Evaluation of the Virtual Physiology of Exercise Laboratory program

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Dobson JL. Evaluation of a virtual physiology of exercise laboratory program. Adv Physiol Educ 33: 335–342, 2009; doi:10.1152/advan.00040.2009.—The Virtual Physiology of Exercise Laboratory (VPEL) program was created to simulate the test design, data collection, and analysis phases of selected exercise physiology laboratories. The VPEL program consists of four modules: 1) cardiovascular, 2) maximal O₂ consumption (V˙O₂max), 3) lactate and ventilatory thresholds, and 4) respiratory exchange ratio. The purpose of this investigation was to compare student learning from the VPEL program with that from traditional “hands-on” exercise physiology laboratory activities. Student participants from the spring 2009 Integrated Programming Course were randomly assigned to either experimental group 1 or group 2. Group 1 completed a hands-on version of a typical V˙O₂max laboratory activity, whereas group 2 completed the VPEL V˙O₂max module. Both groups then completed the same assessment to evaluate their understanding of V˙O₂max laboratory concepts. Group 1 then completed the VPEL lactate and ventilatory threshold module, whereas group 2 completed a hands-on version of that same activity. Both groups then completed the same assessment to evaluate their understanding of lactate and ventilatory threshold laboratory concepts. Mean V˙O₂max assessment scores were 86.39 ± 4.13 and 85.64 ± 6.72 and mean lactate and ventilatory threshold assessment scores were 85.50 ± 8.05 and 86.15 ± 6.45 for groups 1 and 2, respectively. These findings lend additional support to the following conclusion of similar investigations (2, 4, 6): that virtual laboratories instruct students as effectively as hands-on laboratories.

In light of the above, the Department of Applied Physiology and Kinesiology (APK) of the University of Florida decided that the most feasible way to add a laboratory component to the undergraduate exercise physiology course was to incorporate virtual laboratory experiences. While there are a number of excellent general (i.e., basic science) physiology simulations available to purchase, there was only one virtual exercise physiology product available when APK initially made the decision to incorporate virtual laboratories. That one exercise physiology product uses simulations to describe cardiopulmonary and metabolic responses to exercise, as the department wanted, but it was not considered interactive and instructional enough to justify the cost to the students. More specifically, that product does little more than simply simulate selected exercise tests, but the department wanted a program that would interact with users while teaching them how and why to make the proper decisions about setting up tests and conducting and analyzing the data from such tests. APK therefore decided that the best option was to develop and implement a program that has since been titled the Virtual Physiology of Exercise Laboratory (VPEL) program.

The VPEL program is an entirely computer-based program that is hosted by the university’s course management system. As is the case with other laboratory simulations, the VPEL program instructs and interacts with users while they measure physiological variables (Fig. 1). What is perhaps unique about the VPEL program, however, is that it also simulates some of the real world decisions that must be made when setting up such laboratory experiences and it guides users through a linear thought process to help them analyze the test data. The VPEL program does the above through four separate conceptual modules that progress in a specific manner: users must first complete the cardiovascular module, they can then progress to either the lactate and ventilatory threshold module or maximal O₂ consumption (V˙O₂max) module, and, finally, they move on to the respiratory exchange ratio module. Throughout each of these four modules, users are instructed as to exactly what they are going to be doing and why they are going to be doing it. Therefore, no prior training or coursework is required to successfully operate the VPEL program.

The concepts that are unique to the cardiovascular module are relatively simple, and so it was chosen to introduce users to the VPEL program. This module was specifically designed to provide users with numerous prompts (e.g., pop-up windows) to help guide them through each of the module’s phases. As is the case in the three subsequent VPEL modules, the five sequential phases of the cardiovascular module are the 1) introduction, 2) participant selection and pretest health screening, 3) test equipment and treadmill protocol selection, 4) exercise test, and 5) posttest analysis. The introduction phase is a tutorial that describes both the purpose of the laboratory experience and the pertinent physiology that will be measured. The specific purpose of the cardiovascular module is...
to measure heart rate (HR) and blood pressure responses throughout a maximal incremental exercise test.

