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Cross-disciplinary thermoregulation and sweat analysis laboratory experiences for undergraduate Chemistry and Exercise Science students

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Mulligan G, Taylor N, Glen M, Tomlin DA, Gaul CA. Cross-disciplinary thermoregulation and sweat analysis laboratory experiences for undergraduate Chemistry and Exercise Science students. Adv Physiol Educ 35: 206–212, 2011; doi:10.1152/advan.00067.2010.—Cross-disciplinary (CD) learning experiences benefit student understanding of concepts and curriculum by offering opportunities to explore topics from the perspectives of alternate fields of study. This report involves a qualitative evaluation of CD health sciences undergraduate laboratory experiences in which concepts and students from two distinct disciplines [chemistry (CHEM) and exercise physiology (EPHE)] combined to study exercise thermoregulation and sweat analysis. Twenty-eight senior BSc Kinesiology (EPHE) students and 42 senior BSc CHEM students participated as part of their mutually exclusive, respective courses. The effectiveness of this laboratory environment was evaluated qualitatively using written comments collected from all students as well as from formal focus groups conducted after the CD laboratory with a representative cohort from each class (n = 16 CHEM students and 9 EPHE students). An open coding strategy was used to analyze the data from written feedback and focus group transcripts. Coding topics were generated and used to develop five themes found to be consistent for both groups of students. These themes reflected the common student perceptions that the CD experience was valuable and that students enjoyed being able to apply academic concepts to practical situations as well as the opportunity to interact with students from another discipline of study. However, students also reported some challenges throughout this experience that stemmed from the combination of laboratory groups from different disciplines with limited modification to the design of the original, pre-CD, learning environments. The results indicate that this laboratory created an effective learning opportunity that fostered student interest and enthusiasm for learning. The findings also provide information that could inform subsequent design and implementation of similar CD experiences to enhance engagement of all students and improve instructor efficacy.

interdisciplinary; cognitive engagement; student interest; learning; knowledge discovery; physiology

INCREASINGLY, universities have focused on incorporating two or more disciplines together in a single educational setting. There are many reported benefits to this type of learning environment, such as increasing the relevancy of course material and exposing students to an approach to learning that is more realistic due to its wider scope (19). This type of education is broadly called interdisciplinary (ID), although further distinction can be made between the different approaches that fall into this category of teaching and learning. ID learning in its strictest definition refers to combining distinct disciplines so that they are almost fully integrated. A cross-disciplinary (CD) approach to learning, on the other hand, is focused less on integration and more toward exploring one discipline from the perspective of another (4). Distinguishing between the terms is important since they refer to slightly different approaches even though they are both often used interchangeably in the literature.

Both ID and CD learning methods can be implemented in a variety of ways. The processes tend to be similar for both ID and CD, and the differences between the two arise from the level of integration of the two disciplines. Some universities offer ID programs and degrees, whereas other schools offer ID and CD courses and laboratories (2). This report focuses specifically on the design and implementation of a CD laboratory experience in a university undergraduate academic setting that combined Chemistry majors with those majoring in exercise science (Kinesiology majors).

University science courses are typically accompanied by a laboratory component to complement what is learned during the lecture portion of the class. Learning objectives for laboratory sessions often differ slightly from lecture objectives depending on a variety of factors such as the discipline of study and the level of education of the students. However, across disciplines, commonalities are seen in most laboratory learning objectives. Four common laboratory objectives include 1) developing laboratory skills and techniques, 2) discovering knowledge, 3) experiencing the scientific method, and 4) applying theoretical knowledge to practical settings (5). To help students meet these objectives, laboratory sessions are generally designed to include activities that encourage students to be engaged and actively involved with the course material.

