

Measuring Student Effort and Engagement in an Introductory Physics Course

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Abstract. Multiple scales reflecting student effort were developed using factor and scale analysis on data from an introductory physics course. This data included interactions with an on-line homework system. One of the scales displays many characteristics of a metric of the individual level of engagement in the course. This scale is shown to be a good predictor of performance on class exams and the Force Concept Inventory (FCI). Furthermore, normalized learning gains on the FCI are well predicted by this scale while pre-instructional FCI scores provide no additional predictive ability, agreeing with observations by Richard Hake. This scale also correlates strongly with epistemological beliefs that learning is related to effort and is the responsibility of the student. The factors that enter into this scale, writing and mastering expert-like problem-solving, are consistent with this being a measure of individual levels of class engagement.

Keywords: On-line homework, student effort, interactive engagement, Just-in-Time-Teaching, normalized FCI gain.

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INTRODUCTION

Student engagement and effort were demonstrated by Hake to be key elements of learning physics.¹ This has been reinforced by other studies, including learning gains due to requiring students to do homework via an on-line system.² However, Hake gave only a vague definition of interactive engagement as “minds-on” learning and no quantitative measure has since been offered. Such would be valuable to better understand variation among student learning gains within the same course and why some students may struggle in a course in spite of appearing to put forth significant effort in completing on-line homework assignments and attending class. Clearly engagement is not simply effort. Recent work has suggested that the difference is not entirely due to interactive engagement but to reasoning skills.³

Constructing useful measures of student effort and engagement is challenging. Self reporting, e.g. on surveys, has significant drawbacks including subjective self-judgment, influences from student expectations, and providing only a single measurement. An alternate approach is to use the student’s on-line homework system itself as a research tool,⁴ since the information it collects is quantitative and consistent across all students, reflects actual

student behavior, and tracks behavior throughout the entire course. On-line homework systems collect a large amount of information, including when students looked at and submitted assignments, the nature of those responses and general patterns of working, but none of the measures is specifically designed to measure effort and engagement. Therefore any measures of such will need to be constructed and shown to reflect the desired quantity. The focus of the present work is to demonstrate the construction of several measures reflecting student effort in a particular introductory physics class. Data from on-line homework and other class performance measures are analyzed using factor and scale analysis. Finally, it will be shown that one of the constructed scales appears to reflect the level of individual student engagement.

SETTING

The class structure and performance measures will be described in some detail, since the results may be context dependent. The course was an introductory algebra-based physics course taught by the author, taken primarily by non-life science students from the college of science and engineering fulfilling a requirement for their major. University admission is

not highly selective, resulting in a broad range of student abilities and backgrounds. About half report this to be their first physics course, and most do not continue into a second course. As it is the only physics course many will ever take and the course is not taken by physics, engineering or allied health students, the course is intentionally structured such that all students who will put forth sufficient effort will pass the course, at least with a 'D', even if mastery of physics concepts and skills is less than desirable.

The course was taught in an integrated lecture-lab format in a SCALE-UP classroom⁵ with five contact hours over four days (M-Th). Course components included guided-discovery computer laboratories similar to RealTime Physics⁶, two-page chapter summary exercises, cooperative group problem solving,⁷ Just-in-Time-Teaching pre-class questions⁸, on-line homework, written homework, and several exams throughout the semester. Students were assigned to heterogeneous groups of three for laboratories and classroom problem solving.

An explicit problem solving approach⁷ was taught, modeled, and reinforced through templates used in class, on homework and exams. During in-class problem solving exercises students used problem-solving templates that provided a decreasing amount of scaffolding of the approach over the semester. Selected on-line homework exercises were linked to problem-solving templates in Adobe PDF format for students to use in solving the problems and to turn in for a grade. Grades on these written solution assignments were based on correctness and completeness of the problem-solving steps and not the final answer. Written homework assignments consisting of constructing force, energy and torque diagrams were due the class period following that in which they were introduced. Both types of written homework were graded on simple scales, as illustrated by the distribution of points on the force diagram assignment. Six total points were given: attempting all (some) exercises was worth two (one), arrows completely (partially) correct was worth two (one), and labels completely (partially) correct was worth the final two (one).

The pre-class questions and on-line homework were assigned, collected and graded using the WebAssign homework system.⁹ Pre-class assignments due several hours before class consisted primarily of short essay questions while a few involved multiple-choice questions or graphs using GraphPAD.¹⁰ Homework assignments were due twice a week, and contained numerical exercises, graphical response questions,¹⁰ multiple choice, free response questions and symbolic (equation) questions. Approximately half were from the textbook, the remaining exercises

were developed by the author or from RealTime Physics.

