Research
DOI: https://doi.org/10.1128/jmbe.v21i2.1895
JMBE Journal of Microbiology & Biology Education

An Online Interactive Video Vignette that Helps Students Learn Key Concepts of Fermentation and Respiration

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Topics related to energy transformation and metabolism are important parts of an undergraduate biology curriculum, but these are also topics that students traditionally struggle with. To address this, we have created a short online Interactive Video Vignette (IVV) called *To Ferment or Not to Ferment: That is the Question*. This IVV is designed to help students learn important ideas related to cellular respiration and metabolism. Students in various courses across four institutions were assigned the IVV as an out-of-class preinstruction homework assignment. To test the effectiveness of this IVV on student learning, we collected and analyzed data from questions embedded in the IVV, open response reflection questions, and pre- and postassessments from IVV watchers and nonwatchers. Our analysis revealed that students who completed the IVV activity interacted productively with this online tool and made significant learning gains on important topics related to cellular respiration and metabolism. This IVV is freely available via https://www.rit.edu/cos/interactive/MINT for instructors to adopt for class use.

INTRODUCTION

Biology learners often enter their college classrooms with a range of misconceptions and naïve ideas about important topics due to preconceived notions, language issues, faulty mental models, and/or factual errors. These incorrect and/or incomplete ideas may become significant barriers for future learning, as new concepts cannot be learned when incorrect models persist (1). To help undergraduate students grapple with complex ideas embedded within core concepts in biology, broadly described in *Vision and Change* (2) and further articulated in the BioCore Guides (3), we have developed a series of online tools called Interactive Video Vignettes (IVVs). These short web-based learning applications, housed at https://www.rit.edu/cos/interactive/MINT/index.php, employ live-action and real-world settings that are familiar and accessible to a wide range of learners (4, 5). They combine short video segments with interactive elements such as multiple-choice questions, data analysis, graphing, fillable tables, and question-based branching. IVVs are designed to be used as out-of-class priming activities that help challenge students' thinking about common misconceptions and hone their reasoning skills by having them make predictions, answer embedded questions, collect (virtually) and analyze data and, finally, reflect on their learning.

Topics related to the core concept of energy transformation (2, 3), such as cellular respiration and metabolism, typically comprise a substantial part of an undergraduate biology curriculum. Learners, however, struggle with metabolism-related concepts, such as understanding the purpose of oxygen in cellular respiration, recognizing and describing the link between nutrient intake and cellular breakdown of glucose, and knowledge about the process and products of fermentation pathways (6–8). Based on the literature and our collective teaching experiences, we designed an IVV called *To Ferment or Not To Ferment: That is the Question*, referred to hereafter as the Fermentation IVV, as a resource to help students fill in knowledge gaps about metabolism and the relationship between the processes of glycolysis, fermentation, and respiration.

The Fermentation IVV is a short (approximately 12 minutes) vignette in which two undergraduate biology students are puzzling over the results from a microbiology experiment meant to determine whether or not different bacterial strains are capable of fermentation. They reason their way through the problem, and they set up and carry out another experiment to test their ideas (see Appendix 1 for a detailed synopsis of the IVV). In the end, they are able to come to an understanding about the relationship of two key metabolic pathways, fermentation and respiration, and

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Received: 15 August 2019, Accepted: 23 June 2020, Published: 31 August 2020
†Supplemental materials available at http://asmscience.org/jmbe

are able to relate bacterial growth rate and density to the amount of energy harvested from the different pathways. Students also learn that environmental conditions, such as the presence of oxygen, will influence metabolic pathways. The six learning objectives (LOs) for the Fermentation IVV are listed in Table 2.

To test the effectiveness of the Fermentation IVV on student learning, we designed a short assessment to capture student ideas about the various LOs (see Appendix 2). We did not use a multiple-choice (forced-choice) format because it is prone to students "gaming" the system by relying on test-taking strategies to guess at the one correct response. Restricting students to only one answer choice may also result in an inaccurate picture of student learning. For example, research has revealed that students may believe more than one of the given responses are true (9–11) but can only select one option in a forced-choice format, so allowing them to choose multiple options provides for better characterization of student thinking (12–14). We designed our pre- and postassessment questions using a multiple-select format, which prompts students to "select all that apply" to each question stem. This approach greatly diminishes the ability of students to employ test-taking strategies, encourages students to consider each response, allows for more than one concept to be tested within a single question, and gives the instructors a more complete understanding of what was learned (or not) after an intervention, activity, or course. To test user knowledge on the concepts presented in the Fermentation IVV, multiple-select assessment questions were designed, tested, and revised to improve clarity and to ensure alignment with LOs (Table 2).