The next phase is the participant selection and pretest health screening. Users read a text that describes the importance of using health status questionnaires to minimize the dangers of exercise by first identifying any dangerous risk factors. More specifically, users are instructed as to how to interpret two common health status questions: 1) the American College of Sports Medicine (ACSM) coronary artery disease risk factor (CAARK) questionnaire and 2) the ACSM major signs/symptoms suggestive of cardiovascular and pulmonary disease (MSSCDPDQ) questionnaire (1). After this section, users should know that participants that answer “yes” to either at least two questions on the CAARK questionnaire or at least one question on the MSSCDPDQ questionnaire must receive medical clearance before they can safely engage in exercise (testing). Users then cycle through the list of virtual VPEL participants. Each virtual participant represents a different general fitness category within the apparently healthy continuum, and each participant’s description includes that individual’s specific profile information and responses to the two health status questionnaires. When users select a particular virtual participant, they must then interpret that participant’s health status questionnaire responses and correctly decide if those responses necessitate medical clearance before the individual can safely engage in the maximal exercise test. For example, users should know and indicate that the participant shown in Fig. 2 does not require medical clearance before engaging an exercise test, whereas the participant shown in Fig. 3 does require medical clearance.

Once users have completed the process of correctly setting up the laboratory experience, they then enter the actual exercise test phase and begin collecting data. In this phase, users can see the virtual participant performing each phase of the exercise test while, at the same time, both numerical and graphic representations of the test variables from each test stage are being collected (Fig. 1). As was the case with the previous phases, users must make the appropriate choices for the exercise test to work properly. More specifically, users are responsible for sampling the test data and increasing the
treadmill work rate at the exact correct moments that are dictated by the exercise protocol. They must also eventually conclude the test at the exact moment when the virtual participant becomes exhausted. In the cardiovascular module, if users fail to collect data, move to the next work rate, and/or conclude the test at the appropriate moment, then a pop-up window appears and prompts them to perform the appropriate action. When the exercise test has been successfully completed, users are prompted to print off the graphs of the data they have collected.

The final phase of the module is the posttest analysis phase. Here, users progress through a series of questions that build on one another to help guide them through the interpretation of the data they just collected. The specific objectives of cardiovascular module analysis are to help users identify and understand the importance of systolic blood pressure, diastolic blood pressure, and HR responses to maximal incremental exercise. For example, the following series of questions within that analysis ask about (i.e., directs users to focus on): 1) the virtual participants’ HR responses at rest and throughout the exercise test; 2) the virtual participants’ maximum HR; 3) how resting and maximum HR values fit into the Karvonen formula (i.e., the preferred method for determining proper cardiorespiratory training intensity); and 4) the virtual participants’ actual prescribed cardiorespiratory training intensities using the Karvonen formula.

The lactate and ventilatory thresholds, \( V_{O2\max} \), and respiratory exchange ratio modules all appear and progress exactly like the cardiovascular module (as described above) but with two important differences. First, as would be expected, each of the latter three modules has its own distinctive purpose and objectives. Consequently, each incorporates unique and pertinent introductory information, measured physiological variables and equipment requirements (Table 1), and posttest analysis questions to instruct users. The major objectives of each module are shown in Table 2. The second significant distinction from the cardiovascular module is that users are expected to be familiar with the operation of the VPEL program by the time they get to these latter three modules, and so all three contain fewer prompts and instructions. For example, during the exercise test phase of any of these three latter modules, if users fail to properly administer the test (e.g., fail to sample variables or increase the work rate at the appropriate moments), then the test is automatically terminated and must be repeated from the beginning.

The VPEL program was created with the hope of providing a practical alternative to several common traditional “hands-on” exercise physiology laboratory activities. Since the VPEL...
modules can be performed using any computer that has internet access, they are indeed substantially less expensive, and in many ways easier to conduct, than hands-on laboratory activities. Nevertheless, to be considered a reasonably acceptable alternative to traditional laboratory activities, the VPEL program must also provide comparable quality and level of instruction. Therefore, the purpose of this investigation was to compare how effectively students learned to setup, conduct, and analyze the data from selected incremental exercise tests using both the VPEL program and traditional hands-on laboratory experiences. This is the first investigation that has compared the effectiveness of virtual exercise physiology laboratory simulations against traditional laboratory experiences.

