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Teaching movement science with full-body motion-capture in an undergraduate liberal-arts psychology class

Alyssa Shengwei Yao, Elizabeth Queathem,
David Neville, and Damian Keltys-Stephen
Grinnell College
e-mail: keltysda@grinnell.edu

Movement science is a field that is quickly growing in its scope, leaning heavily on psychological expertise for research design with human participants but requiring computational and engineering ability. Undergraduate psychology curricula are in a unique position to train some of its future scholars. This report reviews an attempt to pilot a class on motion-capture for undergraduate psychology students. Recent developments in motion-capture technology have opened up the opportunity for giving hands-on experience with high-quality motion capture for students at liberal-arts colleges with lean research budgets. Post-course responses to the Research on Integrated Science Curriculum (RISC) survey demonstrated that our students made significantly large gains in their ability to organize an empirical approach to studying a complex problem with no clear

solution, and to collect and analyze data to produce a coherent insight about that problem. Students may benefit from incorporating motion-capture into their undergraduate psychology curriculum.

Often neglected in the shadowy academic space between biomechanics, physiology, and psychology (Rosenbaum, 2005), the science and technology of coordinated bodily movement is currently coming into its own. Movement science is becoming essential for an ageing population, for a health-care industry keen to advocate physical fitness as a preventative measure cheaper and more effective than treating the symptoms of sedentary lifestyles, and for a technological industry eager to make our machines more responsive and better adapted to our motor capacities. Movement science will require a multidisciplinary perspective as capable to do the mathematics of biomechanical modeling as to troubleshoot the software and hardware. Whatever movement science learns, the translation of those insights will come in the form of instructions or wearable technologies that need to fit the human users and support the many constraints, preferences, and quirks texturing individual people's goal-directed movement, i.e., to

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Ethics, consent and permissions

This manuscript documents data from the Research on Integrated Science Curriculum (RISC) survey, for which participation is voluntary and exempted from Institutional Review Board (IRB) review. The RISC survey is administered by the Center for Teaching, Learning and Assessment (CTLA) at Grinnell College, and the CTLA regularly consults with Grinnell College's federally compliant IRB to ensure ethicality of continued data collection.

Permission to publish

All participants consent before completing the RISC survey to contributing their responses to the Grinnell College CTLA for research and publication purposes. The CTLA aggregates individual student responses into whole-class data summaries, and instructors whose students complete the RISC survey (e.g., the authors) receive this information only in terms of whole-class data summaries but receive no individual-student responses. Hence, this manuscript only reports on class-data summaries and does not document any individual-student responses. Indeed, while the authors possess no information on individual-student responses, all individual-student responses remain secure in the records of the CTLA.

Competing interests

The authors have no competing interests in the manuscript. Grinnell College is a non-profit institution.

support a truly complex system with a personal, idiosyncratic touch ([Author name redacted for blinding], 2017). So, movement science will remain a solidly psychological science, and we may better serve our psychology students by giving them exposure to this fields of research with hands-on experience and skills. Conversely, exposure to movement science should provide students with skills beyond what standard psychology classes might train.

Aims for this report

At the largest scope of further discourse on technology in the service of science training, the goal of this paper is to provide an existence proof that newly accessible technology for human motion capture offers a rich opportunity for inquiry-driven science training allowing domain-specific training in movement science but also supporting a variety of domain-general skills for an integrated-science curriculum for liberal-arts students. This paper documents the piloting of a class format built around content and technology often completely absent from the curriculum and resources of a small liberal-arts class. We aim to bridge a gap between liberal-arts and technical trainings, emphasizing critical-thinking across disciplines and domain-specific skills, respectively. It may seem that “critical thinking” is too diffuse to be valuable, and it may equally seem that technical skills are too narrowly focused to support the growth of a fully-functioning citizen or professional employee. Newly available technology at prices newly within the budget of a small liberal-arts college’s research funds might allow new expressions of the close-knit, collaborative energies of liberal-arts students. The potential here is for learning new skills in navigating complex empirical/theoretical challenges when technology becomes sufficiently accessible to fall into the hands of a group of students typically more dedicated to training of critical-thinking skills.

