

TWENTY-YEAR TRENDS IN STUDENT READINESS, PERFORMANCE, AND LEARNING IN BIOMECHANICS

ChengTu Hsieh¹, Brian Wallace², and Duane Knudson³

California State University, Chico, California, USA¹
University of Wisconsin, Oshkosh, Wisconsin, USA²
Texas State University, San Marcos, Texas, USA³

The aim of this study was to investigate the trend in student's Biomechanics Concept Inventory (BCI) performance over the past two decades (2003 - 2023) in the United States. The mean pre-, post-tests of BCI performance, and normalised gain (g) were extracted from published studies for analysis. Eight studies with 937 participants were examined. The Mann-Kendall tests were used to assess the trend of the datasets. No significant downward or upward trends were observed for both pre-tests ($p = 1.0$) and post-tests ($p = 0.07$) performance. However, there is an upward trend in students' normalized gains since 2003 ($p = 0.02$). Over the past twenty years, there has been no significant change in students' BCI entry and exit scores, while mean learning measure g had a large increase as more recent studies have focused on active learning (AL) strategies.

KEYWORDS: ACT, concept inventory, GPA, normalised gain, SAT, test.

INTRODUCTION: Are students adequately prepared for rigorous university classes, particularly in the sciences? Historically, students' college readiness has been assessed through various means such as standardized tests or previous academic achievement, specifically High School Grade Point Average (HSGPA) in the US. Standardized tests like the Scholastic Aptitude Test (SAT) and American College Test (ACT) evaluate students' proficiency in reading, writing, math, and science. Recently, these assessments have reported a downward trend in students' achievements, particularly in reading, math, and science skills despite concurrent inflation of HSGPA and college GPA (CGPA), especially during the pandemic (Cohodes et al., 2022; Gershenson, 2018; Horowitz et al., 2023). This inflation of HSGPA does not align with the downward trend of standardised test performance of high school students.

Each year, millions of high school students take standardized tests to demonstrate their readiness for college education in the US. A recent ACT report (NCES, 2023) shows a 5 to 7% consistent decline in average performance since 2017 in reading (21.4 to 20.4), English (20.3 to 19), math (20.7 to 19.3), science (21 to 19.9), and STEM (21.1 to 19.9), as well as the percentage of test-takers who met area benchmarks (27% to 22%). Only the average English performance is still above the benchmark after the decline. 'A benchmark score is the minimum score needed on an ACT subject-area test to indicate a 50% chance of obtaining a B or higher or about a 75% chance of obtaining a C or higher in the corresponding credit-bearing college courses' (Sanchez & Moore, 2022). Although some of this downward trend may be attributed to the outbreak of the pandemic, it started before the pandemic. A smaller decline (4%) was also observed for SAT scores (1068 to 1028) since 2018 after adjusting the test scores to a new scale in 2017 (Nam, 2023; SAT Suite Data and Reports Archive, n.d.). In summary, the continual decline of reading skills contributes to long-standing concerns in kinesiology/exercise science programs (Kelley & Phillips, 1984) regarding student readiness in physical science courses like introductory biomechanics (Hsieh et al., 2014).

Biomechanics instructors have anecdotally noted concern about incoming students' mastery of prerequisite knowledge in anatomy and math (Barlow, 1997). Some data on these preparation concerns and student learning can be gathered from using the Biomechanics Concept Inventory (BCI). Three versions of the BCI (Knudson, 2006; Knudson et al. 2003) are based on the [Guidelines for Undergraduate Biomechanics](#) (SHAPE America, 2018) for kinesiology /exercise science majors in the US. The BCI has 24 questions, 8 related to prerequisite knowledge (anatomical terms, muscles/joints, graphs, & algebra) and 16 related to eight biomechanics concept areas (muscle mechanics, motor units/EMG, linear kinematics, angular kinematics, linear kinetics, angular kinetics, fluids, & application). To quantify learning,

most BCI studies administer a pre-test, post-test, and calculate improvement, often as a normalized gain (g) score (Hsieh et al. 2012). Learning scores like g are superior to performance measures like course grades because they are not subject to grade inflation. Over the past two decades, dozens of studies have used the BCI to assess the learning of biomechanics concepts in response different pedagogical techniques, but not student performance measures like pre-test scores on the 8 prerequisite questions.

