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Introduction and Assessment of i-Newton for the Engaged Learning of Engineering Dynamics

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Introduction

Engineering dynamics (Newtonian mechanics) is often a difficult subject for students to grasp, particularly when taught in traditional lecture-only settings. In lecture-only settings, students often exercise concepts solely through idealized textbook problems which provide little to no opportunity for understanding or exploring in realistic contexts [1]. This is understandable given the considerable expense and resources needed to create companion laboratories where students might otherwise explore concepts through hands-on experimentation. Despite these difficulties, it has been shown across STEM fields that demonstrations and experiments can dramatically improve student learning compared to traditional teaching methods [2, 3]. This project aims to introduce hands-on experiments in an otherwise traditional dynamics course as a new platform of active learning. The hands-on experiments are possible through a MEMS sensor technology that we call interactive-Newton (iNewton) that represents a versatile, portable and inexpensive means for students to explore concepts in dynamics inside or outside of the classroom. In other words, iNewton has the potential to promote the learning benefits on hands-on exploration, but without the large investment otherwise required for a dedicated companion laboratory.

Figure 1: *An iNewton with the sensor-fixed frame of reference etched on top. It contains a triaxial accelerometer and angular rate gyro, which measure linear acceleration and angular velocity, respectively.*

Active learning is a process wherein students engage in activities like cooperative learning, problem-based learning, and hands-on exploration to build their conceptual understanding through their own experiences [4]. The exercises in which the students use iNewton represent an active learning intervention within an otherwise traditional lecture class where exposure to concepts it through textbook problem solving. This intervention will have three levels (Table 1) where we systematically scale up the degree to which the students engage with the technology.

Table 1: *Descriptions of the iNewton intervention levels.*

Level	Intervention (and progress to date)	Description
1	Instructor-Created, Instructor-Led (completed)	Instructors demonstrate two experiments with iNewtons in class for the students
2	Instructor-Created, Student-Led (in progress)	Students conduct two pre-defined experiments with iNewtons outside of class
3	Student-Created, Student-Led (under development)	Students propose and conduct experiments of their own imagining (with instructor feedback) with the iNewtons outside of class

With a previously conducted pilot study as a foundation [5], we hypothesize these different interventions will increasingly and positively affect: 1) student conceptual understanding of dynamics, 2) student self-efficacy, 3) student intention to persist in the field, and 4) student feelings of inclusion.

Methods

The introductory dynamics course covers concepts in three-dimensional particle motion, planar rigid body motion, and basic vibrations. The course uses traditional lecture-only instruction; there is no laboratory associated with this course.

Participants

The intervention took place in an undergraduate introductory dynamics course that serves several engineering disciplines at a large public university. One semester (Fall '16) comprised 3 sections, which enrolled a total of 172 student, 151 of which who completed surveys at the beginning and end of the semester. This semester represents the control group without the iNewton intervention. The two subsequent semesters (Spring/Winter '17, Fall '17) comprised 7 total sections, which enrolled a total of 451 students, 362 of which completed surveys at the beginning and end of the semester. This semester deployed the Level 1 intervention by introducing two instructor-created, instructor-led demonstrations. Within a semester, each section was taught by a different instructor. However, there were common instructors between semesters.

Survey Instruments

At the beginning and end of the semester, students completed an online survey for extra credit that combined two previously validated instruments: Dynamics Concept Inventory (DCI) [6, 7] and Longitudinal Assessment of Engineering Self-Efficacy (LAESE) [8]. The DCI probes student understanding of engineering dynamics with a collection of 29 questions focused on 14 important and/or commonly misunderstood concepts. The results of this survey will evaluate hypothesis (1) that this intervention will increase student conceptual understanding of dynamics. The modified LAESE consists of 45 items designed to measure 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 use a Likert-type scale, thus the values were normalized by the maximum value of the question's scale, and the subfactor scores are computed as the arithmetic mean of the associated normalized item scores. This survey's results will inform hypotheses (2)-(4) that this intervention will increase student self-efficacy, intention to persist in the field, and feelings of inclusion.

Conceptual Frameworks

We use two conceptual frameworks to interpret the results. First, a constructivist framework asserts "that the learner is the one that determines how long term memories are constructed … and the final form of memories are more a function of what already exists in long term memory, how the learner interprets new information, and how the learner forms the connections and formats the content" [9]. Students are building new conceptual understanding of the class material based on what they learn through their experiences with iNewton demonstrations or experiments. The active learning approach lends itself to this framework since the experiments are designed to present the students with a tangible experience of specific concepts.

Second, we will also consider a self-determination lens, which “revolves around the degree to which learners believe they have choice and control over their actions, they are competent to complete a task, and they are part of a community of support and belonging” [9]. Since the students are going to be conducting (Level 2 and Level 3) and eventually proposing their own experiments (Level 3), we believe they will report higher gains for self-efficacy and intention to persist. Furthermore, we believe students will chose to conduct experiments that are interesting to them in Level 3 and will therefore be more inclined to understand the concept they are trying to learn and demonstrate.

iNewton Experiments

Commonly misunderstood concepts, which were identified from the control group DCI responses, confirmed our findings with what has been reported in the literature [10-12]. In particular, Concepts #1, #10, and #11 were among those on which students performed most poorly. Thus, we designed two instructor-created, instructor-led demonstrations to show these principles for the Level 1 intervention. Following the experiment demonstrations, the students were given the relevant data from iNewton and completed an assignment designed to expose and explain these concepts. 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, though focused on these concepts, were distinct between the two semesters. Feedback from students and instructors was solicited during the first semester of demonstrations to improve the experiments and associated assignments.