Our hypothesis was that completion of the Fermentation IVV would help students develop more expert-like conceptions about metabolism. Because IVVs are completed outside of the classroom (away from the eyes of the instructor), we realized that students may or may not actually pay attention to the IVV while completing the assignment. Even well-designed tools will fail if students do not use them as intended. Our first research question, therefore, asked: *Do students productively engage with the Fermentation IVV*? To help us understand whether the Fermentation IVV was an effective learning tool, we also asked: *Does the Fermentation IVV help students learn important concepts related to cellular respiration and fermentation?*

We used a multifaceted approach to answer our question on the effectiveness of the IVV to improve student learning. A portion of our study was a quasi-experiment (at four institutions) and a portion was a case-control study (at one institution). To address student engagement (Research Question 1), we analyzed student data from a number of different courses from which the Fermentation IVV was assigned as homework. We analyzed embedded questions within the IVV and postcompletion reflection questions. To address our question about whether the Fermentation IVV allowed students to learn important concepts (Research Question 2), we analyzed data from the multiple-select format pre- and postassessment, considering both overall performance and specific achievement of the Fermentation IVV LOs. Analysis of our data strongly suggests that students interact productively with our online tool and that they demonstrate evidence of learning. Both of these findings, presented here, support the use of the Fermentation IVV as a way to help students learn concepts related to metabolism.

METHODS

IVV assignment and pre- and post-testing

In order to test the effectiveness of the Fermentation IVV, 303 students from four Northeast U.S. institutions participated in the study over a period of 3 years (Table

TABLE 1.
Test populations.

Population	Institution/course	Institution Characteristics[a]	Timing of Post-Test	No. of Students	
				IVV Watchers[b]	Pre/Post Data[c]
1	A/Intro Cell Bio	Small, private, M1 university	Before in-class instruction	58	52 cases, 56 controls
2	A/Intro Cell Bio	Small, private, M1 university	After in-class instruction	42	42
3	B/Intro Microbio lab	Small, private, M1 university	After in-class instruction	47	38
4	C/Intro Bio	Small, private, M1 university	N/A[d]	64	—
5	C/Honors Intro Bio	Large, private, R2 university	After in-class instruction	56	51
6	D/Intro Microbio	Small, private, M2 university	After in-class instruction	36	11
Total				**303**	**194**

[a] Carnegie Classifications: M1, Master's Colleges and Universities–Larger programs; M2, Master's Colleges and Universities–Medium programs; R2, Doctoral Universities–High research activity.
[b] For whom answers to embedded questions and open-ended reflections were available.
[c] Pre- and postassessment data were included only for students who took both assessments and also completed the IVV.
[d] N/A, not applicable (no pre- or post-test was given).

TABLE 2.
Alignment of IVV LOs with pre- and postassessment questions.

LO	LO Description	Relevant Assessment Questions	
		Correct Options	Incorrect Options
LO1	Describe glycolysis as the first step in the oxidation of glucose, which is then followed by either fermentation or aerobic respiration	1A, 1C, 1D	3A
LO2	Distinguish between fermentation and aerobic respiration in terms of energy outputs (generation of ATP)	2B, 3E	1B
LO3	Correlate products of metabolism to changes in the pH of the environment (growth media)	2C	—
LO4	Recognize that an organism may use different pathways depending on whether oxygen is present	2D, 3C, 3D	2E
LO5	Relate growth rate to amount of ATP made available via different metabolic pathways	—	—
LO6	Relate culture density to amount of energy harvested via different metabolic pathways	2B	—

