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The power of Embodied Learning in an Online Course with Chinese High Schoolers

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Abstract

In recent years, embodied learning has gained significant attention as a valuable approach to STEM education. However, previous studies have often focused on highly controlled lab experiments and have failed to consider the unique perspectives and backgrounds of learners. The current study aims to replicate the findings of Zhang et al. (2022) by integrating the embodied learning intervention into an online class with students that may differ in important ways from American college students (Chinese high school students). Students were introduced to abstract concepts related to randomness and using coding to mimic a shuffling process. Students in sections were randomly assigned to get this introduction through an embodied hands-on video or a less-embodied live-coding video. The learning outcomes were evaluated through authentic class assessments (homework and exam). Results showed that students introduced to target concepts with the more embodied video outperformed those who watched the less embodied video. The benefit of embodiment was observed only on questions related to the topic covered in the intervention videos.

Keywords: embodied learning, cultural difference, class intervention, learner characteristics

Introduction

Background

In the past few decades, research on embodied cognition has revealed an intimate bidirectional relationship between mind and body. This understanding presents a powerful opportunity for instructional design, allowing for thoughtful incorporation of the body as an active participant in the learning process. By utilizing the insights of embodied cognition, educational experiences can be designed to effectively introduce abstract concepts, particularly in STEM fields, through concrete bodily experiences. This has been shown to greatly enhance the ability of learners to grasp, retain, and transfer complex ideas (Foglia & Wilson, 2013; Goldstone & Son, 2005; McNeil & Fyfe, 2012; Shapiro & Stolz, 2019).

Embodied learning is effective because it utilizes the body's interactions with the world to provide meaning to abstract STEM concepts. By engaging in bodily actions, such as performing a task or observing an action, while learning abstract ideas, students can forge neural connections that can be re-activated when students use or think about these concepts later (Barsalou, 1999; Castro-Alonso, Ayres, & Paas, 2015). In addition, humans have limited cognitive capacities. Exceeding one's capacity can result in cognitive overload, which is detrimental to learning (Sweller, 2010). Whereas the body was usually something irrelevant to learning, embodied learning helps students by recruiting the bodily representations to relieve the cognitive load associated with learning complex concepts (Fugate, Macrine, & Cipriano, 2019; Glenberg, 2008; Hayes & Kraemer, 2017; Risko & Gilbert, 2016; Wilson, 2002).

Embodied learning may be a valuable approach to improving STEM education, but research in this domain so far does not integrate the unique perspectives and backgrounds of learners. We will review the existing literature on embodied learning (mostly conducted in Western contexts), and explore how embodiment interacts with prior knowledge and culture. We then detail our study, conducted in a non-Western cultural setting, testing the impact of embodied learning in an authentic learning environment (an online course) while controlling for students' background knowledge. By taking these factors into account, we can learn more about designing learning experiences that are both meaningful and relevant to a broader range of students.

Embodiment in STEM Education

Empirical research has demonstrated the effectiveness of embodied learning in a variety of STEM fields (Alibali & Kita, 2010; Nathan & Alibali, 2011; Novack & Goldin-Meadow, 2015; Zhang, Givvin, Sipple, Son, & Stigler, 2021). Common approaches include the use of gestures and moving manipulatives to facilitate learning. Students benefit when they naturally gesture during learning or are instructed to gesture (Cook, Mitchell, & Goldin-Meadow, 2008; Goldin-Meadow, 2011). They also benefit when their teachers gesture (Alibali et al., 2014).

Even simply observing actions produced by others can

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have a positive impact on learning in mathematics. For instance, a study by Cook and colleagues (2017) demonstrated that children who watched an instructional video featuring a gesturing avatar had better performance on a test about mathematical equivalence than those who watched the same video without gestures.

Although less explored than mathematics, studies have also demonstrated the effectiveness of embodiment in learning complex concepts in data science and statistics (Son, Ramos, DeWolf, Loftus, & Stigler, 2018; Zhang et al., 2021). In the study by Zhang et al. (2021), participants who performed hand movements that aligned with the content of the instructional video (gestures aligned with the horizontal spread of a distribution) had better learning outcomes than those who did not perform any hand movements or whose hand movements were not aligned with the content (i.e., performing vertical motions).

Similar to mathematics, merely observing embodied actions can also enhance learning in statistics and data science (Zhang, Tucker, & Stigler, 2022). These opportunities to observe embodied actions can be more easily implemented in real instructional settings without the impractical need for learners to perform experimenter-designed actions. If observing embodied actions has a beneficial effect on learning, even online courses can benefit from more embodiment.