Our intent is not to make an air-tight experiment demonstrating the superiority of this format to any other comparable class format. We have used a survey standard to

a consortium of small liberal-arts colleges and we this class format in one semester amidst the service requirements for more standard class offerings. The survey provides a pre-semester assessment and a post-semester assessment, but the sample is small because we work at a small liberal-arts college, and there is no control group suitable to this intent because we are not full-time educational psychologists. These limitations have drawn understandably harsh peer review, but we persist in thinking that these results are worth sharing if only as an existence proof.

The motion-capture class

The recent release of lower-cost but high-precision motion-capture technology has opened up greater opportunities to situate motion capture in alternate class formats (e.g., Geroch, 2004; Thewlis, Bishop, Daniell, & Paul, 2013), including those available to students at liberal arts colleges with leaner research budgets. Through internal funding focused specifically on developing innovative pedagogies, we were able to purchase six of Noitom’s Perception Neuron full-body suit (less than \$2000 each), and in Spring 2017, we offered a 300-level course in the Psychology Department called Motion Capture of Human Movement to pilot the proposal that liberal-arts psychology students would benefit from the integrated-science framework prompted—or sooner demanded—by working with motion-capture technology. We therefore anticipated that giving psychology students the suits to work with in the classroom would be a productive, educational experience unlike what they might have expected to find in a psychology classroom.

The format of the classroom was superficially flexible in day-to-day delivery but firmly rooted around workshop-style pedagogical principles. The superficial flexibilities were permitted by the class size allowing for catch-up time, for remedial redeliveries of lecture material, or for class discussion. However, at the root of the course planning was an ethos of investing student effort in repeated iterations of

inquiry-driven work. The iterations repeated a similar form, sending students from communal to individual work and back to communal work each week: Brief lecture-like instruction with a brief reading sample would open a topic or challenge, students would break into small groups or solo efforts to observe and discover, documenting their observations and experiences in formal APA format brought their independent or smaller-group ruminations and observations into a more communal/communicative mindset, and lastly, the students and class would come back together to share lessons-learned and reflect on how the next installment of lecture might bring new questions and discoveries into focus. This iterative fanning-out to smaller groups and returning to the larger-class group repeated around progressively more elaborate, more abstract principles important to the science. This iterative, inquiry-driven process has been a proven way to scaffold undergraduate science students' feelings of understanding and belonging amidst the scientific culture (Di Bartolo et al. 2016; Gregg-Jolly et al., 2011, 2016; Schneider, 2001; Walker & Kelemen, 2010; Walker & Schneider, 1996).

The first week began with lecture on history of motion-capture, brief details on how IMUs work, and some hands-on orientation to donning and calibrating the suit. Class also included time searching peer-reviewed literature on movement research, because the constraints of course offerings at a small liberal-arts college left most students unaware that movement itself was a topic of peer-reviewed basic research. Roughly each week afterwards, there were weekly assignments: students had the task of delving briefly into a small research project, making their own variant of a general concept/task, collecting a rudimentary dataset, performing rudimentary statistical and time-series analysis in the computer language R (R Core Team, 2018), and interpreting their findings and reflecting on use of the motion-capture suits as well as the software. Their weekly assignments culminated in short

narratives about the topic of research and their experience using the motion-capture technology and the software, noting difficulties, discoveries, and successes along the way.

Topics included fine-motor synchronization to a metronome, dancing to music, playing Dance Dance Revolution, playing Rock Band, free-throw basketball shooting, playing table tennis, and target practice with bean bags or Nerf guns. The first three topics allowed them to practice analyzing the measured time series data to empirically determine the frequency of regularly oscillating movements. The fourth topic appeared only after the students had a week of lecture to work through basic concepts of motor coordination, conceived as a set of phase relationships amongst joint angles (Latash & Turvey, 1996). Students then had to estimate not only frequency at one limb, but also task-relevant phase-relationships. For instance, the game aspects of Rock Band allowed students to generate pilot data examining possible relationships between phase patterns and total points scored.