Much has been discovered about factors associated with students' learning (e.g., Hsieh & Knudson 2008; Hsieh & Knudson, 2018; Hsieh et al., 2012) and the effects of instructional strategies on students' learning core biomechanics concepts (e.g., Riskowski, 2015; Wallace et al., 2020). Prior to the COVID-19 pandemic, CGPA coming into the introductory biomechanics course were reported as significantly associated with learning (Hsieh & Knudson, 2008; Hsieh et al., 2012; Hsieh & Knudson, 2022). It is crucial to understand students' entry abilities and be prepared for necessary curricular and pedagogical adjustments to meet students' needs in the future. Given the inconsistency of results from standardized tests (ACT & SAT) and HSGPA for students' performance in science classes, it is important to explore BCI scores throughout the years. Therefore, this preliminary study aims to investigate the trend in mean students' readiness for undergraduate introductory biomechanics classes over the past two decades. The hypotheses examined were that mean students' BCI pre- and post-test performance and learning (g) are declining in the US over the previous 20 years.

METHODS: To examine the study hypotheses reported mean BCI data published in peer-reviewed studies by authors and collaborators between 2003 and 2023 were analysed. To maintain the integrity and the consistency of the BCI test outcome (Amorado & Vilchez, 2023; Knudson & Bopp, 2021), only the studies that delivered the BCI v1 in person were included. This resulted in eight studies between 2003 and 2023, comprising a total of 937 students. The students' mean number of correctly responses in pre-, post-test, and normalised gain (g) in percentage were extracted for analysis (Table 1). Three Mann-Kendall tests were performed for each dependent variable to examine potential linear trends over the years with statistical significance set at 0.05. The trend line for all data points was plotted for analysis.

Table 1: Longitudinal BCI v1 performance (with hyperlink) using the BCI v1.

Study	Year	Sample size	Pre-Test	Post-Test	Gain (g; %)
Knudson et al.	2003	367	8.5	10.5	12.9
Hsieh & Knudson	2008	49	8.8	11.7	19.1
Hsieh	2013	47	8.8	11.7	19.0
Wallace & Knudson	2019	38	9.3	11.5	14.7
Knudson & Wallace [^]	2019	82	9.4	12.6	21.9
Knudson & Wallace [^]	2019	70	9.3	11.6	15.7
Wallace, Knudson, & Gheidi [^]	2020	38	8.0	11.6	22.5
Wallace, Knudson, & Gheidi [^]	2020	71	9.5	13.4	26.9
Wallace & Knudson [^]	2020	70	9.3	11.6	15.7
Wallace & Knudson [^]	2020	31	8.7	12.7	26.1
Knudson	2023	74	8.5	15.3	43.9

Note: Study symbols represent two different data sets provided in the same study.

RESULTS: The authors have published 20 studies using all three versions of the BCI given in person and online with similar mean pre-, post-test scores, and gain (9.3, 12.5, & 22.8%) to this controlled sample. Out of the eight papers using BCI v1 given in person, the average number of correctly answered questions (mean \pm SD) for the pre-, post-tests, and average normalised gain are 8.9 ± 0.5 , 12.2 ± 0.5 , and $21.7 \pm 8.7\%$, respectively. The Mann-Kendall tests revealed no significant linear trend for both pre- and post-tests over 20 years ($p = 1.00$ and 0.07 , respectively). However, a significant ($p = 0.02$) linear increasing trend in normalized gain was observed. Figure 1 shows study means and the trend lines for the number of correct questions in pre-, post-test, and the percentage of the normalised gain throughout the years.

