Continued Assessment of i-Newton for the Engaged Learning of Engineering Dynamics

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Introduction

There is a wealth of research providing quantitative and qualitative evidence supporting the many benefits of engaged learning and its overall importance in the future of higher education. In their seminal work, Chickering and Gamson assert, "Learning is not a spectator sport. Students do not learn much just by sitting in classes listening to teachers, memorizing pre-packaged assignments, and spitting out answers" (1, p. 4). In that regard, the vast majority of engineering dynamics courses do not typically include opportunities that allow for observation and investigation of the Newtonian mechanics derived and studied in class, which is understandable given the financial and logistical difficulties associated with creating companion laboratories. However, engineering dynamics is often regarded as one of the most difficult courses that students encounter during their undergraduate studies [2, 3], and the difficulty is frequently attributed to the abstract nature of the material [4, 5]. One line of research focuses on integrating computer simulations into the curriculum, which has been shown to have positive effects on student conceptual understanding [6-9]. For a number of different STEM fields, demonstrations and experiments have also been shown to markedly improve student conceptual understanding compared to traditional teaching methods [10-12]. To that end, this work introduces a series of engaged learning activities in an otherwise lecture-only dynamics course using a sensor technology that we call interactive-Newton (i-Newton) as a learning platform. This technology (Fig. 1) represents a versatile, portable, and inexpensive means for students to explore dynamics concepts in any setting without a substantial investment in traditional laboratory apparatuses.
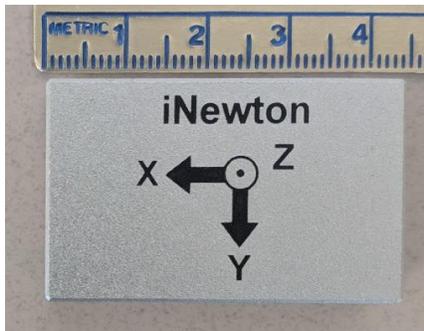

Figure 1: An i-Newton with the sensor-fixed frame of reference etched on top. It contains a triaxial accelerometer and angular rate gyro (that measure linear acceleration and angular velocity, respectively) as well as a microcontroller and flash memory for data sampling and storage.

In the classroom, active learning is traditionally defined as any instructional practice that involves students in the learning process through approaches like cooperative learning, problem-based learning, and hands on exploration [11]. One type of active learning that can be extended outside of the classroom is experiential learning in which students are given the opportunity to explore the subject under study [13], which in the context of this research is engineering dynamics. Given that each i-Newton sensor measures linear acceleration and angular velocity, it readily provides motion data that is highly relevant for a number of dynamics concepts. Thus, the i-Newton represents a novel, ready-made platform to explore and learn engineering dynamics as

a new form of engaging experiential learning that can be implemented in and out of the classroom. The exercises in which the students use i-Newton represent a new learning intervention within an otherwise lecture-only class where previously exposure to concepts was solely through textbook problem solving. This intervention consists of three levels (Table 1) systematically scaling up the degree to which the students engage with the i-Newton technology.

Table 1: *Descriptions of the i-Newton intervention levels.*

Level	Intervention (progress to date)	Description
0	Control (completed)	No intervention
1	Demonstrations (completed)	Instructors demonstrate two experiments with i-Newtons in class for students after which they analyze the data outside of class
2	Prescribed Experiments (completed)	Students conduct and analyze data collected during two prescribed experiments with i-Newtons outside of class
3	Student Created Projects (in progress)	Students propose and conduct experiments of their own imagining (with instructor feedback) with the i-Newtons outside of class

A timeline illustrating how these interventions are being implemented is illustrated in Fig. 2 below. It should be noted that one of the Fall 2018 semesters (a small section of 19 students) had the Level 3 intervention (Student Created Projects). This was to assess how to implement this intervention in the large sections in the Winter/Spring 2019 semester as effectively as possible.

Figure 2: *Timeline describing when the interventions (Control, Demonstrations, Prescribed Experiments, and Student Created Projects) are being implemented in this project. Green boxes denote completed intervention levels and yellow boxes denote intervention levels that are ongoing. Each greyscale box represents a semester indicating many sections and how many students enrolled in the course.*

A previously conducted pilot study [14] provided the foundation for this project's hypotheses that this intervention will increasingly and positively affect student: 1) conceptual understanding of dynamics, 2) self-efficacy, 3) intention to persist in the field, and 4) feelings of inclusion. Previously reported findings suggested the Level 1 intervention (Demonstrations) had limited impact on student conceptual understanding and self-efficacy, a positive impact on intention to

persist, and a negative impact on feelings of inclusion [15]. This paper serves as an update to include the results from the Level 2 intervention (Prescribed Experiments).