Gradually, the class moved closer to more standard focuses of movement science. A brief set of lectures introduced the notion of motor learning in terms that Bernstein (1967) made popular, i.e., an initial freezing of motor components and then, with greater expertise, a relaxing of those limbs to open them up to reactive forces available from the context (e.g., Latash, 2008). Students were all relatively inexpert in table tennis, and so the repeated exposure to it allowed them to test hypotheses about how practice across a week led to observable differences in phase-relationships. The newly developed Immersive Experiences Laboratory on campus—dedicated to exploring new ways to approach liberal-arts pedagogies through 3D, virtual- and augmented-reality technologies—offered students an opportunity to investigate motor adaptation to using virtual reality equipment, posing the intriguing logistical challenge of exploring the mechanical compatibility of two separate

pieces of to-be-worn technology. Virtual reality also poses an altogether new question about how movement might change as users learn to move in two spaces at once: the virtual space of the immersive visual stimulus, and the lab space whose limits (e.g., walls and furniture) run at odds with what the virtual space invites.

The last third of the class focused on gait. Bipedal gait analysis required students to estimate the time-averaged gait cycle (with 95% confidence interval) for ankle, knee, and hip and to estimate phase-relations under the different manipulations of walking with eyes open or with eyes closed. Next, we borrowed from a research paradigm that investigated intralimb coordination between dyads linked mechanically together while walking, e.g., with the hands of the rear walker on the shoulders of the front walkers (Harrison & Richardson, 2009). Lastly, I encouraged students to take the motion-capture suits across the campus, to find accessibility problems, and to examine how different constraints (e.g., walking with a crutch or with a heavy backpack) changed the movement coordination situated in its context.

The RISC Survey

To evaluate what the students drew from this experience, in addition to consulting end-of-course evaluations, we administered the Research on Integrated Science Curriculum (RISC; Lopatto, 2010) survey (see Methods for full details). Many of the items on the survey focused on learning specific subject matter, and we did not expect students to have learned many facts, but rather we expected that gains would be apparent in specifically those items addressing working in groups, on working on problems without clear solutions, on data collection/organization and interpretation, and on using this technology and related data to describe the complexity of human movement. The capacity of the RISC survey or its components to measure students increasing dexterity with these research skills has been demonstrated

repeatedly in inquiry-driven science classrooms (Burnette & Wessler, 2013; Call et al., 2007; Clark et al., 2009; Jordan et al., 2014; Kowalski, Hoops & Johnson, 2016; Lopatto et al., 2008; Mader et al., 2017; Makarevitch, Frechette & Wiatros, 2015; Miller et al., 2013; Reed & Richardson, 2013; Staub et al., 2016; Sarmah et al., 2016). We hoped to identify whether there were post-course gains that might exceed the average of all students responding to the RISC that semester.

Method

Participants

The enrollment for the Spring 2017 offering of Motion Capture of Human Movement at a small liberal-arts college included 11 3rd and 4th-year students. The RISC survey includes questions about demographics, major field of undergraduate study, amount of science background, and plans for future science training. The total number of all students completing the RISC survey in the same semester was 3301. None of these questions bore on our general interest in the efficacy of an integrated-science curriculum, but we include them in the online supplemental materials.¹

Materials

RISC survey. The Research on Integrated Science Curriculum (RISC) survey has been developed by member schools within the Interdisciplinary Learning Consortium (ILC), whose founding members represent Carleton College, Grinnell College, Hope College, St. Olaf College, and Whitman College. RISC surveys have been exempted from IRB review. Participation is voluntary and not a requirement for receiving course credit, and students may discontinue the survey or leave any questions unanswered.

A pre-course RISC survey prompts students, “For each [of 48] Course Element[s], [to] give an estimate of [their] current level of ability before the course begins” (RISC Survey, n.d.; see selection of total 48 in Table 2). These Course Elements appear in list form as verb phrases (e.g., “collecting data” or “analyzing data”) and

address understanding the cultural values of science at large, blending concepts from more than one field together, and engaging in science creatively with hands-on problems without clear solutions. The pre-course RISC survey prompts students to rate their own ability in each item on a scale from 1 (“No experience or feel inexperienced”) to 5 (“Extensive experience or mastered this element”). The post-course RISC survey prompts students to “Please rate how much learning [they] gained from each element [they] experienced in this course” (RISC Survey, n.d.) for precisely the same list of 48 verb phrases as in the pre-course survey and asking for ratings from 1 (“No gain or very small gain”) to 5 (“Very large gain”). The post-course RISC survey also asks students to evaluate their Learning Gains on 21 skills normally developed in summer research experiences (Table 1). Specifically, the RISC survey asks students to “consider a variety of possible benefits you may have gained from

your course experience” and to rate each of a list of skills (e.g., “ability to integrate theory and practice”) on a scale from 1 (“No gain or very small gain”) to 5 (“Very large gain”).