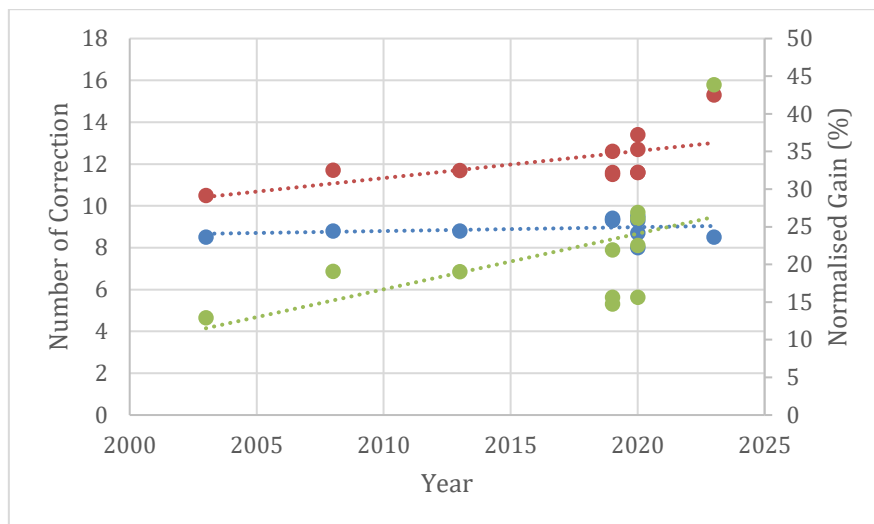


Figure 1: Trend lines for BCI pre-test (●), post-tests (●), and normalised gain (● in percent).

DISCUSSION: Students' entry knowledge about biomechanics using the BCI is consistent during the past two decades and did not share the same trend as any standardised tests, HSGPA, or CGPA. Across the past twenty years, students consistently answered a little over one-third of the questions correctly, approximating 9 questions (37%). It is important to reiterate that BCI assesses multiple areas of competency with limited number of questions in each area. Specifically, only about four questions in the BCI pertain to math ability. Hsieh et al. (2014) implemented BCI v3 to examine students' ($n = 162$) competence in biomechanics and found that students' entry algebra and graph reading skills (pre-test) was about 52%, equivalent to about 2 out of 4 questions. Assuming the students who participated in 2014 study were all juniors, their average ACT math performance (60 questions) in 2011 as high school seniors was about 58% (NCES, 2023). This 6% of difference is not even one question apart on algebra and graph reading skill in BCI test. Therefore, BCI may not be sensitive enough to detect the declines in math skill due to its limited number of math-related questions (4 out of 24). Moreover, the most dramatic drop in standardised test performance coincided with the onset of the pandemic in 2020. This would not be visible in this study, however, given the most recent BCI study examined here likely had students graduating high school in 2018-2020. Continued monitoring of students' performance is necessary to gauge the impact of ongoing trends in standardized test performance.

The lack of a downward trend in BCI pre- and post-tests do not align with the GPA in both high school and college. While GPA inflation can be attributed to overall course performance, it is crucial to recognize that grades do not directly assess students' subject matter competency. Grades often involve subjective factors, including participation, effort, extra credit, make-up assignments, and more. Studies (Horowitz et al., 2023; Sanchez & Moore, 2022) underscore the multifactorial issues contributing to grade inflation, such as considerations for financial disadvantage, concerns about pushback from entitled students, potential bias charges related to grading disparities, and the desire for positive teaching evaluations.

Inspection of Figure 1 indicates improving trends in BCI post-test and learning (g), however, only was statistically significant. It is possible the lack of an effect in post-test scores is related to low power from the small sample size. The moderate ($d = 1.4$) linear increase in normalized gain may be attributed to more recent studies emphasizing AL that has been consistently shown to improve learning beyond passive lecture instruction (Hake, 1998). One set of data published in Knudson (2023) demonstrated high improvement, which may warrant further investigation regarding pedagogical approaches and student learning behaviours.

The limitations of the current study include a small sample of intact biomechanics classes, mean BCI scores represent multiple competencies, pedagogical approaches within and between the instructors were not controlled, and time gaps that may influence trend line estimation. It is suggested to continue monitoring students learning post-pandemics and

expand the BCI questions with more specific questions for different backgrounds of students to monitor students' entry, performance, and learning improvement.

CONCLUSION: A close monitor of student's learning in biomechanics is warranted due to the down trend of ACT and SAT performance despite a steady entry ability and final performance in BCI given in person in the US. AL instructions, regardless format, shows an upward trend of student's learning improvement through the years.

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