Online Data Collection and Analysis in Introductory Physics

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Abstract. Online implementation of physics learning materials may present a powerful method of data collection for physics education research, in addition to being useful for supplemental instruction. This may have implications for composite instruction and research designs. We have developed three lessons on Newton's laws and implemented them on the Internet. The lessons ask students to make observations and measurements using video clips, perform calculations and answer open-ended questions. Responses are collected via an online response system. One hundred ten university students enrolled in an algebra-based physics course and 30 high school physics students worked through some or all of our lessons, and their responses were collected. We present a qualitative and quantitative analysis of their responses and assess the implications for optimal design of online lesson materials for collecting meaningful data about students' understanding of basic physics concepts.

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INTRODUCTION

Interviews, in-class assessments, and observation are the primary data collection methods in physics education research. Research into students' epistemological beliefs indicates that students' thought processes, responses to questions, and, by necessity, the conclusions that we draw from them, can be impacted by students' perceptions about the context in which they are working [1,2]. This means that observing students in different contexts is of interest to fully characterize student understanding.

Here the Internet provides an opportunity. It has emerged as a useful means of disseminating learning materials [3,4]. The Internet's capacity for interaction also allows us to collect data from students about their interactions with those materials and their understanding of physics. Students' epistemological beliefs might again differ when working at home or in a computer lab, as compared to the classroom, or interview room. Since students can respond to online materials on their own schedule and in locations of their choosing we can use interactive web technologies to connect with students in these environments. The Internet may yield different information about student understanding by examining their responses in another assessment environment, which is natural, like the classroom, but less formal, and chosen by the student.

The Internet may present another opportunity as it enables researchers to collect data from a larger number of students more quickly than would be possible using clinical interviews. Since materials must be designed so that students can use them independently, data can be collected from many students at the same time without the need of a facilitator. Similarly since data are collected online no transcription or further manual data entry is necessary.

There are, however drawbacks to this approach. Generally the computer cannot intelligently alter the course of a research protocol in reaction to a student's response. Nor can it ask deeper, probing questions to clarify what a student is trying to convey. The way in which students work with the materials also cannot be monitored. There is no way to know whether a student is working with online materials individually or with assistance from others, nor is it possible to know what outside resources they are using concurrently. Despite these disadvantages, we feel that online data collection schemes warrant deeper exploration so as to ascertain the extent of their beneficial use.

In this paper we examine a subset of data obtained from students' use of multimedia-based lessons deployed via the Internet. This work is being done as part of the Advanced Learning Technologies (ALT) Pathway project that seeks to develop and evaluate a web-based, interactive, synthetic tutoring system that uses pre-recorded video clips to answer students' questions about physics in a manner that simulates a natural dialogue. It builds on technology already used to interactively instruct pre-service and in-service teachers on teaching physics [5]. This work is part of an ongoing effort to test and refine lessons designed to give structure to this tutoring interface.

DESIGN & RESEARCH QUESTIONS

The lessons we designed were written using a three-stage learning cycle [6]. Since many variations on the learning cycle exist, we note that in our implementation the first stage consists of minimally guided exploration activities, the second stage consists of a formal concept introduction, and the third stage consists of exercises in which students apply their new knowledge. To take advantage of the Internet's multimedia capabilities and create lessons that establish clear connections to the physical world, we constructed lessons in which students make observations, measurements, and predictions using video clips, and then interpret those clips using Newton's laws. We used a combination of objective and subjective questions, favoring subjective free-response questions.

The first and third stages of the learning cycles were broken down into two to four sub-sections each focusing on a video, or set of related videos. The formal concept introduction stage consisted of a written passage that addressed the relevant concepts in the context of the videos clips from the exploration.

We embedded the video clips and questions into a webpage (http://web.phys.ksu.edu/altpathway) to enable students to have flexible access to them. The questions were embedded using an online survey system so that student responses could be collected in an efficient manner. Ideally we would want the same level of detail in our qualitative data from having students use this website as we get from clinical interviews. Clearly this ideal is unattainable because of the inherent limitations discussed previously. Still, the question of whether students will provide detailed answers to online questions without any encouragement from a facilitator is central to determining whether online data-collection can be a viable means of studying student understanding. A related issue is whether those responses give us insight into students' conceptions of physics. The data and analysis discussed below shows progress towards answering these questions.