Methods

This study is conducted in the context of an introductory dynamics course that includes units dedicated to three-dimensional particle motion, planar rigid body motion, and basic vibrations. Historically, the course operates using traditional lecture-only instruction with no associated laboratory.

Survey Instruments

Students completed an online survey for extra credit that combined two previously validated instruments: Dynamics Concept Inventory (DCI) [4] and Longitudinal Assessment of Engineering Self-Efficacy (LAESE) [16]. The DCI is a collection of 29 questions relating to 14 important and/or commonly misunderstood concepts previously identified via a modified Delphi process [4]. Recent results revealed several questions on the DCI may not actually be giving additional information about student understanding of dynamics concepts [17]. In that study, four questions were deemed unsuitable based on an assortment of statistical criteria. After conducting the same type of analysis on end of semester DCI responses collected to date on this project, four items were dropped from consideration (three of which were the same as those dropped in [17]). Therefore, the remainder of the analysis regarding the DCI (overall scores and gains) concerns the remaining 25 questions. Gains in conceptual understanding were calculated using the definition from [10]

$$gain = \frac{post\ score - pre\ score}{100\% - pre\ score} \tag{1}$$

which represents a normalized gain in the sense that how much a student gained normalized by how much they could have gained given what they came into the class already knowing. This survey is intended to address our first hypothesis that the i-Newton intervention will improve student conceptual understanding of dynamics.

The modified LAESE is a collection of 45 items relating to four subfactors: 1) engineering self-efficacy, 2) course-specific self-efficacy, 3) intention to persist in the field, and 4) feelings of inclusion. These items are rated on a Likert-type scale, which means the values were normalized by the maximum value of the question's scale. The subfactor scores are computed as the arithmetic mean of the normalized item scores. Gains were evaluated on an absolute scale. The results from this survey are intended to inform the other three hypotheses that the i-Newton intervention will improve student self-efficacy, intention to persist in the field, and feelings of inclusion.

i-Newton Demonstrations and Prescribed Experiments

The control group's DCI scores determined which concepts were not well understood by the students at the close of the semester, which was also confirmed with what has been reported previously in the literature [17-19]. For example, students struggled the most with the following concepts covered by the DCI [17]:

- Different points on a rigid body have different velocities and accelerations, which vary continuously.
- The direction of the friction force on a rolling rigid body is not related in a fixed way to the direction of rolling.
- A particle has acceleration when it is moving with a relative velocity on a rotating object (also known as Coriolis acceleration).

Thus, two demonstrations were designed by the instructors to show these principles for the Level 1 intervention. Following the in-class demonstrations, the students were given the relevant i-Newton data to complete an assignment outside of class that exposes and explains these concepts. Specifically, the two demonstrations were focused on explaining: 1) Coriolis acceleration in the context of particle motion, 2) angular velocity and acceleration of different points on a rigid body, and 3) the rolling without slip condition. The assignments were different between the two semesters following feedback elicited from both the students and instructors during the first semester of demonstrations. A detailed description of these demonstrations is provided in [21].

The first prescribed experiment (Level 2 intervention) focused on familiarizing the students with the IMUs as well as developing student intuition for acceleration. The assignment, which involved balancing an inverted pendulum in the palm of a hand, was kept purposefully simple to promote quick learning of how an i-Newton works. For the assignment, students used the fact that the i-Newton is measuring acceleration due to gravity to determine the lean of the pendulum, a measure of balance performance. The mass of the bob is significantly greater than the mass of the dowel rod, and students explored the difficulty of balancing the pendulum with the bob at three different predefined heights. Students were asked to repeat the experiment with the bob at the tallest height with both hands. Whichever hand did better (using the balance performance metrics they derived and calculated), they were then instructed to conduct the experiment two more times with the bob at the lower two (more difficult) heights.
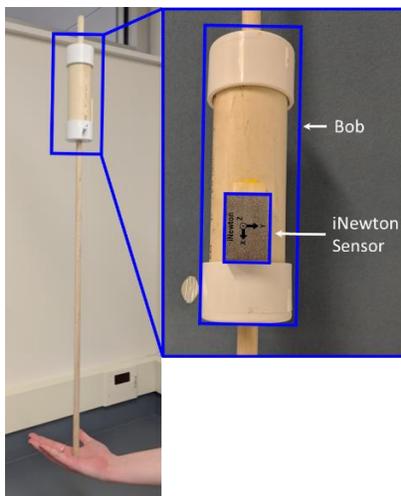

Figure 3: Photo of the first prescribed experiment (Level 2 intervention) with a callout of the i-Newton attached to the bob of the inverted pendulum.