End of course evaluations.

Students filled out evaluations, indicating their agreement from 1 (Strongly disagree) to 6 (Strongly agree) with each of six statements. The first five statements dealt specifically with how well the class meetings, instructor, group activities, oral/written exercises, and readings each supported student learning, and the sixth queried the students’ estimation of whether they had “learned a lot” in the class.

Results and Discussion

Table 1 shows the average response as well as standard error (SE) on a scale from 1 (strongly disagree) to 6 (strongly agree) in response to six statements about the class from student’s end-of-course evaluations. Students rated

Table 1. *End-of-course evaluations*

<i>Statement to agree or disagree with</i>	<i>Average</i>	<i>SE</i>
The course sessions were conducted in a manner that helped me to understand the subject matter of the course.	5.22	0.28
The instructor helped me to understand the subject matter of the course.	5.56	0.18
Worked completed with and/or discussion with other students in this course helped me to understand the subject matter of the course.	5.56	0.29
The oral and written work, tests, and/or other assignments helped me to understand the subject matter of the course.	5.33	0.24
Required readings or other course materials helped me to understand the subject matter of the course.	4.86	0.36
I learned a lot in this course.	5.56	0.24

the class favorably across all items, with the lowest average rating for readings

(Question 4) but with all other responses between 5 and 6. This low point is

understandable given that there was no single text, and the students' readings came from literature searches of peer-reviewed literature.

Response to the RISC survey includes both Course Element Gains and Learning Gains. Students rate their gains on the post-course survey on a scale from 1 (least gain) to 5 (most gain). Table 2 lists the post-course Course Element Gains for

which the present course exceeded the average for all students completing the RISC survey.

This course led students to feel they had gained most in the skills of approaching a new problem with unknown solution, learning to plan an empirical approach in a group and to have direct input into that plan that included collecting, analyzing, and

Table 2. *Gains on Course Elements reported on the post-course RISC survey*

<i>Course Element</i>	<i>My students</i>	<i>All students</i>
Problems where no one knows the answer	4.50	3.31
At least one problem assigned and structured by the instructor	4.13	3.74
A problem where students have input into process or topic	4.38	3.84
Work in small groups or teams	4.00	3.86
Collect data	4.38	3.68
Analyze data	4.63	3.89
Approach problems in different and conflicting ways	4.00	3.81
Present intellectual work in written papers or posters	4.00	3.54
Attempt complete understanding of a complex problem	4.00	3.72
Computer modeling of complex systems	4.00	3.26

interpreting data under uncertainty using computer models to understand a complex system.

The other Course Elements not listed here (but available through online supplemental materials) had more to do with mastery of subject-specific content. The students did not rate other gains higher than average for the other Course Elements, perhaps because they saw motion capture as homogeneous no matter the subject material. Whereas the course did pose a diverse set of subject materials for applying motion-capture technology, instruction did keep needed data-organizational and data-analytical tools to a minimum, so as to give students a set of

tools to practice and hone without overwhelming the students with options. Perhaps a repeat offering of the course might include more about different approaches to analyzing the motion-capture data. However, keeping the programming needs to a minimum did allow students unfamiliar with programming to master this small number of approaches and gain more confidence in their new skills. Course Elements focused on reading primary materials, listening to lecture, and providing poster/oral presentation did not show stronger gains because this class directed student effort mostly towards hands-on experimentation in groups, and only written documentation. Oral presentations might

make a nice addition to a potential future iteration of the course, particularly if the students had the challenge of developing a semester-long project around a theme of their choosing.