To provide data for refining our lessons and obtain answers to the two questions presented above, 110 college students in an algebra-based physics class and 30 high school physics students completed all or part of our lesson materials. The college students, who volunteered for extra-credit, were allowed to complete the materials in a time and location of their choice over the course of a week. To ensure fair access to the Internet and computers, the high school students worked on the materials during their normal class time, working intermittently over several weeks with the lessons incorporated into the instructor's normal teaching schedule. The lessons were made available to both sets of students at times that roughly corresponded to the point in their respective courses when Newton's laws were being addressed.

ANALYSIS & RESULTS

We examine student responses on one sub-section of one lesson. The data are taken from the application section of the lesson on Newton's first law. In this activity students are presented with the problem of obtaining a coin that is lightly stuck to the interior bottom surface of a graduated cylinder. The students are asked to suggest a method for obtaining the coin and to justify their method using Newton's first law. After they type a response, they are then instructed to watch a video that demonstrates the solution, comment on the correctness of their previous response, and explain the events of the video using Newton's first law. The exact phrasings of the questions are:

Question 1:
"Answer this question BEFORE viewing the video clip:
Consider a coin stuck lightly with tape to the bottom of a graduated cylinder. The cylinder is narrow and long so you can't reach in and get it. Given your knowledge of Newton's first law, how would you go about getting the coin out of the cylinder? Explain your answer clearly."

Question 2:
"Answer this question AFTER viewing the video clip:
Was your answer to the previous question correct? Explain why this works using Newton's first law."

In the video it is shown that simply inverting the graduated cylinder, or hitting its base is insufficient to obtain the coin. It is obtained by inverting the cylinder, bringing it and the coin into motion and stopping the cylinder quickly via impact on a surface. The coin continues in motion after the collision and is obtained. An activity in the first section of the lesson focused on the related task of explaining the motion of an unrestrained crash-test dummy during a crash, giving us reason to believe the students had considered this type of situation at least once previously.

Ninety-six of the 110 college students and 28 of the 30 high school students responded to these questions. Student responses were first disaggregated based on whether they were written in sufficient detail for qualitative analysis. Responses were determined to be sufficient for analysis if one complete idea beyond an objective response was expressed. The high school students' responses to the first question were typically less detailed than their responses to the second question. Only 32% (9 responses) of the high school students' responses to the first question were sufficient for coding. However 82% (23 responses) of their responses to the second question were sufficient. The college students' explanations were more consistent. Seventy-four percent (71 responses) of their responses to the first question were sufficient for coding, as were 98% (94 responses) of their responses to the second. The inter-rater reliability, based on four raters, for the response detail was 94%. Despite meeting the criterion for further analysis, the high school students' responses were generally less detailed than those of the college students, as expected.

Responses that were sufficient for coding were then analyzed from a phenomenological perspective. The analysis was based on overall correctness, actions proposed, physics concepts mentioned, and ideas expressed in the explanations.

Three ideas were common to many student responses. Many students did express ideas that were consistent with Newton's first law. One student, for example wrote:

"…cylinder and the coin are moving at the same speed. Then the external force of the table stops the cylinder…the coin continues to move at the same speed…until it stops from the force of the table..."-College student, question 2

More students expressed the idea that one needed to apply a force to the coin to obtain it. This student, for example clearly associates the impact on the table with a force on the coin:

"I would go about getting the coin…by turning it upside down and hitting the cylinder on the table until the coin came out. …to create a downward force on the coin causing it to go into motion." -College student, question 1

Others expressed the idea that a force is needed to obtain the coin, and that the force must exceed the force applied by the tape. For example, this student, who proposes a similar action, explicitly adds that the force of the tape must be overcome:

"I would probally [sic] exerte [sic] a greater force on the opening in a downward motion…to overcome the tape's force…" – High school student, question 1

The number of students who were found to have expressed each idea, along with those expressing all other ideas is shown for the college students in Table 1 and for the high school students in Table 2. The percentages in parentheses reflect the fraction of total detailed responses collected on that question.

