A PRACTICE-ORIENTED TEACHING STRATEGY INVOLVING BOULDERING IMPROVES STUDENTS' ACADEMIC UNDERSTANDING OF MECHANICS

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Practical experience is recommended in teaching to overcome students' difficulties in learning and applying theoretical concepts such as Newtonian mechanics. The purpose of this study was to test whether incorporating bouldering in a biomechanics course improves students' academic understanding of mechanics. Twenty-one students participated in 10 weeks of traditional lecturing and a subsequent 4-week bouldering intervention. Using different versions of a validated biomechanics test, exam scores were higher after bouldering (73±15%) than before (53±21%) (Z=-3.783, p<0.001). Questionnaire data suggested positive effects of bouldering practice on motivation and satisfaction. Practice-oriented teaching may be adopted in various subjects to facilitate students' learning of theoretical concepts and enhance applicability of knowledge.

KEYWORDS: active learning, biomechanics, physical education, sports science.

INTRODUCTION: Biomechanics is an integral part of physical education and exercise curricula. However, students often have difficulties learning Newtonian mechanics and applying theoretical concepts of physics in practical tasks (Knudson et al., 2009). Various nontraditional learning strategies may help to overcome those difficulties:

Physical activity as breaks and as elements of instruction resulted in improvements in cognitive functioning and learning (Donnelly & Lambourne, 2011; Liu et al., 2017). Cognitive activity during learning, referred to as "active learning", represents another recommended strategy (Rosenthal, 1995). In particular, involvement in laboratory activities helped sport science students to learn biomechanics (Knudson et al., 2009). However, a biomechanics laboratory may be seen as a specific, research-oriented environment. Therefore, more sports-practical scenarios may also be worth consideration for implementing active learning strategies to learn mechanics in human movement.

Various other forms of learning are known for their positive effects: "collaborative learning" allows students to work with peers to create a product, with academic, social, and psychological success (Laal and Ghodsi, 2012). "Cooperative learning" involves teachers with different backgrounds (e.g., "linking agents" from the industry) to support knowledge transfer (Becheikh et al., 2010). "Problem-oriented learning" allows to resolve complex, realistic problems under guidance that effectively fosters deep understanding (Allen et al., 2011). Visualizations like video simulations can help in understanding theoretical content and applying them in practice (Miller & Metz, 2015).

A practical intervention as part of an academic biomechanics course may combine the abovementioned alternative learning strategies, tackling the deficiency in applied understanding of mechanics in sports. Despite the lack of evidence on which sport may be most suitable for such endeavor, one particularly promising option is bouldering, a variant of climbing, because bouldering techniques mainly center around the manipulation of mechanical concepts (e.g., location of center of gravity, optimizing friction through force direction). Due to the limited heights and pre-defined routes, bouldering presents no serious risks and allows for repeated experience of mechanical sensations and the direct impact on movement. This, in combination with the problem-solving nature of sending a route and finding solutions in collaborative efforts with peers, creates great learning opportunities. Therefore, the purpose of this study was to test whether incorporating bouldering in a biomechanics course after completing regular theoretical lectures improves students' understanding of mechanics.