An inherent risk to learning in laboratory settings is that students may get into a routine in which they closely follow the outlined instructions but devote very little thought toward the relevance and implications of the activity (7). When this occurs, cognitive engagement is typically low, and the material is studied on a superficial level (3). Reading critically, considering the concepts from multiple perspectives, and putting the material in context will increase the likelihood that students will come away with a better understanding of the topic and learn more (11). Thus, while laboratory skills may be developed in a conventional laboratory setting, many course-related learning objectives, such as applying theoretical knowledge to practical settings and discovering knowledge, may not be met (3, 7).

ID and CD laboratories offer a potential solution to this problem. Many of these innovative laboratories have been implemented with success in a variety of disciplines. An area in which this is particularly common is that of chemistry, with chemistry laboratories being combined with disciplines such as biology or physics (17), or even integrating separate disciplines
within the field of chemistry, such as physical and analytical chemistry or organic and inorganic chemistry (8–10).

It is difficult to apply an experimental approach to investigate the quality and quantity of learning in this style of laboratory session compared with traditional arrangements. Preliminary evidence suggests that students in the ID laboratory had a better understanding of the material and an improved ability to apply their knowledge to novel situations than the non-ID students (17). In addition, other studies of ID and CD laboratory settings have reported positive student feedback regarding student experiences in these sessions (8–10).

Student engagement is one of the better measurable predictors of learning outcomes and has been positively linked to enhanced critical thinking skills and traditional measures of academic performance (1). The use of nontraditional learning arrangements constructed to optimize student engagement by carefully considering opportunities for student interactions with each other and with the content could favorably influence the learning and the experience for the students. Although any student could benefit, the effect of student engagement on learning outcomes seems to be most influential for lower-ranking students, thus allowing an important opportunity to address critical content with these students (6).

Chemical analyses of human samples, including sweat, are common in practical, research, and teaching situations for both disciplines (12). Despite this, there does not appear to be any assessments of academic laboratory learning from the CD perspective. The purpose of this study was to explore the student experiences regarding the unique CD laboratory sessions and to identify key themes for consideration in further implementation. Specifically, feedback from students will help determine whether or not this CD laboratory experience met its goal of being contextually relevant, applicable, and of interest to the students involved.

MATERIALS AND METHODS

Participants. This CD laboratory experience involved students from an analytical chemistry laboratory course [Department of Chemistry (CHEM)] and an exercise physiology course [School of Exercise Science, Physical and Health Education (EPHE)]. Both courses were upper-level science-designated courses and included senior undergraduate students with a laboratory learning history. Ten of the twenty-eight EPHE students were in the final year of their undergraduate degree. One of the forty-two CHEM students was graduating, and the remaining students were in the third year of a 4-yr program. Approval was granted by the Human Research Ethics Board of the University of Victoria.

Of the CHEM participants (mixed gender, mean age: 23 yr), 37 of 42 students were upper-year students in the Chemistry major program, for which Analytical Chemistry was a required course. This was a full-year laboratory course, scheduled to include 3 h of laboratory time each week. The students all had some previous experience in analytical chemistry since one of the prerequisites courses is Introductory Quantitative Analysis.

Of the EPHE participants (mixed gender, mean age: 24 yr), 26 of 28 students were upper-year students in the BSc Kinesiology major program. For these students, the Exercise Physiology course was a degree requirement. The students all had previous experience with human physiology laboratories as part of their degree program. A full year in introductory chemistry is also required for students in the Kinesiology major program. As such, the students had at least some experience in a chemistry laboratory, although not specifically an analytical chemistry laboratory.

CD laboratory design. The newly developed CD laboratory combined the ion analysis of sweat samples obtained during human exercise thermoregulation by having students study the physiological response to exercise while samples of sweat were collected from the exercising participant. The collected sweat samples were then analyzed to determine electrolyte concentrations. The physiological observation of continuous exercise as well as the sweat collection and analysis were the common bonds between the CHEM and EPHE students in this CD laboratory experience.