The second prescribed experiment (Level 2 intervention) is effectively the same as the second demonstration (Level 1 intervention). It was designed to study rigid body kinematics, rolling

without slipping, and Newton's second law for a rigid body. Students were instructed to push a Frisbee to produce initial linear and angular velocities and then allow the Frisbee to roll freely thereafter (while leaning against a wall) subject to dissipative forces. They measured how far the Frisbee rolled and compared it to the distance they estimate from the i-Newton data they collected during the trial.

Participants

The introductory dynamics course is either mandatory or serves as an elective for several engineering disciplines at a large public university. Within a semester, each section was taught by a different instructor, though there are common instructors between semesters. It should also be noted that 4 of the 19 sections were small sections of 20 students or fewer.

Table 2: *Participants in the study to date for each intervention level. Participation is defined as any student who attempted to complete any portion of the surveys at the beginning and end of the semester. Intervention (Student Created Projects) is currently in progress, so participation is not yet available.*

Level	Intervention	# Semesters	# Sections	Total Enrollment	Total Participation (Response Rate)
0	Control	1	3	172	148 (86%)
1	Demonstrations	2	7	451	353 (78%)
2	Prescribed Experiments	2	5	473	352 (74%)
3	Student Created Projects	2	4	299	TBD

Even though the students were incentivized to complete the surveys for modest course extra credit (meaning the stakes are very low), it was previously reported that administering the DCI in this setting yields results that are representative of students' conceptual understanding in a high stakes setting [20]. However, to discriminate between students who completed the survey questions with effort from those who did not, three inclusion criteria were used: number of questions answered, time spent taking the survey, and longest run of the same answer (e.g., selecting the response "a" repeatedly). Furthermore, there were also students who took the class multiple times thereby completing the surveys on more than one occasion. For these cases, the first instance of their participation was retained in the study. Out of a total of 853 students who attempted to complete both surveys, 57 student responses were excluded from the sample based on these criteria (giving a total of 148 students in the control group, 346 in the Level 1 intervention group, and 302 in the Level 2 intervention group).

Results

The results presented forthwith are comparing the control, Level 1 intervention group (demonstrations), and Level 2 intervention group (prescribed experiments). This represents the parts of the study that have been completed to date.

Conceptual Understanding

After confirming normality and homogeneity of variance assumptions, an Analysis Of Variance (ANOVA) revealed there were no statistically significant differences in beginning or end of semester DCI scores across the 3 sections in the control group, the 7 sections in the Level 1 intervention group, or the 5 sections in the Level 2 intervention group. The results for the beginning of semester scores implies each section was generally representative of the student population taking the course in any given semester. The results for the end of the semester scores implies there were not any differences in learning between sections. The ANOVA for the control group's beginning of semester survey $(F(2,145)=0.98, p=0.38)$ confirms that the students in each section start with the same level of knowledge. The ANOVA for the end of semester survey $(F(2,145)=0.53, p=0.59)$ confirms students received the same level of instruction independent of instructor. This is also true for students in the Level 1 intervention group for the beginning $(F(6,339)=0.24, p=0.96)$ and end $(F(6,339)=0.96, p=0.45)$ of semester surveys. Finally, the Level 2 intervention group also followed this trend with the students' beginning $(F(4,297)=0.81, p=0.52)$ and end $(F(4,297)=0.91, p=0.46)$ of semester surveys. The descriptive statistics for the groups' performance are documented in Table 3 below.

Table 3: *Mean (standard deviation) of scores on the DCI subset at the beginning of the semester (pre), end of the semester (post), and overall gain (Eqn. 1).*

	pre %	**post %**	**gain**
Control	40.3 (16.1)	50.1 (19.0)	0.17 (0.23)
Level 1 Intervention	44.1 (16.6)	51.3 (18.8)	0.12 (0.29)
Level 2 Intervention	43.1 (17.4)	49.8 (19.8)	0.11 (0.28)

For the ANOVA performed on the DCI beginning of semester scores, there was not a significant relationship between intervention group and DCI pre scores $(F(2,793) = 2.72, p = 0.07)$, implying that the students at the start of the term were largely the same entering the course. For the ANOVA performed on the DCI end of semester scores, the intervention groups also did not significantly differ from one another $(F(2,793) = 0.58, p = 0.56)$, implying that the students at the end of the term knew roughly the same material. For the ANOVA performed on the DCI gains, the intervention groups still did not significantly differ from one another $(F(2,793) = 2.08, p = 0.13)$, implying that the first two levels of the intervention (demonstrations and prescribed experiments) have limited impact on student conceptual learning by this measure.