1). All courses were introductory biology or microbiology courses. Pretest questions were given at the beginning of the semester in which the IVV was used. Students were either presented with a paper copy of the assessment to complete in class or were provided with an online version of the questions. Post-tests were administered in the same format as pretests and were administered either before in-class instruction on IVV topics or after in-class instruction (within a few weeks through the end of the semester) (Table 1). All students in the courses were expected to complete the IVV, the pretest, and the post-test, and completion compliance was at least 90% in all classes. Each instructor was provided a unique URL for the Fermentation IVV to share with students. Instructors made the IVV assignment available for approximately 1 week, and most instructors awarded a small number of points for completion of the IVV assignment. In population 1, students were randomly assigned to experimental or control groups (Table 1). Experimental group students were assigned the IVV as above, while control groups were assigned a Khan Academy video on cellular respiration and fermentation as an alternative assignment. The Fermentation IVV takes an average of 12 to 15 minutes to complete (see Appendix 1). The IVV software records the time spent on each online page and the responses users enter to the embedded questions. By querying our IVV database, the research team was able to flag users who did not spend the minimum amount of time (12 minutes) completing the IVV. Their data was removed from the analysis (these students could not be considered "watchers" because they did not complete the IVV). If a student logged on and completed the IVV assignment more than one time, only the data that were collected during their first attempt was used in subsequent analyses. Either users entered their names or their faculty-assigned unique code numbers (which were also used for pre- and post-testing) so that we could align IVV completion status with pre- and post-tests.

Analysis of embedded questions

The Fermentation IVV includes interactive elements, with five multiple-choice questions (IVVQ1 to 5) and a final reflection question asking students to list three things they learned from the IVV. IVVQ1 and IVVQ2 check students' understanding of the first experiment, IVVQ3 and IVVQ4 ask them to predict the outcome of the second experiment, and IVVQ5 requires them to interpret a graph, comparing two growth curves that resulted from the second experiment. Students who choose the wrong answer to IVVQ5 are given further explanation and asked to try again. Student responses were recorded in a database and included any response entered from all students, regardless of completion. For the analysis of embedded questions, data were pulled from the database only for students who completed the IVV assignment in all six populations, regardless of whether pre- and post-tests were also completed. For multiple-choice questions, we determined the percentage of students who answered each question correctly.

The Fermentation IVV also includes a final reflection page asking students to list three things they learned from the IVV. Responses from 303 students from all six populations were analyzed and coded for alignment with each of the six LOs (Table 2). Two coders worked independently through 185 of the responses. Interrater reliability was checked using Cohen's kappa for each category. Scores ranged from 0.670 to 0.854 on all categories except for LO1, which was in the range of low agreement (0.528). The two coders worked together to reestablish rules for coding this category, and the remaining 118 rows of data were coded independently by both coders for LO1. The new comparison yielded a kappa score of 0.964 for LO1. All disagreements were discussed to resolution. One coder completed the coding for the other five LOs.

Analysis of pre- and post-test data

A three-question multiple-select pre- and post-test was developed to assess learning gains made by students who completed the Fermentation IVV. Five of the six populations were given the assessment, but only IVV watchers who had completed both pre- and post-tests were included in the analysis (Table 1). The percent change in selection of correct answers or incorrect answers on the pretest compared with the post-test was calculated for each question and for each LO. A case-control study was run over 3 years in population 1 at Institution A, where only half the students were assigned the Fermentation IVV. The other half were assigned a Khan Academy video of approximately the same length and subject. Post-testing occurred after the IVVs were completed but before in-class instruction on the topic of metabolism. Normalized learning gains were calculated using the formula (post – pre)/(1 – pre). Significance was evaluated by one-tailed *t*-test, and effect size was calculated using Cohen's *d*.

Human subjects review

IRB approval was obtained from each participating institution prior to the commencement of research protocols at each institution.

RESULTS

Students appropriately engage with the Fermentation IVV

In order to determine whether students were engaging appropriately with the IVV, we analyzed responses to multiple-choice questions embedded within the IVV itself (embedded questions are a feature of all IVVs). These questions were designed as scaffolding tools to help users make connections, stay engaged, and check their understanding during the IVV. The Fermentation IVV includes five multiple-choice questions, which watchers must answer before being allowed to move on. A total of 303 watchers completed the IVV and were included in this analysis. The percentage of watchers who correctly answered each embedded question ranged between 65% and 88% (Fig. 1). Students who did not answer the fifth question correctly were directed to a new page that included feedback on their incorrect response and were asked to answer the question again. Of these 39 students, 29 (74%) answered this final question correctly on a second attempt. The overall high rate in which 97% of students (293 of 303) selected the correct answer for IVVQ5 within two attempts indicates students were attempting to answer the questions correctly (the correct rate is much higher than the guess rate). This suggests that users are engaged by the IVV and not randomly picking a response. It also suggests that the IVV provides enough scaffolding for students to follow along and answer the embedded questions correctly as they are watching the story unfold. Finally, the