METHODS

All experimental procedures were approved by the University of Florida Institutional Review Board. The participants in this investigation were students in APK’s spring 2009 Integrated Fitness Programming course. Although the VPEL program was primarily designed for use in an exercise physiology course, the Integrated Fitness Programming course was chosen because it enrolled many of the same students and because it incorporated many exercise physiology concepts. In fact, the Integrated Fitness Programming course has been terminated largely due to its overlap with other APK courses like Exercise Physiology. APK’s Integrated Fitness Programming and Exercise Physiology courses were not designed to be taken in a specific sequence, neither course was a prerequisite for the other, and almost all enrollees in both courses were typically either second-semester sophomores or third-semester junior APK majors. Indeed, among the spring 2009 Integrated Fitness Programming students, 84% of the students had not yet taken Exercise Physiology, 88% were second-semester sophomores, and 88% were APK majors. It is important to clarify that neither experimental treatment (i.e., the VPEL or traditional hands-on laboratories) required any prior knowledge or coursework to successfully perform. It is also important to remember that the four students that had already completed Exercise Physiology course did not have a distinct advantage in this investigation because that course did not have a laboratory component.

Student participants were first placed into categories based on their academic major, concentration, and course history experience. Students within each of those categories were then randomly assigned to either experimental group 1 or group 2. Consequently, the number of students in both experimental groups were as evenly divided as possible to 1) those that were and those that were not APK majors, 2) those that had and those that had not taken APK’s Human Physiology course, and 3) those that had and those that had not taken the Exercise Physiology course. Students from both groups then completed the introductory cardiovascular module of the VPEL program to familiarize themselves with the operation of the program. Both groups then participated in a VO2max laboratory activity and assessment followed by a lactate and ventilatory threshold laboratory activity and assessment. With both experiences, one group performed the laboratory activity using the pertinent VPEL module and the other group performed a traditional hands-on version of the activity. With the hands-on version of an activity, students went to a laboratory.
were instructed as to how to perform the activity, participated in the collection of the activity data, and were instructed as to how to apply the data. However, to maintain consistency between the two experimental groups, the participant data that were actually analyzed and discussed during the hands-on laboratory activities were taken from the VPEL program. That is, during the hands-on laboratory activity, students conducted the test (i.e., either the $V_{\text{O}_2\text{max}}$ or lactate and ventilatory threshold test) and gathered data on one another but the instructor then emphasized VPEL participant data when he guided them through the analysis and discussion portion of the laboratory. Consequently, both experimental groups always analyzed, discussed, studied, and eventually answered assessment questions about the same participant data.

With specific regard to the $V_{\text{O}_2\text{max}}$ laboratory activity and assessment, group 1 performed the hands-on version of the activity, whereas group 2 completed the VPEL $V_{\text{O}_2\text{max}}$ module. Both groups then completed the same 30-question assessment to evaluate what they had learned from the $V_{\text{O}_2\text{max}}$ laboratory activity. With the lactate and ventilatory threshold laboratory activity, the groups switched such that group 1 completed the VPEL lactate and ventilatory threshold module and group 2 performed the hands-on version of the activity. Both groups then completed the same 25-question assessment to evaluate what they had learned from the lactate and ventilatory threshold laboratory activity. Both the $V_{\text{O}_2\text{max}}$ and lactate and ventilatory threshold assessments were composed of multiple-choice and true-false questions that asked about each of the elements involved in those activities, including the purpose of the activity, the physiology involved, the pretest health screening of the participants, the exercise protocol and equipment used, how the measured variables changed during exercise, and the analysis and interpretation of the data. Selected questions from both the $V_{\text{O}_2\text{max}}$ and lactate and ventilatory threshold assessments are shown in Table 3.

Once the students had completed all of the above procedures, they were encouraged to rate their experiences using a followup questionnaire (Table 4). One of the most relevant components of that questionnaire asked students to indicate which laboratory type they preferred (hands on vs. VPEL). A second relevant component asked students to indicate how informative and educational they thought the VPEL program was.