Previously, the laboratory sessions in both the Analytical Chemistry and Exercise Physiology courses were mutually exclusive and conducted independently with no form of CD interaction. CHEM students analyzed a nonhuman biological sample provided to them for the determination of the concentration of a given ion. EPHE students studied thermoregulation by observing, recording, and analyzing the physiological (primarily cardiorespiratory) response to continuous exercise.

Currently in practice, sweat analysis (i.e., analyzing electrolyte concentrations in sweat) is being increasingly used by exercise physiologists to monitor elite athlete hydration status and to assist athletes in developing fluid replacement strategies to optimize performance during training and competition (12). Such monitoring relies on the integration of concepts from both exercise physiology and chemistry. Simulating an athlete monitoring session in an undergraduate laboratory setting provided an excellent learning opportunity that would benefit both CHEM and EPHE students.

Joint learning outcomes provided to the students from both disciplines at the outset of the CD experience are listed below:

1. Prepare, collect, and transport field sweat samples using proper and rigorous technique.
2. Observe and describe the processes and instrumentation used in gathering other physiological parameters, such as heart rate, blood pressure, core temperature, skin temperature, \( \text{O}_2 \) consumption, and \( \text{CO}_2 \) production during rest and exercise.
3. Explain how these parameters are related during thermoregulatory response.
4. Validate the ion chromatography method in terms of accuracy and precision.
5. Explain how ion analysis of sweat would be useful for an athlete.

This CD laboratory experience involved 2 consecutive weeks of collaborative work with the first week being conducted in the EPHE laboratory and the second week in the CHEM laboratory. During the first week, after informed consent had been obtained, 12 students (6 students of each gender and divided between CHEM and EPHE students) completed 30 min of continuous stationary cycling at a target intensity of 70% of the age-predicted maximum heart rate. Physiological parameters measured by the students under the guidance of the EPHE instructor included oxygen uptake, heart rate, blood pressure, stature, pre- and postexercise nude dry body weight (to estimate sweat loss), core temperature, skin temperature, ear temperature, and psychophysiologic indexes of effort, thermal sensation, and thermal comfort. Sweat samples were collected by the students under the guidance of the CHEM instructor from ethanol-cleansed forearms using gauze held in place with water-resistant first aid tape. After 30 min of continuous stationary cycling, the gauze was removed using gloved hands and laboratory tweezers, placed into transport containers, transported across campus (500 m) by foot to the CHEM laboratory, centrifuged, and stored. In the subsequent week, the stored samples were diluted and analyzed. Under the guidance of the CHEM instructor, students of both disciplines partook in centrifuging, sample dilution, and instrument preparation. All samples underwent ion analysis by all students and the CHEM instructor using two techniques and instrument-specific methods: ion-selective electrodes and ion chromatography.

Focus groups and student feedback. All 70 students from both courses were invited to voluntarily participate in the focus groups through an announcement in their respective classes describing the
opportunity and what participation would entail. To accommodate student schedules across the two disciplines, a total of five focus group sessions were conducted 1 mo after the CD laboratory was completed. This recruitment yielded a total of 25 students; all had participated in both laboratory experiences. The CHEM and EPHE student focus groups were held separately. From CHEM, 16 students participated in one of three focus groups. The remaining nine students made up the two EPHE focus groups. The students who took part in the focus groups were all volunteers, and they all gave their consent to be audio recorded during the interviews.

The purpose of conducting the focus groups was to obtain feedback from the students who had participated in the CD laboratory and to explore the relevance and effectiveness of this learning experience. Specifically, student feedback was used to determine which aspects of the laboratory were beneficial to the students, which areas of greatest interest, and the major challenges faced. This information was collected to help implement improvements for subsequent years.

Each of the five focus group sessions lasted between 30 and 45 min. All focus group sessions were conducted by the same investigator, who also fully transcribed the discussions from the audio recordings. Analysis of the transcripts from the CHEM student focus groups and EPHE student focus groups were conducted separately, again by the same investigator.