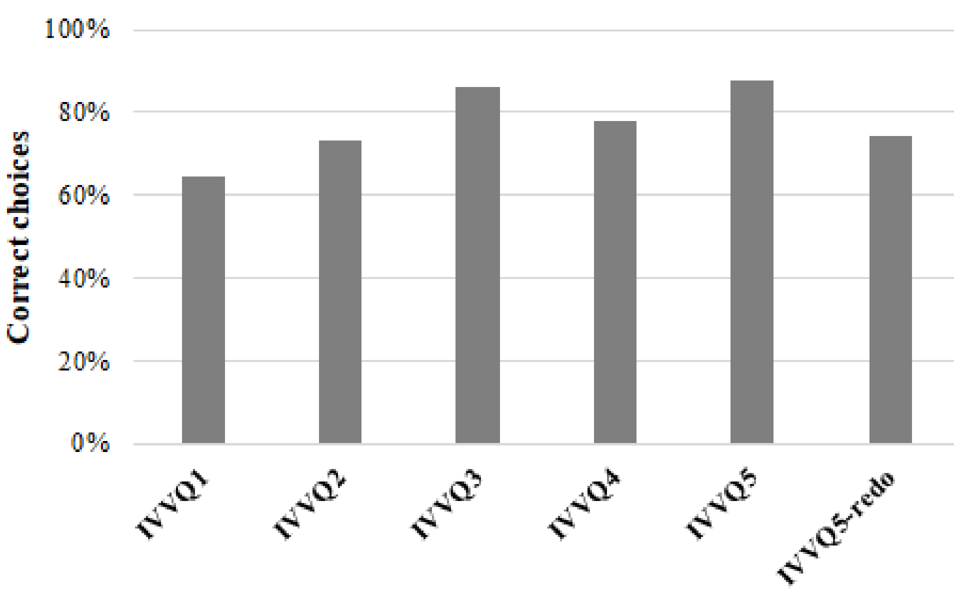

FIGURE 1. Percentages of watchers (*N* = 303) who answered embedded multiple-choice question correctly. The watchers who got IVVQ5 wrong were given additional instruction and a second chance to answer the question (IVVQ5-redo, *N* = 39).

TABLE 3.
Evidence of success on LOs.

LO	Correct on Pre-Test	Correct on Post-Test	Mentioned in Open-Response Reflection
LO1: Describe glycolysis as the first step in the oxidation of glucose, which is then followed by either fermentation or aerobic respiration	57%	71%	5%
LO2: Distinguish between fermentation and aerobic respiration in terms of energy outputs (generation of ATP)	65%	87%	52%
LO3: Correlate products of metabolism to changes in the pH of the environment (growth media)	47%	75%	35%
LO4: Recognize that an organism may use different pathways depending on whether oxygen is present or not	69%	78%	21%
LO5: Relate growth rate to amount of energy made available via different metabolic pathways.	—	—	41%
LO6: Relate culture density to amount of energy harvested via different metabolic pathways.	38%	79%	44%

last question is an interpretation of growth data presented via a graph, requiring watchers to interpret results in the context of previously presented information. The increasing percentage of correct responses from IVVQ1 to IVVQ3 (Fig. 1), combined with the high number of correct responses to the final question support the finding that students are appropriately engaging with the IVV itself.