METHODS: Five female and 16 male sports science students (19 – 27 years; 3 undergraduate, 14 graduate, 4 PhD students; completed at least one introductory biomechanics course before; sports practice: weekly activity – national elite level; no prior bouldering experience except for one student) enrolled in a course about applied mechanics in biomechanics. Students were informed about the study, participated voluntarily, signed written consent, and were free to withdraw from the study at any time without consequences for course participation and grading. The course design included traditional classroom teaching during the first ten weeks (control phase) and a subsequent 4-week bouldering experience (intervention phase). Following established recommendations, traditional teaching attempted to be engaging for students, involving realistic illustrations and focusing on sports examples in the classroom setting. During the second phase, students engaged in one hour of bouldering practice per week, experimenting with techniques and body postures, analyzing mechanics with peers, and finding solutions for routes. The practice sessions were held by one biomechanics professor and one climbing coach. In a 30-minute discussion after practice, students discussed their observations. Students worked in teams, recording video material, displaying and explaining mechanical concepts, and submitting a audio-visual analysis at the end of the semester.
Before and after the second phase, respectively, a pre- and a post-exam tested students' understanding of mechanics. The exams were designed based on three different versions of the established Biomechanics Concept Inventory (BCI; Knudson et al., 2003; Knudson, 2004; Knudson, 2006). Adjustments served the purpose of including only the sections relevant for the course (i.e., mechanics) and avoiding misunderstanding due to language barriers. The difference between exam scores in percentage points expressed students' learning gains as g-scores. Absolute g-scores were normalized to the maximum possible improvement between exams (Knudson et al., 2009). In addition, an 11-item questionnaire with 5-point Likert scales (1=strong disagreement to 5=strong agreement) was administered between the first and the second phase to obtain the students' motivation to choose the course, perceived difficulties in learning mechanics, anticipated value of such interventions, and satisfaction with the course design (Figure 2).
Statistics were conducted in IBM SPSS Statistics, version 25.0 (IBMCorp., Armonk, NY, USA), presenting descriptives as mean±standard deviation. Shapiro-Wilk tests revealed that the data were not normally distributed. Consequently, Wilcoxon matched-pairs signed-rank test examined differences between pre- and post-exam scores. Effect sizes were expressed as Z-values. The significance level was set a-priori at $p < 0.05$.

RESULTS: Exam scores including descriptive and inferential statistics were presented as boxplots in Figure 1. Out of all 21 students, 18 individuals performed better in the post- than in the pre-exam, and three students reached identical scores in both exams. No negative performance development was documented. Mean g-score was 20±13% (absolute difference in percentage points) and 40±22% (normalized by maximum possible improvement).

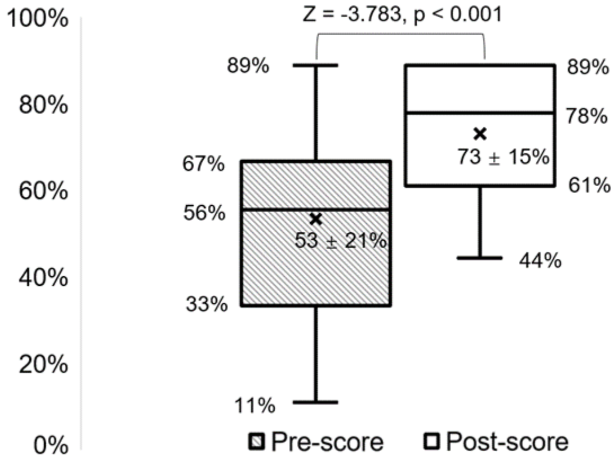

Figure 1: Boxplots with quartiles and ranges of exam scores [%], including mean ± standard deviation and Wilcoxon result for the difference between pre- and post-scores.

The eleven items of the questionnaire and the distribution of responses were presented in Figure 2. Likert scores were averaged within the following response categories: satisfaction with the course design (items 1, 5, and 9): 4.3±0.4; anticipated value of the intervention (items 2, 6, and 10): 4.4±0.1; perceived difficulties in learning mechanics (items 3, 7, and 11): 2.4±0.2; and motivation to choose the course (items 4 and 8): 2.8±0.9.