As for Learning Gains, students in the motion-capture class reported significantly higher ratings than the entire sample of RISC respondents in all but four Goals (Table 3).

Table 3. *Learning Gains, ranked from highest to lowest in my class and compared to all SURE-item respondents.*

<i>Learning Gains</i>	<i>My students</i>	<i>All students</i>
Skill in the interpretation of results	4.25	3.46
Ability to integrate theory and practice	4.25	3.45
Understanding of how scientists work on real problems	4.25	3.58
Ability to analyze data and other information	4.13	3.62
Tolerance for obstacles faced in the research process	4.00	3.47
Understanding the research process in your field	4.00	3.44
Understanding science	4.00	3.50
Becoming part of a learning community	4.00	3.49
Understanding that scientific assertions require supporting evidence	3.88	3.55
Learning laboratory techniques	3.88	3.39
Understanding how knowledge is constructed	3.75	3.40
Skill in science writing	3.75	3.24
Self-confidence	3.75	3.74
Learning to work independently	3.75	3.25
Readiness for more demanding research	3.63	3.40
Understanding of how scientists think	3.63	3.34
Confidence in my potential as a teacher of science	3.25	2.89
Learning ethical conduct in your field	3.25	3.32
Ability to read and understand primary literature	2.83	3.29
Skill in how to give an effective oral presentation	2.50	3.12
Clarification of a career path	2.38	3.01

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These ratings suggest that this course was a successful attempt to train students in applying theory and technology to build their own empirical projects and to collect data that can speak to theoretical issues. Specific learning gains included interpretation of results, integrating theory with practice, understanding how scientists work on real problems and surmounting obstacles in a communal process, ability to analyze data and synthesize disparate sources of information. The experience gave students better command of scientific communication and of their ability to teach the science that they learn. It was also a helpful experience in helping students understand science in general, as a social process in which multiple voices work to construct knowledge in a social process that leaves room for independence while also affording group work in the search for new evidence and/or better solutions to pressing problems.

Not all learning gains were better in this class than in other classes. Ethical issues may not have fit organically with the rest of the class business, but future offerings of this class could attempt it. The other items with lower ratings were not part of original goals for the class, so they highlight room for development of the course, rather than shortcomings.

Detailed reflections and example student experiences

The course necessarily involved a fluid, context-sensitive format, in which students regularly discovered previously unknown constraints as well as unknown capacities. We see some of this point in the strong learning gains having to do with understanding the scientific process and learning to apply theory while also learning to tolerate obstacles. As an illustrative example, one pair of students struggled with the motion-capture suit failing to function as usual one day. These two students took the occasion to debug the problem—indeed, they might not have recognized their efforts as debugging, but they were discovering their very own principled manner of testing the functioning of subparts. These two

students—relatively untrained in programming or engineering—were able to isolate the specific part of the suit that had broken, and furthermore, they discovered a flexibility in the motion-capture system that allowed alternative connections around the broken portion, i.e., patching a work-around that allowed typical motion capture through most of the suit. Motion-capture research can be peppered with unanticipated and unclear technology failures that can and do frustrate professional researchers and require letting participants go without any successful data collection. This debugging served as only one among many exercises in problem solving that the students experienced.

Practiced scholars in movement-science fields have taken that patient diligence on as second nature. Behind this illustrative case of experience with debugging is crucial point. Liberal-arts students may often feel insecure and unable to wield technology as anything more than an end-user swiping a touch screen, and truly enough, there has been much clamor and controversy about the value of a liberal-arts education as contrasted with more vocational training in technical skills (e.g., Breneman, 1994). But the dichotomy between liberal-arts values of learning how to learn in any context and vocational values of honing technical skills with digital technology may just be a false dichotomy (Grubb & Lazerson, 2005; Selingo, 2016). There is an opportunity not just for greater skill with digital technologies but also for metacognition about how critical thinking really will transfer to tasks that do not look like traditional liberal-arts. That is to say, digital technologies like motion capture may be a ready vehicle for liberal arts lessons.

Overall, this project was a productive and instructive early effort. The initial results suggest that a motion-capture laboratory fits well with the aims and constraints of a small liberal-arts college setting.

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