In addition to the focus groups, CHEM and EPHE student written feedback from the end of term course evaluations was also obtained. Only the written feedback pertinent to the sweat analysis CD laboratory was included in the data set. This included written responses from 19 students about their experiences during the 2 laboratory sessions.

Data analysis. The first step in the data analysis was to review the transcripts and to use an open coding strategy to identify the major issues discussed by the students. Coding topics were generated during the analysis of the transcripts. Upon completion of this step, there were 12 common items identified in each data set. Many of these items overlapped with each other, so an additional step was taken to collapse the data set by reviewing each item to determine how it related to the other items and to the data set as a whole (14). In doing this, the items identified in open coding were combined and arranged to form the five themes for each discipline, which are presented in Table 1.

RESULTS

Summary data from all focus groups and the course evaluations are presented in this section. There were five main themes identified (Table 1), which were obtained from both the CHEM and EPHE students. These themes reflected the common student perceptions that the CD laboratory 1) stimulated their interest in this area of physiology, 2) provided insight into practical applications of the laboratory techniques they had learned previously within their respective discipline, 3) offered an opportunity to understand their course curriculum from another perspective, and 4) allowed for valuable interactions with students from another discipline. A fifth theme reflected challenges faced when working in a CD environment.

Each of the five themes are summarized (Table 2) and described briefly below, with a representative example of statements made by students.

Theme 1: interest and enthusiasm stimulated by the CD laboratory. While the primary focus of the laboratory for EPHE students was the physiology of thermoregulation during exercise, attending the session in the CHEM laboratory stimulated an interest in sweat analysis techniques.

“It was interesting to see how easy it is to taint a sample. There was just so much going on with transport etc. Especially when they [CHEM students] had it over in the CHEM lab, and then there are things that we [EPHE students] could have done to mess it up. I guess it just shows how exact a science has to be to come up with more accurate numbers.”

EPHE focus group participant

The CHEM students were equally enthusiastic about the opportunity to see what happens in laboratories in other fac-

Table 1. Major themes identified through data analysis from both CHEM and EPHE student feedback

<table>
<thead>
<tr>
<th>CHEM Students</th>
<th>EPHE Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest and enthusiasm stimulated by CD laboratory</td>
<td>Interest and enthusiasm stimulated by CD laboratory</td>
</tr>
<tr>
<td>CD student interactions</td>
<td>CD student interactions</td>
</tr>
<tr>
<td>Influence of CD laboratory on course content (field sampling techniques and procedures)</td>
<td>Influence of CD laboratory on course content (thermoregulation and electrolyte balance)</td>
</tr>
<tr>
<td>Influence of CD laboratory on applicability to real world situations</td>
<td>Influence of CD laboratory on applicability to real world situations</td>
</tr>
<tr>
<td>Challenges faced</td>
<td>Challenges faced</td>
</tr>
</tbody>
</table>

CHEM, chemistry; EPHE, exercise physiology; CD, cross-disciplinary.

Table 2. Influence of the CD thermoregulation and sweat analysis laboratory on student experiences

<table>
<thead>
<tr>
<th>Major Category</th>
<th>CHEM students</th>
<th>Learning-Associated Factors</th>
<th>EPHE students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest and enthusiasm</td>
<td>What occurs in other faculties, principles of EPHE, seeing the entire process</td>
<td>Using prior CHEM knowledge, methods of sweat analysis</td>
<td></td>
</tr>
<tr>
<td>CD student interactions</td>
<td>Enjoyment, desire for more interaction and integration, more stimulated discussions</td>
<td>Sharing knowledge of EPHE, increasing their own knowledge, desire for more interaction in the future</td>
<td></td>
</tr>
<tr>
<td>Course content</td>
<td>Exposure to field sampling, learning new skills, lack of participation, lack of competency</td>
<td>Further explore fluid replacement</td>
<td></td>
</tr>
<tr>
<td>Applicability</td>
<td>Improvement over other analytical laboratories, exposure to field sampling, working on a personal level</td>
<td>Multidisciplinary approach, practical application of EPHE</td>
<td></td>
</tr>
<tr>
<td>Challenges faced</td>
<td>Amount of work</td>
<td>Clarity and amount of information provided, lack of discussion, benefits of being challenged</td>
<td></td>
</tr>
</tbody>
</table>
ulties and specifically about learning the basic principles of exercise physiology.