**RESULTS**

A total of 25 students (13 women and 12 men) completed both the $V_{\text{O}_2\text{max}}$ activity and lactate and ventilatory threshold activity assessments. Of those students, 12 students were in experimental group 1 and 13 students were in group 2. The mean $V_{\text{O}_2\text{max}}$ activity assessment scores were 86.39 ± 4.13 and 85.64 ± 6.72 for groups 1 and 2, respectively. The mean lactate and ventilatory threshold activity assessment scores were 85.50 ± 8.05 and 86.15 ± 6.45 for groups 1 and 2, respectively. There were no significant differences between the two groups for either experimental assessment, nor was there a significant effect associated with laboratory type order (i.e., hands on and then VPEL vs. VPEL and then hands on). The results of the $V_{\text{O}_2\text{max}}$ activity and lactate and ventilatory threshold assessments were analyzed using repeated-measures ANOVA. Statistical significance was set at $P < 0.05$, and data are expressed as means ± SD. The assessment questions were also analyzed to determine the number of correct and incorrect responses each group had on each assessment question.

### Table 1. Test variables and equipment associated with each VPEL module

<table>
<thead>
<tr>
<th>Variables Measured</th>
<th>Equipment Needed</th>
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</thead>
<tbody>
<tr>
<td><strong>Cardiovascular module</strong></td>
<td></td>
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<tr>
<td>HR, beats/min</td>
<td>HR monitor and transmitter</td>
</tr>
<tr>
<td>Systolic/diastolic blood pressure, mmHg</td>
<td>Sphygmomanometer</td>
</tr>
<tr>
<td><strong>Lactate and ventilatory threshold module</strong></td>
<td></td>
</tr>
<tr>
<td>HR, beats/min</td>
<td>HR monitor and transmitter</td>
</tr>
<tr>
<td>Blood lactate concentration, mmol/l</td>
<td>Biochemical analysis system</td>
</tr>
<tr>
<td>Minute ventilation, l/min</td>
<td>Mouthpiece and nose clip</td>
</tr>
<tr>
<td>$V_{\text{O}2\text{max}}$ module</td>
<td></td>
</tr>
<tr>
<td>Blood lactate concentration, mmol/l</td>
<td>Catheter and syringe</td>
</tr>
<tr>
<td>Minute ventilation, l/min</td>
<td>Ventilation meter and hose</td>
</tr>
<tr>
<td>$V_{\text{O}2\text{max}}$, ml·kg·min$^{-1}$</td>
<td>Head gear</td>
</tr>
<tr>
<td>$V_{\text{CO}2}$, ml·kg·min$^{-1}$</td>
<td>Metabolic cart</td>
</tr>
<tr>
<td>Rate of perceived exertion, Borg scale</td>
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</table>
Which of the following is NOT an indirect criterion for identifying VO₂max?

A. Feel safe to immediately administer a graded exercise test to that individual
B. Insist that the individual receive medical clearance before you administer a graded exercise to him/her
C. Refuse to ever administer a graded exercise test to that individual

Which of the following pieces of equipment is NOT needed to accurately measure gas exchange (e.g., VO₂)?

A. Biochemical analysis system
B. Metabolic cart and ventilation meter
C. Mouthpiece
D. Nose clip
E. Ventilation hose

Work rate is varied in the Bruce protocol by adjusting ________, and work rate is varied in the Modified Runner protocol by adjusting ________.

A. Speed; speed
B. Speed; both speed and grade
C. Both speed and grade; speed
D. Both speed and grade; both speed and grade
E. None of the above

Which of the following describes how minute ventilation responds to increasing work rates?

A. Minute ventilation increases linearly
B. Minute ventilation increases exponentially
C. Minute ventilation increases linearly through the low to moderate work rates but then increases exponentially through high work rates
D. Minute ventilation increases exponentially through low to moderate work rates but then increases linearly through high work rates

Which of the following is NOT an indirect criterion for identifying VO₂max?

A. Blood lactate concentration > 8 mmol/l
B. RER ≥ 1.15
C. Rate of perceived exertion > 17
D. HR within 10 beats/min of the age-predicted maximum
E. All of the above are, in fact, secondary/indirect criteria for identifying VO₂max

Which of the following occurs when the lactate threshold is exceeded?

A. There is a decrease in lactate removal
B. There is an increase in lactate production
C. There is a decrease in lactate production
D. Both A and B
E. Both A and C

Given that the O₂ cost required to run 1 mile every 6 min is roughly 55 ml·kg⁻¹·min⁻¹, could a person with a VO₂max of 45.8 ml·kg⁻¹·min⁻¹ run a 6-mile race in 36 min?