Students who complete the Fermentation IVV can communicate key ideas presented in the IVV

While correct responses to embedded questions suggest that watchers were paying attention to the Fermentation IVV as they completed it, we were interested in learning whether watchers could also communicate the

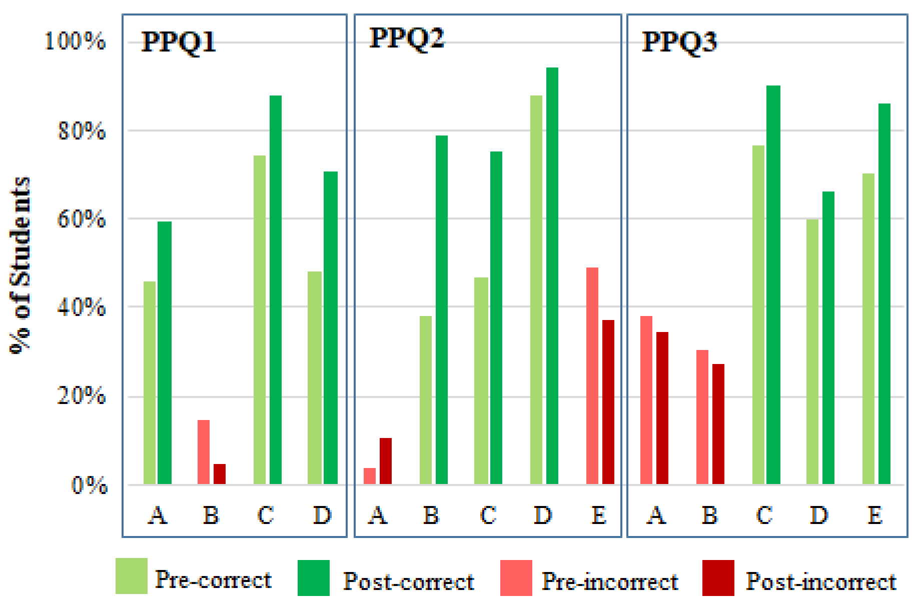

FIGURE 2. Percentages of students choosing each option on the pre- and postassessment. Students were instructed to "choose all that apply" for each question. The data include all students who watched the Fermentation IVV and took both pre- and post-tests (N = 194 students). Green bars indicate correct choices, red indicates incorrect choices. PPQ, pre-/post question. Light-colored bars indicate pre-test data, and dark-colored bars indicate post-test data.

broader concepts from the IVV. The Fermentation IVV includes a reflection opportunity on the final page of the vignette, where users are asked to describe three things they learned in an open response format. These free responses were analyzed for alignment with the IVV LOs (Table 2). Statements were considered to be in alignment with a LO when they correctly described the general concept of the objective even if they might not fully describe it; some statements aligned with multiple LOs (see the appendices for statement examples). All LOs were cited within the set of student responses, with some identified more than others (Table 3). Overall, 93% of students mentioned at least one LO, and 38% of students identified three or more LOs within their responses. On average, students mentioned two LOs. Students also often mentioned elements of the experimental methodology, particularly: 1) a shaking incubator forces more oxygen into the culture (34%), and 2) phenol red changes color with changes in pH (30%). Only 18 students (6%) made incorrect statements (e.g., "phenol red can be broken down by lactic acids"). Combined with the analysis of embedded IVV question data, this analysis strongly suggests that students are interacting productively with the Fermentation IVV.

Students who complete the IVV perform better on post-test assessments

The Fermentation IVV was designed to address six LOs related to glycolysis, fermentation, and respiration (Table 2). We used a three-question pre- and post-test with a multiple-select format to assess learning gains made as a result of IVV completion. Because IVVs are not intended to be the sole method of instruction on a topic but serve as a primer prior to in-class activities, we analyzed correct and incorrect responses independent of each other and looked at changes in the frequency of selection of either correct options or incorrect options (Fig. 2). In general, students were more likely to select correct options on the post-test, while they were less likely to select incorrect options (Fig. 2). We did note that the frequency of selection of incorrect responses on both pre- and post-tests was much lower than selection of correct responses. However, more students selected more correct options for each question on the post-test ($p < 0.00001$, Cohen's $d = 0.95$) (Fig. 3). Because each question includes options that address different LOs (Table 2), the selection of multiple correct options within one question suggests that students are beginning to develop a more complex understanding of these concepts, as different options align with different LOs. One population (at Institution A) included the Fermentation IVV with preclass assignments for about half of the students while the other half was assigned a YouTube video of comparable length. Since the postassessment was given before any formal in-class instruction or in-class activities on glycolysis, fermentation, and respiration, we were able to compare overall learning gains as a result of IVV completion (Fig. 4). The learning gains made by watchers (0.319) were nearly double the learning gains made by nonwatchers (0.157), which