“At the end of the actual sweat collection, when they were showing us what the data meant—like they showed the VO2 max curve. It was cool to actually see that and to know that over there [in the EPHE lab], someone is actually doing it. It’s not something you just read about in a magazine.”

CHEM focus group participant

Students were also interested to learn how the entire process of sweat analysis occurred, from the initial collection in the EPHE laboratory, to the analysis in the chemistry laboratory, to determining the implications of the results for athletes and exercise physiologists. Throughout the entire process, students were able to learn about the relevance of these techniques to real world situations.

“I thought it was sort of interesting to be able to see the full circle of it. You actually collect everything, run it yourself, you see what the results are and you go back to the people who you sampled it from. You see the entire process as opposed to just seeing a machine.”

CHEM focus group participant

Related to the high level of enthusiasm in combining two laboratories into a CD laboratory, many of the CHEM students expressed interest in further integrating the laboratories so that all the aspects of the laboratory came together at the end.

Theme 2: CD student interactions. Both groups of students were enthusiastic about having the opportunity to interact with the students from another faculty. This came mostly from EPHE students being able to discuss and share their knowledge of exercise physiology with undergraduate CHEM students. Some EPHE students felt that this sharing of knowledge helped them to better understand the concepts of thermoregulation covered in the lecture and laboratory.

“I liked it. My partner asked me questions and I was like, ‘Wow! I can actually answer these!’ It was awesome. I felt way smarter that I usually do.”

EPHE focus group participant

The CHEM students also realized the importance of being able to communicate with others but felt that this was an area of the laboratory that was not developed to its full potential. In particular, during the EPHE laboratory, CHEM students found that their discussions with their EPHE partners were not as stimulating as they had hoped.

“It was good to talk to the EPHE students and get them to explain things. I think it could be helpful to have more interaction with the partners.”

CHEM focus group participant

Students also expressed interest in encouraging more interaction between students from two disciplines, during both the EPHE and CHEM laboratories. Teaching EPHE students, for example, was a suggestion that was received with enthusiasm as the CHEM students felt that this would improve their own learning.

“If you have a partner [during the sweat analysis] and you have to tell them what’s going on at the same time then you’d have to learn the stuff beforehand or at least try to understand that was going on at the moment just to explain it to them.”

CHEM focus group participant

Theme 3: influence of the CD laboratory on course content. One of the goals of participating in this CD laboratory for the CHEM students was to gain insight into the importance of the collection techniques and methodology for field sampling in chemical analysis as well as an understanding of how to apply these techniques.

Students found that the CD laboratory taught them about certain aspects of sampling that they had not previously considered. For example, the CHEM students noted the following components of field sampling that were enhanced by their participation in this laboratory:

“I think for me it helped me understand a lot more about sampling and the errors it can introduce while analyzing samplings. It also clarified the concept of extracting analytes from a matrix, like gauze.”

CHEM focus group participant

Most EPHE students felt that the CD experience had little effect on their understanding of electrolyte balance in the thermoregulatory aspects of exercise. However, there were some students who thought that they had indeed considered the influence of electrolytes and expressed interest in pursuing the issue further.

“Coming up with different values, I thought that was really interesting because there was a huge range between some different people and I thought that was really cool.”

EPHE focus group participant

Theme 4: influence of the CD laboratory on applicability to the real world. CHEM students indicated that this experience was more realistic than the other laboratories conducted during the Analytical Chemistry course.

“Everything in analytical chemistry that we do is just like, ‘Here’s a sample. Pretend this was a bullet fragment and run it through a machine.’ Now it’s like you actually have something and you can actually run tests on it and see what you got! So it was kind of interesting to see that maybe there are some applications of this somewhere.”