A. No
B. Yes
C. The answer cannot be determined with the given information

Teaching In The Laboratory

The primary purpose of this investigation was to compare how effectively students learned from selected VPEL and traditional hands-on laboratory activities. The results indicated that students from the two experimental laboratory type groups performed equally well on both the VO₂max and lactate and ventilatory threshold assessments. The similarity between the two laboratory type groups pertained to not just the overall scores on the assessments but also to the breakdown of correct and incorrect responses on each of the assessment questions. More specifically, of the 30 VO₂max assessment questions and the 25 lactate and ventilatory threshold assessment questions, both laboratory type groups performed essentially the same on 53 of those questions. There were only two assessment questions in which the number of students that answered correctly from one group was more than two greater than from the other group. Both of those questions appeared on the on the lactate and ventilatory threshold assessment, for which the students in group 1 prepared by completing the VPEL version of the laboratory, whereas the students in group 2 completed the hands-on version. On the first of those two questions (Table 5), 10 of 12 students in group 1 correctly indicated that lactate is a product of glycolysis, whereas only 7 of 13 students in group 2 chose that correct answer. The outcome was the opposite on the second question (Table 5), as only 6 of 12 students in group 1 correctly indicated that one’s lactate threshold strongly correlates with one’s 10-km running time, whereas 10 of 13 students in group 2 chose that answer. It is not evident why the groups performed differently on those two particular questions because those concepts were covered during both the VPEL and hands-on threshold laboratory activity assessments are shown in Fig. 4, and the responses to the followup questionnaire are shown in Fig. 5.

Main findings. The primary purpose of this investigation was to compare how effectively students learned from selected VPEL and traditional hands-on laboratory activities. The results indicated that students from the two experimental laboratory type groups performed equally well on both the VO₂max and lactate and ventilatory threshold assessments. The similarity between the two laboratory type groups pertained to not just the overall scores on the assessments but also to the breakdown of correct and incorrect responses on each of the assessment questions. More specifically, of the 30 VO₂max assessment
activities. Regardless, both experimental groups performed nearly the same on 96% of the total assessment questions, and so the bulk of the evidence indicates that the VPEL and hands-on laboratories were equally effective at preparing the students for the assessments.

The results of this investigation agree with previous studies that have demonstrated that laboratory simulations benefit anesthesiology students (7, 14), veterinary students (6, 17), occupational therapy students (19), undergraduate exercise science students (3, 10), and various other types of undergraduate students (2, 4, 11, 12). It is important to mention that one investigation (8) has provided evidence that computer simulations do not enhance student learning as much as textbook readings. Nevertheless, even that one exception to the trend in the literature (8) concluded that computer simulations are an important educational tool because they facilitate relatively better retention of knowledge. It is also important to point out that, of all of the above studies, only three studies (2, 4, 6) actually compared student learning from computer simulations against that from traditional laboratory activities. All three of those studies (2, 4, 6), now with the addition of this investigation, have provided evidence that virtual laboratory programs may increase student learning as effectively as traditional hands-on laboratory activities. This was, however, the first investigation to provide such evidence while studying the concepts and laboratory experiences that are unique to exercise physiology.

It has been argued (15) that multiple-choice/true-false tests may provide too narrow a measure of laboratory skill mastery to be valid. For example, a multiple-choice/true-false test cannot measure the kinesthetic components of laboratory activities (e.g., how well one physically operates the equipment), and so such tests may not adequately evaluate student learning from laboratory activities. It could therefore be considered a limitation to this investigation that student knowledge was measured using assessments that contained 30 \( V\dot{O}_2\)max activity) and 25 (lactate and ventilatory threshold activity) multiple-choice/true-false questions. However, those assessments were very similar, in both question type and question number, to tests used in several other comparable published studies (4, 6–8, 14). Furthermore, the primary justification for adding a laboratory component to APK’s exercise physiology course was not to enhance students’ understanding of how to physically operate exercise physiology equipment. Instead, the primary motivation, and therefore the major goal of the VPEL program, was to incorporate and reinforce concepts that are emphasized by exercise physiology laboratory experiences. The \( V\dot{O}_2\)max activity and lactate and ventilatory threshold assessments were thorough and objective measures of the concepts APK wanted to emphasize, and so they were appropriate for this investigation. Additionally, the scores on those assessments were comparable with the scores that APK students typically earn on summative exams.