Results

We present results for the control and Level 1 intervention groups; the two portions of our study completed to date. Because the surveys were administered online with course extra credit as incentive, the stakes are very low. Thus, to discriminate between students who completed the survey questions with effort from those who did not, we used three inclusion criteria: amount of time spent taking the survey, number of questions answered, and longest run of the same answer (e.g., selecting the response “a” repeatedly). Out of a total of 442 students who completed both surveys, 21 students were excluded from our sample based on these criteria (giving a total of 145 students in the control group and 346 in the Level 1 intervention group).

Conceptual Understanding

After confirming normality and homogeneity of variance assumptions, an Analysis Of Variance (ANOVA) revealed there were no statistical differences in beginning or end of semester DCI scores across the 3 sections in the control group or the 7 sections in the Level 1 intervention group. The ANOVA for the beginning of semester survey ($F(2,142)=0.59$, $p=0.56$) confirms that for the control group, the students in each section start with the same level of knowledge. The ANOVA for the end of semester survey ($F(2,143)=0.98$, $p=0.38$) 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 ($F(6,339)=0.41$, $p=0.88$) and end ($F(6,339)=1.26$, $p=0.27$) of semester surveys. The descriptive statistics for the groups are documented in Table 2 below. For the Welch’s t-test performed on the DCI beginning of semester scores, the control group did not significantly differ from the Level 1 intervention group ($t(275.5) = -1.96$, $p = 0.06$). This implies that, at the start of the term, the students in the control semester did not significantly differ from the students in the Level 1 intervention. For the Welch’s t-test performed on the DCI end of semester scores, the control group still did not significantly differ from the Level 1 intervention group (t(255.1)=-0.05, p=0.65), implying that the Level 1 intervention had limited impact on student conceptual learning.

Table 2: *Mean (standard deviation) of scores on the 29-item DCI at the beginning of the semester (pre), end of the semester (post), and overall gain (defined in [3] as (post-pre)/(100%-pre)).*

	pre %	**post %**	**gain**
Control	37.7 (14.6)	46.1 (18.3)	0.14 (0.22)
Level 1 Intervention	40.6 (14.9)	46.9 (17.2)	0.10 (0.23)

When *post* scores are broken down by DCI concept, the difference in performance between the students in the intervention group and those in the control group was statistically significant for Concept #3 (t(256.5)=-1.98,p=0.04), with the intervention group scoring higher. This concept concerns angular velocities and angular accelerations of a rigid body can vary with time, but not with location on the rigid body. This concept was used to design one of the iNewton experiments and represents a key concept stressed during the follow up assignments.

Self-Efficacy and Intention to Persist

Gains on the LAESE subfactors are defined as the end of semester score minus the beginning of semester score. We conducted t-tests for each subfactor for the control and Level 1 intervention groups to determine if they were significantly different from zero (Table 3). For the control group, inclusion had significant positive gains whereas course-specific self-efficacy had significant negative gains. For the Level 1 intervention group, inclusion had significant negative gains whereas persistence had significant positive gains.

Table 3: *Results for t-tests conducted on gains and means (standard deviations) of gains for LAESE subfactors (engineering self-efficacy (ESE), inclusion (INC), persistence (PER), course-specific self-efficacy (CSE)). *Significant at α=0.05.*

	ESE		**INC**		**PER**		**CSE**	
	gain	**p**	**gain**	**p**	**gain**	**p**	**gain**	**p**
Control	-0.01 (0.12)	0.34	0.03 (0.13)	<0.01*	-0.01 (0.09)	0.75	-0.05 (0.25)	0.01*
Level 1 Intervention	-0.01 (0.10)	0.08	-0.02 (0.14)	0.03*	0.02 (0.07)	<0.001*	-0.03 (0.21)	0.01*

Between the control and Level 1 intervention groups, gains in engineering self-efficacy and course-specific self-efficacy did not differ. However, there was a significant difference in gains in student intention to persist (t(220.4)=-2.11, p=0.04), with the Level 1 intervention group reporting higher gains. There was also a significant difference in gains in feelings of inclusion (t(280.4)=3.9, p<0.001) with the Level 1 intervention group reporting lower gains.

Discussion and Conclusions

With respect to overall student conceptual understanding of the course material, two instructor-created, instructor-led demonstrations (Level 1 intervention) over the course of an entire semester have limited impact on improving understanding. This form of the intervention does not require active engagement of the students beyond passively watching two demonstrations and then completing two associated assignments. This is not altogether unsurprising given confirming results from our pilot study [5] as well as the results reported by Hake in [3]. Hake found that traditional courses that used little to no active engagement of the students resulted in significantly smaller gains compared to the courses that made considerable use of active learning techniques [3]. Therefore, we hypothesize the effects discussed above will become prominent only after students become more engaged with iNewton experiments (i.e. in Level 2 and Level 3 interventions). Given the small impact the Level 1 intervention had on conceptual understanding, engineering self-efficacy and course-specific self-efficacy are understandably very similar as that the control group. The increase in persistence bodes well for further increase with Level 2 and Level 3 intervention.

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