Zhang and colleagues (2022) conducted an important study that is foundational for the design of the current project. The study showed that American college students benefit from observing hands-on demonstrations to understand the concept of randomness and how to simulate it using R, an open-source programming language. In their study, students were randomly assigned to one of two groups: hands-on video versus live-coding video. The hands-on group watched a video of an instructor's hands manipulating and "shuffling" data printed on strips of paper. In contrast, the live-coding group watched a screen recording of an instructor typing R code that "shuffled" data in a similar way, without hands being shown. Both videos explained the same content: the shuffle function in R (Pruim, Kaplan, & Horton, 2017) which simulates a random data-generating process. The key difference between the two groups was the way the process was presented, the hands-on video was physically embodied and the live-coding video was programming based.

Then, in that study, all students watched a second live-coding video where the instructor used a larger, more realistic dataset to demonstrate how statistical inferences can be made using the shuffle function. Thus, the hands-on group had a concreteness fading experience where they first saw randomness instantiated in a concrete and embodied way before a more abstract experience, using code to instantiate randomness (Fyfe, McNeil, Son, & Goldstone, 2014). In contrast, the live-coding group had two opportunities to learn about randomness in a more abstract, live-coding way. The more embodied hands-on video group scored higher on a posttest where students had to explain and apply the shuffle function and the concept of randomness.

Learner Background and Context in Embodied Learning

The studies discussed have shown the potential for embodiment in teaching even highly abstract concepts such as mathematics and coding. However, most of these studies have largely ignored the background characteristics of learners. Yet past research has shown a broad contextual effect of cross-cultural work in the field of psychology and education, where we see a different and sometimes even reverse effect of one factor when we examine the factor in a different culture. For example, parental harshness was positively related to child aggression in European Canadian families, but negatively related to child aggression in South Asian cultures (Ho, Bluestein, & Jenkins, 2008). More specifically to embodied learning, recent research also suggests that there is an interaction between embodiment and the characteristics of the learner, such as prior knowledge and cultural background. For example, the activation of brain regions related to embodiment can vary depending on an individual's expertise and prior experience in the domain (Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005).

There is also some preliminary but promising evidence that the background and expertise of the learner can impact the effectiveness of an embodied learning experience (Fyfe, McNeil, & Borjas, 2015; Zacharia, Loizou, & Papaevripidou, 2012). For example, Zacharia and colleagues (2012) showed that learners with low prior knowledge of the concept in the domain need higher levels of embodiment during learning. In that study, kindergarteners who had low prior knowledge about balance scales benefited more from physically manipulating a balance scale than virtually interacting with a computer-based scale.

In addition to expertise and prior knowledge, the cultural background of a learner might also affect embodied learning. Although body configuration and embodiment are universal to some degree, there are differences in the use of the body in different cultures. For example, English monolinguals from the United States tended to produce more representational and nonrepresentational gestures than Chinese monolinguals (So, 2010). In addition, people growing up in Germany tend to use both hands to represent numbers from six to ten, whereas people growing up in China tend to do so with just one hand (Domahs, Moeller, Huber, Willmes, & Nuerk, 2010).

Such cultural differences in embodied activity can relate to differences in cognition (Bender & Beller, 2012; Domahs et al., 2010; Fischer, Fischer, Englich, Aydin, & Frey, 2011). Domahs et al. (2010) found that those German adults were significantly faster when making numeric comparisons between a pair of numbers crossing 5 (e.g., 4 and 6) than Chinese adults, perhaps because in these pairs, the representation of the smaller number needs one hand whereas the larger number needs two hands. This result suggests that embodied differences between cultures (e.g., finger counting) could have upstream effects on concepts as abstract as numbers.

Most research on embodied learning has been conducted in Western settings thus the benefits of embodiment in different cultures have been largely underexplored. Can embodied interventions designed for US students have similar benefits for learners in non-Western contexts (e.g., China)? Chinese students, particularly from large cities, have exhibited high mathematical achievement and competency in a number of international assessments (Ni, Chiu, & Cheng, 2010). Cross-culturally, students also experience different educational systems with different pedagogy and cultural expectations. It is possible that the embodied learning intervention that has worked for US students will not work for Chinese students.

However, given the potential relationships between embodiment and learner characteristics, it is important to investigate whether embodied learning can be effective for a very different group of learners, who do not share the same prior experience as learners from Western cultures.

In addition, most embodied learning research has been conducted in controlled laboratory settings and/or separated from students' authentic learning and assessment experiences. There is limited empirical evidence on the benefits of embodied learning in authentic learning settings (Malinverni, Ackermann, & Pares, 2016). In the study conducted by Zhang et al. (2022), the study was administered as an extra-credit survey that students completed on their own, with extra credit awarded based on the completion of the survey. When the study assessment is separated from the class, students often lack the motivation to perform well on the exam, which makes it tricky to assess students' real learning from the embodied intervention.