**Questionnaire responses.** Numerous investigations (3–5, 10, 13, 15, 18) have reported that students enjoy working with physiology laboratory simulations and, in some cases, may actually prefer them to traditional laboratory experiences (3, 4, 13, 18). It is important to note that, in those latter four investigations (3, 4, 13, 18), the preference for simulations was largely attributed to the fact that simulations do not require animals to be killed. That justification does not apply to the types of laboratory activities explored in this investigation, however, because human subjects are typically used.

![Fig. 5. Student responses to the followup questionnaire questions about I) which laboratory type they preferred (A) and what they concluded about the educational value of the VPEL program (B).](http://advan.physiology.org/)

**Table 5. Selected questions from the lactate and ventilatory threshold assessment**

<table>
<thead>
<tr>
<th>Question 1</th>
<th>1. Lactate is a product of ________ metabolism.</th>
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<tbody>
<tr>
<td>A. Creatine phosphate</td>
<td>B. Glycolytic</td>
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<table>
<thead>
<tr>
<th>Question 2</th>
<th>2. Studies have shown that there is a strong correlation between one’s lactate threshold and one’s performance in a ________ running race.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. 0.1 km</td>
<td>B. 1 km</td>
</tr>
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</table>

Students in **group 1** prepared for this assessment by completing the VPEL version of the laboratory, whereas students in **group 2** prepared for this assessment by completing the hands-on version of the laboratory. **Question 1** was correctly answered by 83% of the students in group 1 but was correctly answered by only 54% of the students in group 2. **Question 2** was correctly answered by only 50% of the students in group 1 but was correctly answered by 77% of the students in group 2.
In this investigation, 52% of the students indicated a preference for the traditional hands-on laboratory activity. This finding was not surprising for the following reasons. First, most APK students are far more familiar with traditional laboratory activities, and many had never before used laboratory simulations. Second, the instructor that taught the traditional laboratory activities was a very dynamic and engaging teacher that was skilled at motivating and drawing students into the experience. Finally, the VPEL program required each student to work individually, and it forced them to read through a number of laborious text-heavy sections. In light of these challenges, it was somewhat encouraging that roughly half of the class either actually preferred the VPEL program (32%) or did not prefer one laboratory type over another (16%). Furthermore, students unanimously agreed that the VPEL program was at least moderately educational (32%), but most thought that it was very educational (68%).

Summary. Traditional hands-on laboratory activities have set the standard for quality laboratory experiences against which virtual laboratory programs must be compared. As with many virtual laboratory programs, the VPEL program does not provide as complete of an experience as do traditional hands-on laboratory activities. The VPEL program does not teach users how to operate the important pieces of equipment it simulates, nor does it teach users the actual techniques involved in measuring the physiological variables it describes (e.g., auscultation of blood pressure, extracting tissue, etc.). Furthermore, unlike hands-on laboratories, the VPEL program does not allow users to collect, and therefore learn from, poor, unusual, or uncharacteristic data (e.g., incorrectly collected data, data collected during a mechanical failure, etc.). Instead, the VPEL presents only predetermined sets of data, it teaches users about little more than the pertinent concepts, and it allows users to practice only the timing associated with the administration of a graded exercise test. On the other hand, the VPEL program does present ideal data, is self-contained and comprehensive (i.e., describes pertinent physiology, explains how to perform tests, and simulates tests and guides users through the data interpretation), and requires no prior training to successfully operate. Since the VPEL program has already been fully designed and revised to correct errors, there should be almost no cost associated with using again and again in the future. Perhaps most importantly, the VPEL program, unlike traditional hands-on activities, engages each individual user in every phase of each activity, and it does so in a manner that progresses at exactly the pace that is preferred by the user.

In conclusion, students using the VPEL and traditional hands-on laboratory methods performed equally well on summative assessments, and the VPEL program was unanimously rated as moderately to highly educational. The results of this investigation therefore lend support to the following conclusion of similar investigations (2, 4, 6): that virtual laboratory programs instruct students as effectively as hands-on laboratories. This investigation provides the first of many steps needed to determine if the VPEL program can be a useful supplement, or perhaps even an effective alternative, to hands-on exercise physiology laboratory activities.

REFERENCES