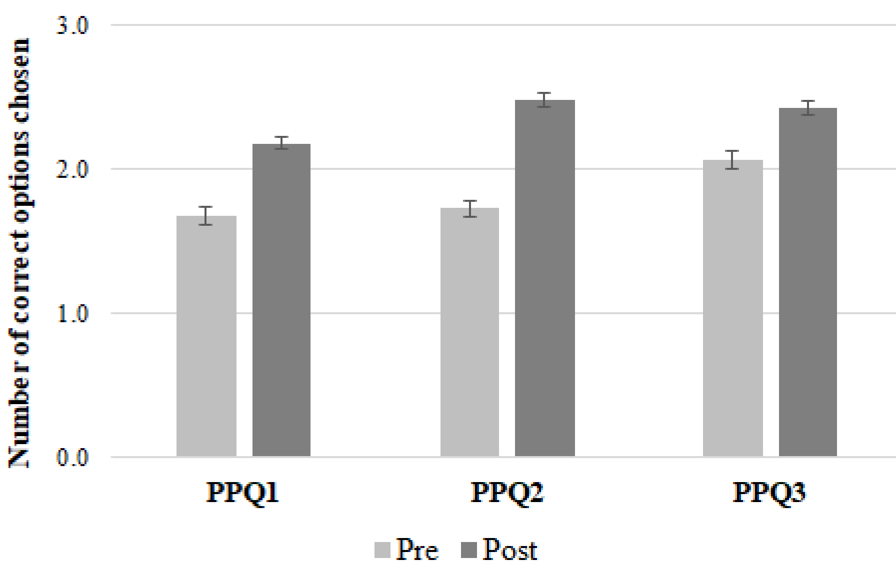

FIGURE 3. Average number of correct options that are selected per question on pre- and post-test assessments. Students chose more correct options for all questions on the post-test. Each question had three correct options. On average, students increased from 5.5 to 7.1 total correct answers out of 9 ($N = 194$ students). Error bars represent standard errors of the means (SEM). The pre-test–post-test differences were highly significant by t-test ($p < 0.00001$ for each question and overall), and the effect size was medium to large (Cohen's $d = 0.46$ to 0.98 for each question and 0.95 overall).

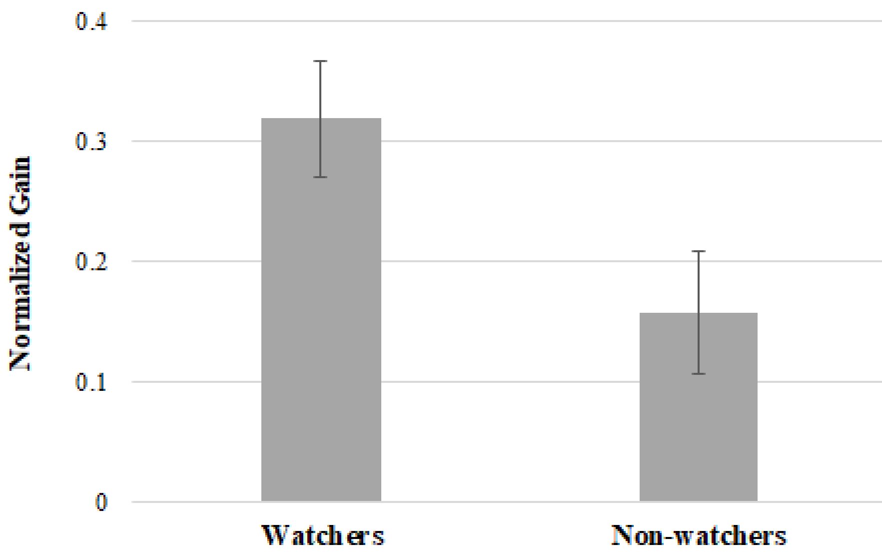

FIGURE 4. Normalized learning gains by Fermentation IVV watchers versus nonwatchers. At Institution A, watchers (N = 52) made nearly double the learning gains of nonwatchers (N = 56). Normalized learning gains were calculated using the formula (post – pre)/(1 – pre). Error bars are SEM. The difference was significant by t-test (p = 0.0119), and the effect size was moderate (Cohen's d = 0.6389).

strongly suggests the Fermentation IVV does help students learn important concepts about energy transformation (p = 0.01, Cohen's d = 0.64).

