiles
Formulas	Control	11/20 (55%)	14/21 (67%)		12/15 (80%)		
	Tablet	26/30 (87%)	28/29 (97%)		13/16 (81%)		
	χ^2, p	6.25, <0.012	10.51, <0.001		0.008, >0.929		
Drawings	Control	0/20 (0%)	0/21 (0%)	0/13 (0%)		4/18 (22%)	0/6 (0%)
	Tablet	25/30 (83%)	6/29 (21%)	9/17 (53%)		13/23 (57%)	17/25 (68%)
	χ^2, p	33.33, <0.001	4.93,<0.026	9.83, <0.002		4.89, <0.027	9.034, <0.003
Force diagrams	Control				2/15 (13%)	0/18 (0%)	
	Tablet				14/16 (88%)	22/23 (96%)	
	χ^2, p				17.05, <0.001	37.15, <0.001	

such as, "You can either draw a free-body diagram or make a detailed table of the forces." In Table 2, the rows indicate how many students in each group used formulas, drawings, or force diagrams in the different lab reports. Empty cells represent representations that were not necessary for that lab report. There were significant differences between the groups' use of representations in their lab reports, except for the use of formulas in the Mobiles lab. In the Roller Coaster and Crater labs, students in the Tablet group were much more likely to use formulas in their lab reports. Tellingly, the formulas used in the Mobiles lab (Torque=F•d) were much simpler than in other labs. Students in the Tablet group were much more likely to include drawings and force diagrams in their lab reports. In most of the cases where drawings or force diagrams were relevant, no students in the control group used either representation in their lab reports.

A force diagram drawn with digital-ink in a report can be seen in figure 1. The diagram looks very similar to ones drawn with regular pens and paper.

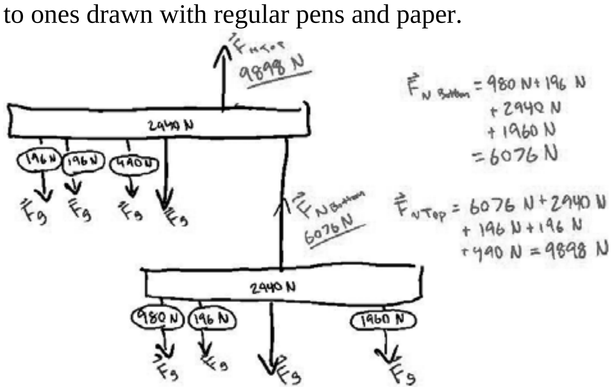

FIGURE 1. Example of force diagram.

Although there was no difference between the frequencies with which the groups included representations in their notebooks, there were subtle differences in the way students incorporated results of simulations and computer-acquired data in their notebooks. For example, in a lab on planetary motion, when asked which simulation parameters gave a stable system, all the students in the control group copied the parameters into their notebooks, while 22/23 students in the Tablet group clipped images of the simulation showing the appropriate parameters. This saved time and reduced the chances of transcription errors. Furthermore, when students in the Tablet group clipped an image obtained with another program, they sometimes used digital-ink to annotate the image. In the Newton's 2nd Law lab, for example, 6/17 students used ink annotations to explain the origin of data in a table or graph; additional students added labels or titles to graphs. In a kinematics lab, in which students related graphs and physical motions, 11/17 students annotated graphs to differentiate between the ideal motion and the real one, as exemplified by Figure 2. The integration of writing space and digital space facilitated a range of interactions between the Tablet students and electronically obtained data, from writing down information for later review, to communicating with the instructor, to reflecting on a motion graph after the experiment was over. These annotations have the added value of giving the teacher insight into students' thinking.

The tools used in preparing lab reports also influenced the instructor by limiting what could realistically be asked of students. In cases with long or complicated formulas, or when the technical steps were complex (for example, importing an image from a program and making measurements on it), it did not seem appropriate to ask students in the control group to submit a typed report.