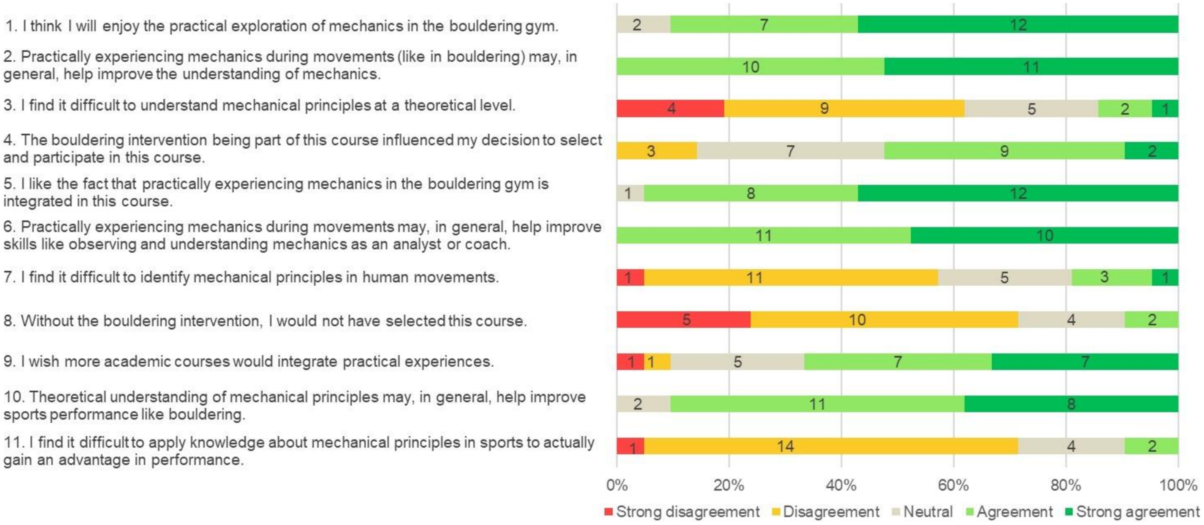

Figure 2: Questionnaire items and students' responses [total number of responses for each response category].

DISCUSSION: Investigating the effect of an integrated bouldering intervention on the academic understanding of mechanics, most students (18 out of 21) improved performance in the post-exam compared with the pre-exam. No negative-responders (i.e., students with decrease in performance) were reported. Currently observed normalized g-scores of 40±22% exceeded the range of normalized g-scores (12-28%) reported in previous studies on teaching biomechanics and physics (Hsieh et al., 2012; Knudson et al., 2009; Redish, 1999). This is remarkable because the current baseline performance (53±21%) was better than the scores in a previous sample of 367 students (pre: 35%, post: 44%) that were also tested via BCI (Knudson et al., 2003). Such a difference was expected as the current sample mainly consisted of graduate students, whereas Knudson et al. (2003) tested students from introductory biomechanics classes (presumably undergraduate students).

Reduced range (pre: 78%, post: 45%) and standard deviation (pre: 21%, post: 15%) were observed in post- compared to pre-exam. Considering that almost all students improved, the reduction in range and standard deviation implied that the intervention facilitated progress in students at all levels while allowing students with weaker baseline performance to catch up with stronger students. We interpret this observation as desirable because it aligns with the idea of equal chances in public education (instead of mechanisms of selection).

Questionnaire responses showed that most students were (strongly) satisfied with the integration of bouldering practice in the course and anticipated the intervention to be valuable. Such positive attitude before entering the intervention may likely contribute to more active engagement and positively influence learning outcomes (Cant et al., 2023).

Although learning biomechanics is typically perceived as difficult by many students (Knudson et al., 2009), most of the current students stated that they do not find it difficult to understand and apply biomechanics (items 3, 7, and 11). First, this may be explained by the current students' background and special interest in biomechanics, enrolling for this selective course. Second, students may have overestimated their own abilities as we would argue that the pre-exam results did not match the students' confidence.

Finally, students' responses (item 4) tended to show that the integration of bouldering in the course had influenced their decision to select the course. Since item 1 and 5 showed great anticipation and satisfaction for bouldering being integrated, we can infer a positive influence despite not being decisive (item 8). However, two students (10%) would have decided against selecting the course without bouldering, thus missing the chance of deepening their understanding of mechanics entirely. Overall, the positive influence of the intervention was helpful to attract students and raise interest in an academic biomechanics course.

The linguistic modifications of BCI questions facilitated correct understanding in non-native speakers and were not deemed influential on validity. Regarding the lack of a control group, the course instructor exploited the possibilities of traditional teaching during the control phase. In addition to infeasibility, continued traditional teaching for an extended time in a control group seemed not promising, and significant improvements would not be expected.

Sensations of altered mechanics within one's own body, combined with analyzing practical experiences alongside peers, appeared to be beneficial mechanisms in the bouldering intervention for enhancing learning. By offering a comparable framework for gathering such experiences, similar effects may also be attainable through other sports.

CONCLUSION: The study implemented a bouldering practice intervention, successfully increasing motivation and academic performance in students. Positive effects on learning gains suggested that incorporating practice-oriented experiences and assignments in academic programs may represent an addition to traditional teaching. This concept may also find application in other subjects.

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