Three midterm exams and a final exam were given. They all included questions involving definitions, concepts, graphs and diagrams, single and multiple step numerical problems, and a "set up" problem where students used a problem-solving template to set up but not actually solve a challenging problem.

The Force Concept Inventory¹¹ (FCI) was administered the first and last weeks of the semester. Students completed the Epistemological Beliefs Assessment for Physical Sciences¹² (EBAPS) on-line¹³ at the beginning of the semester.

The final grade was calculated as 12% for each midterm exam and 20% for the final, 20% for homework, 20% for in-class assignments (laboratories, group problem solving) and 2% each for chapter summaries and pre-class questions. Most chapter summaries and pre-class questions received full credit, and laboratory and group problem solving scores included significant amounts of participation credit. Partial credit on exams was largely based on the number of correct problem-solving steps present. The class on which this work is based was the fall of 2006, which began with 28 students of which 22 completed the semester. There were a total of 42 pre-class, 25 on-line homework, 10 written solution and 3 diagram assignments collected.

DATA COLLECTION AND ANALYSIS

Data was compiled as follows. Data on student interactions with WebAssign included information on each viewing and submission of an assignment, identifying the student, assignment, time, question and question part, student response and if correct. This data was imported into a Microsoft Access database and various measures were constructed. This included the number of homework and pre-class assignments submitted, the average time before the assignment was due that the assignment was first downloaded and submitted, the average fraction of assignments that was attempted, average fraction of assignments correct on the first and last attempt, average response length (in characters) of pre-class question responses, and other measures. Data in addition to that from the on-line homework included the number of written homework assignments submitted and scores, number of chapter summaries submitted, scores on exams, total score by category for pre-class, in-class, chapter summary and homework assignments, final grades, pre- and post-FCI scores and scores on each of the five EBAPS scales.

The data described above contains about a dozen measures related to student effort and engagement. A

factor analysis (Table 1, produced in SPSS with Varimax rotation) shows that they cluster into three factors. Collectively these three factors account for 83% of the variance. A scale analysis for the measures in each factor shows that each cluster forms a good scale, with the value of Cronbach's Alpha being 0.88, 0.92, and 0.75 for Factors 1, 2 and 3, respectively. Cronbach's Alpha is measure of to what degree the different measures agree with each other; a value of 0.7 is acceptable, and 1.0 is the maximum value possible.

TABLE 1: Clustering of measures of activity. Rotated factor analysis was used to obtain these loading factors. Values in bold face are the factor with the greatest loading.

Student activity	Factor		
	1	2	3
Number assignments turned in			
Pre-class assignments	.89	.27	.14
Chapter summaries	.94	.22	.00
Online homework	.91	.17	.05
Paper homework	.66	.23	.62
Time before assignment due			
Looked at pre-class	.17	.92	-.04
Looked at homework	.41	.85	.10
Submitted homework	.39	.81	.16
Fraction assignment attempted			
Pre-class	.00	.81	.27
Homework	.40	.77	.37
Score on diagram assignments	.21	.14	.78
Score on written solutions	.01	-.02	.87
Length of pre-class responses	-.05	.44	.76

Three factors are identified representing different aspects of student effort and engagement. Factor 1 ('Dutifulness') reflects the completeness of students turning in assigned work, and Factor 2 ('Online Discipline') reflects early and complete work on on-line assignments. The interesting thing about Factor 3 ('Engagement') is that average scores on written assignments and length of pre-class question response lengths are not obviously related quantities, suggesting that this scale reflects something more fundamental. This scale also correlates at the $p < 0.05$ level with two EBAPS scales: Nature of Knowing and Learning (0.47) and Source of Ability to Learn (0.57).

Factor 3 also proves to be the most useful measure in explaining student course performance. Stepwise linear regressions were carried out on each of the major grade categories, exams, and FCI scores as functions of these three factors plus pre-instructional FCI scores, the last serving as a measure of initial physics understanding. (See Table 2.) Factor 3 (Engagement) demonstrates a significant predictive ability on eight of the ten measures of student

performance listed, and is the only significant factor on five measures. The last measure, gain on the FCI was calculated following Hake,¹ except for each student individually:

$$\text{FCI gain} = \frac{\text{FCI}_{\text{post}} - \text{FCI}_{\text{pre}}}{100\% - \text{FCI}_{\text{pre}}} \quad (1)$$

TABLE 2: Predictive value of the Engagement Factor. Shown are the normalized linear regression coefficients (β) for ten measures of student performance in the course as a function of the three effort scales and pre-instructional FCI scores.