TABLE 1. Ideas in College Students' Explanations

Idea Expressed	Question 1	Question 2
Force Required to Get Coin	28 (39%)	43 (46%)
Force Exceeds Tape's Force	18 (25%)	9 (9.5%)
Newton's 1st Law	16 (23%)	33 (35%)
Other Ideas Expressed	9 (13%)	9 (9.5%)

The average inter-rater reliability when assessing the presence of these ideas in student responses was 88% conducted with four raters.

TABLE 2. Ideas in H.S. Students' Explanations

Idea Expressed	Question I	Question II
Force Required to Get Coin	3 (33%)	10 (43%)
Force Exceeds Tape's Force	3 (33%)	9 (39%)
Newton's 1st Law	2 (22%)	4 (17%)
Other Ideas Expressed	1 (11%)	0 (0%)

We also observed a few student responses in which different physics terminology is used interchangeably. For example:

"…the acceleration was larger than the mass or the force holding the coin"-College student, question 2

This is a common phenomenon observed in physics education research [7].

For the 67 college students who provided detailed responses to both questions, we looked at how the ideas expressed differed in their two responses. Fifty-seven percent of these students expressed similar ideas on both questions. Nineteen percent expressed ideas consistent with Newton's first law on the second question but not the first. Eight percent focused on exceeding the tape's force in one response, but only on applying a force in the other. No other single change accounted for more than 6% of the students' responses. Only two students who responded to the first question in a manner that was consistent with Newton's first law responded to the second question in a way that was inconsistent.

It is difficult to assess whether the video prompted a change in thinking for those students whose first answer did not correctly relate to Newton's first law, but whose second answer did. Seeing this type of behavior naturally suggests a need to look at student responses to more questions, and over longer time periods. An analysis of students' performance on the remainder of the lesson materials may provide more information about whether the lessons had an actual effect on student understanding.

Because only nine high school students gave detailed responses to the first question, an analysis of changes in their responses did not yield significant information. One student's response set did stand out because of the high contrast in concepts expressed:

"Turn the cylinder upside down and thrust downward, then stop suddenly. The coin will want to keep moving, so it will release from the tape and fall…" -High School student on question 1

"…you wouldn't be able to stp [sic] thrusting downward enought [sic] to break the force of the tape on the coin, but by hitting it on the table, the froce [sic] would be great enought [sic] for the tape to release the coin" -The same student on question 2

This kind of contrast was uncommon in this these data, but potentially interesting. Other infrequent but interesting responses were also noted. Despite having previously watched the crash test video, which was directly related, only three students noted a parallel between that situation and the coin in the graduated cylinder. Two students' responses indicated that the graduated cylinder video was consistent with their idea of hitting the base of the cylinder to get the coin, despite the fact that the video showed no such event. A similar result on physics that does not exist in videos has been reported [8].

CONCLUSIONS & FUTURE WORK

This preliminary analysis indicates that our online data collection scheme shows initial signs of promise for collecting meaningful qualitative data. The majority of participating students provided useful responses to one or both of our questions, and those responses provided some means for differentiating amongst different modes of thought on a physical scenario. Analysis of the students' responses to the rest of the lesson materials, as well as a deeper analysis of this data, is necessary to determine if this continues to hold true, as well as if any broader trends in student understanding emerge.

One area for improvement is to encourage more students to write responses that are detailed and have a high level of clarity. One possible change to the interface is adjusting the level of feedback the student receives with regard to their answers to objective questions. Finding and varying these types of design parameters may provide controls for optimizing the quality of student responses.

Further research should be done along these lines to continue to test the quality of data that can be obtained via online response and to investigate the ideas expressed by students in the online context. That work might also have implications for free-response questions in online homework systems. We will refine our lessons and construct our synthetic tutor based on our analysis of students' responses. Technical improvements along with a more interactive design should provide better tools for studying students' conceptions of Physics via the Internet.

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