Interesting information can be obtained from the frequency with which Tablet students used typing or

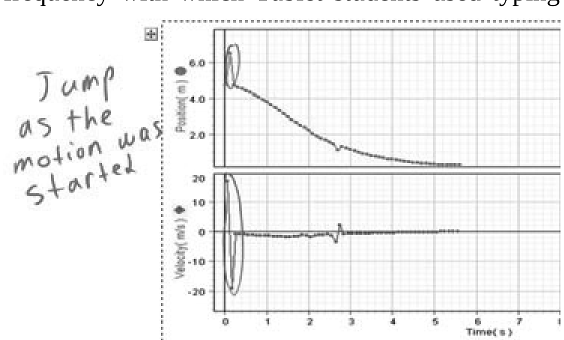

FIGURE 2. Example of students' annotations.

handwriting. It was observed that different students have different patterns of digital-pen usage. Some use the pen most of the time, others mostly type, and others alternate. On an end of semester survey, students reported different factors affected their choice, including their perception of the accepted norms, their feelings about "neatness," their mood, and the quality of the digital-pens. When an answer did not require formulas, most students typed their answers, but for questions requiring equations, the longer or the more symbols included, the more students answered with digital-ink. In sum, students found the affordances of the Tablets valuable for creating MRs.

Students' survey responses provide insight into their perceptions of the Tablets. Out of 25 students, 18 expressed a preference for using OneNote in the lab, with 4 students neutral, and only 3 preferring using pen and paper. When asked whether they agreed or not with the statement, "The pen allows me to do things that I otherwise wouldn't be able to do on the computer", 19 students agreed or strongly agreed, 2 were neutral, and 4 disagreed or strongly disagreed. The reasons more frequently mentioned when explaining their answers were that the digital-pen can be used to write equations (9), to draw pictures (4), to do calculations (3), to make diagrams (3) and to use colors (3). In the same survey, when asked, "How frequently do you type a formula in the lab report rather than hand-write it with a pen?", 13 said never and 8 said rarely. Asked about what determines if they use the digital-pen, 6 said it was the complexity of the formula, 5 said it was whether the symbols (subscripts, roots, etc) were on the keyboard, and 5 said that they always wrote symbols and formulas by hand. Summarizing, students were positive about the Tablets and appreciated how they facilitated the use of MRs.

While much research has focused on the conceptual aspects of students' use of MRs, our findings suggest that whether or not students use MRs depends on more than cognitive factors. Students who were able to generate MRs in paper notebooks did not do so when using laptops to write their lab reports. While it is technically possible to make equations or drawings using software tools, affective factors and context are also important. For instance, one of students' goals is to finish the lab in a certain amount of time. Therefore, if they perceive that introducing MRs takes too much time, there is a tension between this goal and their perception of what is acceptable and desirable in a lab report.

CONCLUSION

If we want to convey a clear message that MRs are a useful symbolic resource commonly used by scientists while analyzing physical situations and as a communication tool, then we should expect and assess their use in lab reports. Students' awareness and mastery of MRs is not enough: we need to provide students with appropriate tools that allow them to participate in this kind of practice. Although the lab is a natural place for using MRs, their use is problematic when students need to coordinate the use of paper and pen with the use of computers. Our research shows that students use MRs when they can quickly create them on paper or with digital-ink, but students use representations much less frequently when using regular laptops to prepare lab reports.

Our experience suggests not only that the use of Tablets in the lab is possible, but also that the transition from the use of paper and pencil to digital-ink is smooth and that students have a positive attitude towards the use of Tablets in the lab. They perceive the Tablet as a tool that allows them to use MRs while using computerized software easily and quickly.

When students need to submit electronic lab reports in laptops, the technical difficulties make them avoid the use of complicated formulas, drawings and force diagrams. In contrast, when students have the opportunity to use digital-ink, they tend to use MRs in their reports as a natural way of communicating scientific knowledge. In this sense, the use of Tablets helps to foster a desired culture in the lab.

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