CHEM focus group participant

In addition to making the experience more realistic to how analytical chemistry can be used outside an academic learning environment, this CD laboratory experience offered an example of an application of analytical chemistry taking place on a much more personal level.

“I’ve never really considered analytical chemistry to be very interactive. I’ve considered it to be more...you can work with soil samples, or chemicals, trace elements of things, but never really on a personal basis. So I thought this was kind of neat to do something with a biology aspect to it.”

CHEM focus group participant

Most EPHE students felt that while their laboratory experiences in the EPHE program were already relevant to nonacademic settings, this CD experience further exposed them to realistic situations that they might encounter after graduation.

“I thought it was fabulous because it showed an interdiscipliary approach and how you don’t just work as an isolated community in kinesiology, but together with other people who have different specialties and different interests.”

EPHE focus group participant
In addition, the sweat analysis exposed some of the students to a practical application of something that could be done with a degree in Kinesiology.

“I’m actually doing my practicum at a national sport performance center and I never thought I would ever have to use sweat analysis and I’m having to do sweat analysis down there with them right now. It’s kind of cool because we’ve done it and I kind of know a little bit more of what I’m doing.”

**EPHE focus group participant**

**Theme 5: challenges reported by students.** The major challenge reported by CHEM students related to the amount of work required to complete their assignment. Students found that the amount of work required in this CD laboratory was much greater than in other laboratories conducted throughout the year.

“It was honestly three times the work that we’re normally concerned with. We had to do our own stuff, get results for that and then we had to get our partner’s data and figure out everything for that, as well comparing them. It was basically like you were running two labs all at once.”

**CHEM focus group participant**

Although at first this challenge appears to be related only to the CHEM portion of the laboratory and the CHEM assignment, the amount of work required of the students actually did interfere with one aspect of the CD laboratory, specifically, making the results of the sweat analysis applicable to CHEM students. The large amount of work made it so that the CHEM students did not have sufficient time to focus on the implications of results and how they might relate to exercise physiology.

This time limitation during the CD laboratory experience also affected the EPHE students in the exercise laboratory, as it resulted in there being no time available for the typical end of session review and discussion. The EPHE students found that they struggled to identify the important concepts from the laboratory and to complete their written laboratory assignment due to this loss.

“We really needed a discussion to understand what we were supposed to be doing and what we were supposed to be looking for. We never had something where everyone was on the same page. The whole time I felt like I was constantly talking to other people trying to figure out what we were supposed to do.”

**EPHE focus group participant**

In regard to the CHEM portion of the CD laboratory experience, the EPHE students felt that there was not enough information available to prepare effectively for their session in the CHEM laboratory. This affected their ability to actively participate in that setting. The challenges faced, however, were not all negative. By incorporating CHEM into the experience, a discipline with which they were far less comfortable, EPHE students noted that there were some benefits.

“It sort of just broadened our horizons and put us into a different situation where we hardly knew anything and had to go back to the basics in chemistry.”

**EPHE focus group participant**

**DISCUSSION**

The findings of this study indicate that it was possible to effectively combine two previously established laboratory experiences from CHEM and EPHE courses and form a new CD learning experience focused on thermoregulation and sweat analysis. Results show that implementing this CD experience was not only possible but that it was a positive experience for the students involved. This experience stimulated student interest, emphasized certain aspects of their course material, was perceived as relevant and applicable, and encouraged interaction between disciplines (Table 2). These findings will be discussed below in relation to the role that they play in creating an effective learning environment. There were aspects of the experience found to be challenging by the students as well as some areas in which the students offered suggestions for improvement.