Self-Efficacy, Intention to Persist, and Feelings of Inclusion

Gains on the LAESE subfactors are defined as the absolute gain, meaning the end of semester value minus the beginning of semester value. These results are plotted in Fig. 2 below. The error bars are two times the standard error, which means if the x-axis is contained within those error bars, the gains are not statistically significantly different from zero. For example, all three groups' error bars for course-specific self-efficacy (CSE) do not cross the x-axis, implying all three groups experienced statistically significant negative gains. However, it is also important to

note the scale for those gains. Each subfactor item is normalized to 1 based on the item's Likert scale. This means, for example, a 0.01 gain corresponds to a 1% change overall.
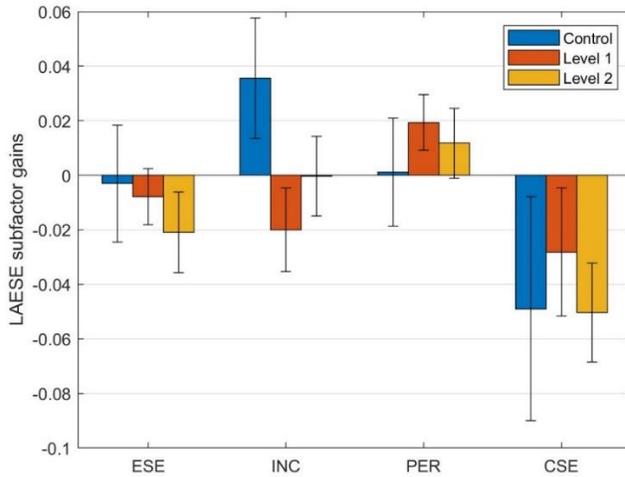

Figure 2: Graphs showing gains with two standard error bars for each intervention group (Control, Level 1, Level 2) for each of the subfactors being measured by the modified LAESE including: 1) engineering self-efficacy (ESE), 2) feelings of inclusion (INC), 3) intention to persist in the field (PER), and 4) course-specific self-efficacy (CSE).

From Fig. 2, engineering self-efficacy (ESE) generally has negative gains regardless of intervention. However, the Level 2 intervention group (Prescribed Experiments) has negative gains that are statistically different from 0 whereas the other two groups do not. All three groups also experience significant negative gains in their course-specific self-efficacy (CSE). Persistence (PER) generally has positive gains, though the Level 1 intervention group (Demonstrations) is the only group with gains significantly different from 0. Feelings of inclusion (INC) has mixed results with notable differences between the groups. This was confirmed with an ANOVA ($F(2,793) = 8.85$, $p < 0.001$) and Tukey post hoc tests, which revealed the control group was indeed significantly different from both the Level 1 intervention group ($p<0.001$) and the Level 2 intervention group ($p=0.02$).

Discussion and Conclusions

With respect to overall student conceptual understanding of the course material, two demonstrations (Level 1 intervention) and two prescribed experiments (Level 2 intervention) over the course of an entire semester have limited impact on improving conceptual understanding. The demonstrations did not require active engagement of the students beyond watching two demonstrations and then completing two associated assignments. The prescribed experiments did require the students to actively engage with the process by performing the experiments themselves, but the process itself was more akin to a "plug and play" exercise, meaning the students were essentially required to closely follow directions. The conceptual understanding results are not altogether unsurprising given confirmatory evidence in the pilot study [14] as well as the results reported by Hake in [10]. In particular, Hake found that little to no active engagement resulted in significantly smaller gains compared to courses that made

considerable use of active learning techniques [10]. It is likely that both the demonstrations and prescribed experiments fall into the category of little to no active engagement. Nevertheless, we hypothesize the effects previously alluded to will become prominent when the students have the opportunity to transfer the content learned in class to a context outside of class. In the third and final intervention level, students will be designing and conducting experiments of their own imagining wherein they will need to make the connections between what they are proposing and the course concepts. Importantly, the students are required to identify the concepts from the class that are present in the experiments that they design. The small impact the first two levels of the intervention (demonstrations and prescribed experiments) had on conceptual understanding suggests the activities are likely not significantly contributing to the students' overall experiences in the class. In light of this, engineering self-efficacy and course-specific self-efficacy are also understandably very similar as that the control group since students in all of the different groups have largely the same experience in the course. The increase in persistence bodes well for further increase with Level 3 intervention. Feelings of inclusion, however, have mixed results suggesting there are likely other factors that could explain this finding.

Acknowledgements

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