	Factor			Pre
	1	2	3	FCI
Pre-class Total	.39	.09	.59*	-.13
Chapter Total	.69*	.16	-.15	-.27
In-class Total	.37	.22	.31	.12
Homework Total	.82*	-.03	.22*	-.02
Exam 1	.01	-.15	.44*	.58*
Exam 2	.17	-.16	.61*	.35
Exam 3	-.23	-.40	.64*	.28
Final Exam	.14	-.28	.53*	.17
Post FCI	-.12	-.26	.46*	.54*
Gain on FCI	-.18	-.29	.53*	.01

* Significant at the $\alpha=0.05$ level.

Note the very small value of beta for pre-instructional FCI into the FCI gain, which has a p value of nearly 1 (no relation). Note also in Table 3 that the Engagement Factor proves to be a better predictor of FCI gains than any of the individual components it comprises.

TABLE 3: Comparison of linear regression of gain on the FCI by the Engagement Factor and the three measures it is comprised of. The combination of the three is a better predictor than any individually.

Independent variable	R ²	β	p
Engagement Factor	.28	.53	.020
Score on diagram assignments	.25	.50	.030
Score on written solutions	.20	.45	.053
Length pre-class response	.19	.43	.065

RESULTS AND DISCUSSION

Three different scales representing different aspects of student effort and engagement were constructed, and one proved to be productive in predicting many measures of student performance, including gains on the Force Concept Inventory. The statistical evidence arguments that the Engagement Factor reflects student engagement will be summarized, followed by a discussion as to why these particular measures seem to reflect student engagement in the course.

The Engagement Factor is a significant predictor of all but chapter summary and in-class scores. The chapter summary grade depends largely on simply turning in the assignments (reflected in Factor 1) and similarly the overall homework score is most affected

by missed assignments. In-class score reflects group activities with significant participation credit, so it largely reflects class attendance. The pre-instructional FCI score is only significant on the first exam and would enter in with a decreasing beta with each subsequent exam, consistent with the author's observation that students with strong physics backgrounds often can 'cruise' through the first unit, but that advantage disappears with subsequent exams. The Engagement Factor is a strong predictor of FCI gains while pre-instructional FCI is not, consistent with Hake's original claim of the utility of the normalized gain. The Engagement Factor also correlates significantly with two scales on the EBAPS, the only one of the three factors and pre-FCI that correlate with any of the EBAPS scales. Furthermore, it correlates significantly with the two EBAPS scales that seem most related to productive student engagement: *Nature of Knowing and Learning* which probes how much they believe learning is a matter of effort compared to innate ability, and *Source of Ability to Learn*, which concerns the role of the student compared to that of teacher/instructional materials. The combination of the three measures into the Engagement Factor is also a better predictor than each alone. The Engagement Factor demonstrates statistical characteristics that would be expected of a quantitative measure of student engagement.

The reasons that these particular measures combine into a scale reflecting student engagement may reflect particular aspects of the course. The diagram assignments were due the day after the diagrams were introduced and students had practiced making such diagrams in class. As the assignments concerned different situations than class examples, assignment scores reflected in part the student's ability to grasp and internalize the principles used in class and apply them in a different situation. The written solutions were typically on more challenging homework exercises following examples worked out in class and group-problem solving of problems for that topic; again this represents in part the student's ability to extract, internalize, and apply principles to slightly different situations. The pre-class questions were graded 'on effort,' which in practice meant full credit for any meaningful response. Therefore, the length of the responses was entirely up to the student, reflecting the degree that students chose to answer questions completely, explain their reasoning, describe their own experiences, ask questions themselves, and otherwise fully engage themselves in answering the questions.

CONCLUSIONS

This work demonstrates the usefulness of on-line homework systems in constructing measures of student behavior. One such measure, composed of written homework scores and length of pre-class responses, not only demonstrates strong predictive ability for class test scores but also explains gains on the FCI completely independent of pre-instructional scores. Thus this measure appears to capture, at least in part, the level of individual student engagement with the material. Further work needs to look at the degree this or similar measures are predictive in different instructional settings.

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