The Present Study

In the current study, we use the methodology of Zhang et al. (2022) but make two modifications to increase the generalizability of the findings. First, we aim to replicate the study conducted by Zhang et al. (2022) with a different population, specifically a group of students who may be different in important ways from the American college students previously studied. In addition, we integrated the intervention into the students' regular class instruction and evaluated their learning through class assessments. This approach will not only increase students' motivation on the assessments, but it will also allow us to assess the impact of the embodied intervention on questions specifically related to the intervention versus other topics covered during class.

Thus in this study, the participants were high school students from China and the stimuli were incorporated into a week-long summer class introducing concepts of data science. We assessed students' learning using the homework assignment and the final exam. These assessments included questions related to the core concept of randomness addressed by the intervention but also included questions irrelevant to the intervention (other topics covered during class). Thus we pursued more valid methods of measuring what students learned in the brief course as well as what they learned specifically about the concept of randomness, the focus of the experimental intervention.

Method

Participants

Participants were 57 high school students from China. They were recruited as a part of a large summer class organized by HAUSCR (Harvard Association for US-China Relations) Summit for Young Leaders in China (HSYLC), which aimed to bring the liberal arts experience to Chinese high school students. They took an online seminar class on research design in psychology and data analysis for five days. There were 4 days of instruction (one hour each day) and students took a final exam on the fifth day.

Design and Procedure

We offered the class twice in the summer of 2022, with each offering consisting of two sections that met one hour apart. For the first offering (N=31), students in the early section (N=17) were assigned as the experimental group and the later section was the control group (N=14). For the second offering (N=26), the experimental group (N=10) had their class an hour later than the control group (N=16). This allowed us to counterbalance any potential impact of the time of instruction on students' learning.

The first three days of instruction were the same for the experimental group and the control group: an introduction to research methods and design in psychology, data visualization in R, and foundations of data analysis. On the fourth day, students learned how to simulate randomness to make statistical inferences through two instructional videos played during class time.

In these two videos, they learned about the shuffle function in R which can be used to randomly reorder data (e.g., either the rows of a data set or the values of a variable). Experimental sections saw an embodied hands-on video first while the control sections saw a live-coding video first. The second video, a live-coding video, was the same for both groups.

There were two assessments relevant to the study: homework assigned immediately after day 4 and the final exam.

Materials

Hands-on video This introduction video was a birds-eye view of an experimenter's hand cutting a printed data table into pieces (e.g., into rows or columns) and then "shuffling" (i.e., randomly reorganizing) those pieces. The voice-over narration explained how the R function shuffle manipulated the data in the way demonstrated by the hand movements of the paper. This offered a concrete and embodied representation of what the shuffle function does to a dataset.

Live-coding video While the experimental students watched the hands-on video first, the control group watched a live-coding video introducing the shuffle function. A screen recording showed the instructor typing R code in a Jupyter notebook to "shuffle" the same dataset that was printed on

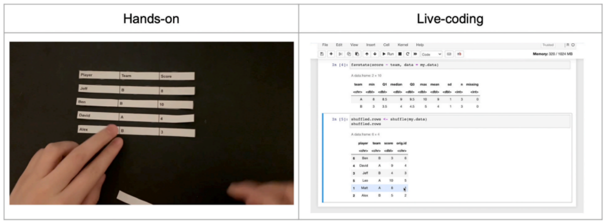

Figure 1: Screen Grabs from the Hands-on Video and the Live-coding Video

paper in the hands-on video. The live-coding video used almost identical narration as the hands-on video. The only difference in the narration was references to the data shown as R output rather than on pieces of paper.

The second video (common across the two conditions) was similar in format to the introductory live-coding video, and it applied the same concepts to a larger dataset. This video went on to show how shuffling data can be used to apply the concept of randomness to reason whether one variable explains some variation in the outcome variable. All narrations were in English. A more detailed description of the videos can be found in Zhang et al. (2022). Figure 1 shows screengrabs from the hands-on video and the live-coding video.

Measures

Homework Students were assigned homework after the intervention instruction on day 4. The assignment consisted of six open-response questions, three related to intervention videos (i.e., about the shuffle function, randomness, and their role in statistical inferences) and three unrelated to these constructs, based on concepts covered earlier in the week. For brevity, we will call these related and unrelated questions. The homework was due 12 hours after the intervention.

Final Exam The final exam assessed students' understanding of the topics covered in the past 4 days. It consisted of 13 questions (11 free-response and two multiple-choice questions). Like the homework assessment, there were questions related to the intervention videos (7) and unrelated questions (6).

Planned Analysis

For the homework assessment, we want to examine whether the experimental and control students differed on questions related to and unrelated to the intervention. To examine performance on related questions, we planned to use ANCOVA (Analysis of COVAriances) with the condition and unrelated questions in the homework as predictor variables. For unrelated questions, we planned to use independent samples t-tests.

