Condition × Test interaction was not significant for the Symmetric-Equal questions ($F(2, 98) = 2.77$, $p < .068$, $\eta_p^2 = .05$), while it was significant for the Asymmetric-Unequal questions ($F(2, 98) = 9.70$, $p < .001$, $\eta_p^2 = .17$). Table II shows the results of a repeated measures ANOVA comparing the pre-test and post-test accuracies of these groups for these questions. Both the hands-on and embodied groups improve from pre- to post-test on both types of questions, but improvement is greater on the more difficult questions. The effect size for the embodied group is twice the effect size for the hands-on group on Asymmetric-Unequal questions, suggesting a stronger effect (though these group differences are not statistically significant).

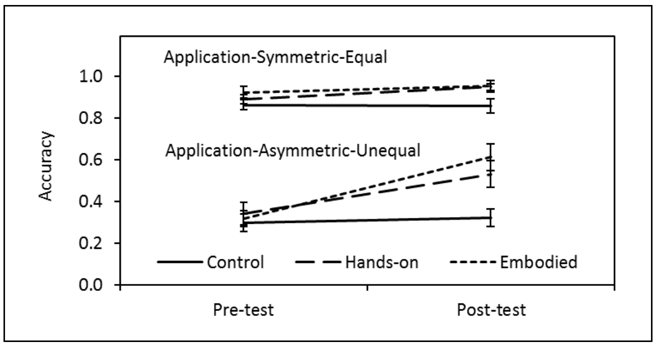

FIG 4. Accuracy by condition of Control, Hands-on or Embodied group on pre- and post-test questions that were categorized as either Application-Symmetric-Equal (top) or Application-Asymmetric-Unequal (bottom).

IV. CONCLUSIONS

In this study, we investigated the effects of two training experiences on people's understanding of the concept of center of gravity. When participants performed a set of guided balancing activities using a meter stick and a set of disks, either by using a fulcrum or their own hands, the participants' overall accuracy on center of gravity problems improved. The lowest accuracies at pre-test and the greatest improvement at post-test were observed for questions where the balanced object was asymmetric, the system CoG was at a different location from the extended object CoG, and participants were asked to identify the balance point, or the location of the fulcrum or disk that would allow the extended object to balance. Prior research comparing embodied experience with observational experience in learning concepts related to angular momentum suggests that the gain in learning specifically due to embodied activities may be observed only for these more challenging questions [7].

TABLE II. Results of a repeated measures ANOVA comparing the pre-test and post-test on Application Symmetric-Equal (SE) and Asymmetric-Unequal (AU) questions for the hands-on and embodied groups.

		ANOVA Result
SE	Hands-on	No significant Condition × Test interaction
	Embodied	
AU	Hands-on	$F(1, 98) = 17.24$, $p < .001$, $\eta_p^2 = .15$
	Embodied	$F(1, 98) = 42.27$, $p < .001$, $\eta_p^2 = .31$

Several factors pose challenges for making a clean comparison between the hands-on and embodied experiences in this study. While it is true that a system will balance at its CoG, the experience of balancing maps indirectly onto the concept of CoG, particularly in comparison to the angular momentum study that used a system of double bicycle wheels. As a consequence, participants in both of our training groups required substantial verbal description from the experimenter in order for the training to make sense. The verbal descriptions, which were equivalent for both training groups, may have dominated the training experience, in a sense over-training the participants and weakening group differences. In addition, the pre- and post-tests included a significant fraction of questions (e.g., Application-Symmetric-Equal questions) that participants were able to answer with high accuracy (> 0.85) at pre-test, and for which the training had a fairly small, positive effect (possibly indicating a ceiling effect). Future studies will reduce the amount of verbal description given to participants in the training groups, and will include a greater proportion of questions that are in categories we have found to be the most challenging for students.

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