Students who completed the IVV demonstrated significant improvement in understanding the Fermentation IVV LOs

In addition to improved performance following IVV completion, we were specifically interested in whether or not students improved in their understanding of the Fermentation IVV LOs. Pre- and post-test scores were determined for each LO based on all pre- and post-test options (Table 2). All pre- and post-test comparisons were highly significant by t-test ($p < 0.0001$). The average normalized learning gain was calculated for LOs 1 to 4 and 6 and ranged from 0.31 to 0.65 for all students who completed the Fermentation IVV.

DISCUSSION

In general, the Fermentation IVV is effective at both engaging students and helping them improve understanding of the metabolic processes of fermentation and respiration. The high rate of correct responses to embedded questions within the IVV suggests not only that students are attempting to answer questions correctly, but also that the IVV is providing enough scaffolding for students to follow along and correctly answer the embedded questions. Student watchers are engaged as the story unfolds and new concepts are introduced. This is additionally supported by the high correct response rate of 97% to the last embedded question—this question is based on interpretation of data in the context of information provided earlier in the IVV. Student responses to the postcompletion reflection questions are also evidence of learning; students were able to communicate key ideas presented in the Fermentation IVV using their own words. Students also correctly described some of the methodology that was used to conduct the experiment in the IVV, further evidence that students were engaged and paying attention to the IVV narrative.

IVV watchers made impressive gains on the pre- and postassessments, lending strong evidence to support our hypothesis that the Fermentation IVV helps promote learning on important metabolism topics. On the post-test, question option 1a was the only correct option that fewer than 60% of students selected. This particular option involved the oxidation of glucose, which was not a major focus of the IVV itself. Likewise, question option 2e was the incorrect option selected most often on the post-test. It too addressed a topic that was not a focus of the IVV ("fermentation is a mechanism used by yeast to grow in the presence of alcohol"). Students are most likely selecting this option because they are aware of the relationship between yeast and alcohol production; however, the IVV did not address the notion that alcohol is a possible waste product of fermentation.

Several challenges may lead to inaccuracies in our assessment of the effectiveness of the IVV as a learning tool. First, we did not have an assessment question on the pre- and post-test that aligned with LO5. In the open-response reflection questions, though, 41% of student users did write about LO5, strongly suggesting LO5 was partially met. Second, across the four testing institutions, there was not a uniform timeline of pre- and post-test administration with respect to in-class coverage of the topic, nor were in-class lesson topics coordinated. Therefore, it is not possible to know what impact, if any, additional resources (e.g., textbook readings or participation in study groups) had on student learning. However, in all cases, we did see strong gains of the Fermentation IVV LOs, suggesting that the Fermentation IVV promotes learning of the targeted concepts. The case-control study (Fig. 4) clearly demonstrates that IVV watchers made significantly greater gains than nonwatchers who were assigned an alternate passive video to control for time on task. It should be noted that we did not have a means to confirm that the control group watched the alternative video and, as such, cannot conclude that the gains seen in the watchers' group were the result of time on task or due to the interactivity of the IVV itself.

CONCLUSION

We have developed an online interactive tool for learning concepts related to energy metabolism. We have shown that this tool, the IVV *To Ferment or Not to Ferment: That is the Question* is productively engaging for students. Additionally, we have shown that students who use this tool as priming material prior to in-class lessons on glycolysis, fermentation, and respiration demonstrate strong learning gains in these areas. This resource, along with other IVVs for Biology, is freely available at https://www.rit.edu/cos/interactive/MINT/index.php.

SUPPLEMENTAL MATERIALS

Appendix 1. Detailed synopsis of the IVV
Appendix 2. Multiple-selection assessment instrument
Appendix 3. Examples of student reflection free responses and alignment with IVV LOs

ACKNOWLEDGMENTS

This material is based on work supported by the National Science Foundation under Grant No. DUE-1432303 and DUE-1432286. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. We thank Robert Teese for his help in data collection and thank the instructors who agreed to implement this IVV and pre- and postassessments in their courses. The authors have no conflicts of interest to declare.

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