A similar set of analyses were planned for investigating performance on the final exam. For the related questions, we planned to use an ANCOVA with three regressors: condition as well as performance on unrelated questions in the homework and unrelated questions in the final exam. For the unrelated questions, the ANCOVA included two regressors: condition and performance on unrelated questions in the homework.

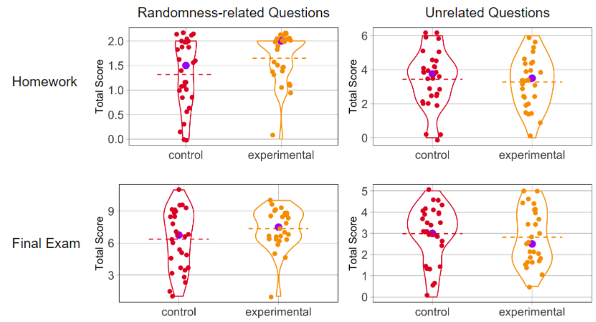

Figure 2: Distribution of Students' Performance on Randomness-related and Unrelated Questions on the Homework and Final Exam

Results

Homework

On related questions, there was a significant effect of condition ($F(1,54) = 8.17$, $p = .006$), and performance on unrelated questions was a significant covariate ($F(1,54) = 32.02$, $p < .001$). Students in the experimental condition (M=1.64, SD=0.50) performed significantly better on the randomness-related questions than the control group (M=1.32, SD=0.69). On unrelated questions, there was no effect of condition ($t(55) = -0.37$, $p = .716$).

Final Exam

On the final exam, students in the experimental group (M=7.35, SD=1.93) also performed significantly better on the related questions than in the control group (M=6.37, SD=2.76; $F(1, 53) = 7.59$, $p = .008$). Students' performance on the unrelated questions of the homework was also a significant predictor ($F(1, 53) = 26.18$, $p < .001$), whereas performance on the unrelated questions of the final exam was not ($F(1, 53) = 3.64$, $p = .062$).

For the unrelated questions on the final exam, the experimental group did not perform significantly better than the control group ($F(1, 54) = 0.11$, $p = .743$), whereas performance on the unrelated questions of the homework significantly predicted performance on the unrelated questions on the final exam ($F(1, 54) = 35.10$, $p < .001$).

Discussion

The students who were introduced to shuffling and randomness with the hands-on video performed better on relevant homework and final exam questions compared to those who received only live-coding videos. These results serve as a replication of Zhang et al.'s (2022) study in a culturally different group of students in a more valid learning environment (an online summer course).

Notably, the benefit of embodiment was evident only on questions related to the topic covered in the intervention videos indicating that this benefit could not be explained by better overall learning in the class. Nevertheless, students' mastery of other topics from the class predicted their performance on randomness-related questions, which is consistent with the well-documented importance of prior knowledge in learning (Witherby & Carpenter, 2022).

Our findings contribute to the understanding of the effect of embodied learning in a population that has been less studied, specifically high-school students from China. Previous research on embodied cognition and embodied learning has primarily been conducted in Western cultures but these results suggest that the benefits of embodied learning may be generalizable to a population that may differ in a number of respects: embodied activity (So, 2010), embodied representations of knowledge (Domahs et al., 2010), and math achievement (Wang & Lin, 2009).

Our study also serves as a practical demonstration of how to implement embodied learning in a real online class in order to assess students' authentic learning in such environments. Although the field of cognitive science is rife with research findings that have the potential to improve education, for those findings to be fully translated to education, they must be reevaluated in real-world learning environments and assessed using typical in-class assessments used by teachers. This study highlights the value of incorporating embodied learning into a real online class, showcasing its efficacy in supporting students' learning.

Some limitations of the current study merit emphasis. First, our results did not shed light on the mechanisms responsible for the benefit of watching an embodied representation. Different explanations could be proposed to account for this finding. For example, it could be that the presence of hands helps students offload cognitive load to an embodied system, or it could be that the lack of concreteness in the "live-coding" video makes it difficult for students to connect their new learning to prior knowledge. Second, our results do not indicate which concepts would benefit from an embodied intervention. The concept of shuffling can be physically demonstrated with hands and concrete manipulatives but other concepts are less amenable to physical demonstrations.

Despite the above-mentioned limitations, it is important to note that the findings of this paper contribute to the understanding of the potentially broad reach of embodied interventions in learning. Given that observing embodied actions can impact learning in domains as abstract as statistics and coding, more authentic instruction should incorporate the body. Even in an online class, there are creative ways to bring in actions and manipulatives to deepen and ground the learning of abstract ideas. Weaving together embodiment with thoughtful consideration of learners' background, culture, and learning context can help us design effective experiences that are meaningful and relevant to a broader range of students.

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