**Interest and enthusiasm, course content, and applicability.** One of the main findings from the focus group discussions was that the CHEM and EPHE students found this laboratory experience to be of great interest. Given their different backgrounds, it is not surprising that the CHEM and EPHE students were interested in different aspects of the laboratory. This may have been due to the fact that, as senior undergraduate students in a specialized degree program, they were more likely to be focused on their own discipline. CHEM students were particularly interested in learning about sampling, whereas EPHE students were more interested in learning about the methods of sweat analysis and the implications of electrolyte loss. One common point of interest for both groups was the opportunity to interact with students from another faculty (Table 2). This experience gave them insight into how another faculty operates, allowed them to share their own knowledge of their field of study, and introduced them to unfamiliar subjects that they had not encountered in their degree programs. This exposure to unfamiliar yet relevant topics, while somewhat challenging, was viewed positively by the students from both disciplines since it forced them to expand their horizons.

Overall, students were enthusiastic about the idea of participating in a CD laboratory, and they were interested in what was being taught (i.e., thermoregulation, sweat analysis, and sample collection). Most students across both disciplines felt that it had the potential to be used as an excellent learning tool in the future.

Educational literature has focused a great deal on the role that interest plays in motivating students to learn. Students who are interested have been reported to devote more time to studying and think about the material being presented on a deeper level (13). In addition, it has consistently been shown that students who engage in this deep approach to learning, that is, an approach in which they go beyond simply memorizing the facts, have a better understanding of the material and an improved ability to apply what is learned (11, 18). It is not surprising that interest plays a large role in student learning and may result in students receiving better grades, indicating that by traditional measures their learning is enhanced (13). Since learning was not measured in this present study, it cannot be stated that the CD laboratory experience improved learning. However, student feedback on the experience indicates that the CD laboratory did stimulate their interest in the topics studied, in particular, thermoregulation, electrolyte balance, and field sampling techniques (Table 2). It would thus appear that the implemented CD experiences created a more positive learning environment, one in which students may be more motivated to learn about the topics presented to them and how to apply these...
to practical situations. For example, the CHEM students were exposed to field sampling for the first time. They were interested in this and noted that they learned the role that contamination plays in sampling as well as how to apply corrections and use method and transport blanks and spikes in a chemical analysis.

For the EPHE students, this laboratory learning experience offered the opportunity to consider the role of electrolytes and their importance in fluid replacement strategies for elite athletes, in addition to the opportunity to monitor variables associated with thermoregulation during exercise. Some students thought that they did not focus enough on electrolytes and, therefore, that the experience was not particularly useful in that regard (Table 2). As a counterargument, prior offerings of the EPHE laboratory experience focused solely on the cardiovascular thermoregulatory response and did not include any content regarding sweat ion concentrations. As such, even though students reported that they would like to spend more time with the concepts of electrolyte balance and fluid replacement, their awareness of the topic was much greater than that of students who experienced the same course in previous years.

In addition to introducing the topics of field sampling and electrolyte balance, one of the principal reasons for implementing this CD laboratory was to increase the relevancy of the laboratory and expose students to a practical application that would rely on their knowledge of chemistry and exercise physiology. This was seen to be important because many educational laboratories, especially in chemistry, fall into a “cookbook” pattern, in which students simply go about following instructions with little thought or attention to what they are doing (7). While approaches such as these may allow students to develop their technical skills, they are not as effective in challenging students to apply their knowledge to practical situations (3, 7). The student feedback presented in this study demonstrates that this CD laboratory experience did partially achieve the goal of having students apply their knowledge to practical situations. Students stated that this laboratory was applicable, but at a similar, or only slightly greater, level than other courses (Table 2). This CD laboratory experience, however, did expose students from both disciplines to a view of practical applications that many of them had not previously considered. This was especially true for the CHEM students, many of whom had never considered analytical chemistry to be a subject that involved much personal interaction.

**CD collaboration.** For both the CHEM and EPHE students, the experience introduced to them the idea of collaboration between disciplines (Table 2). The students thought that this was particularly applicable since communicating with experts in other disciplines is a skill that is transferable to a variety of situations beyond the classroom. Until this experience, it seems that many students had not considered how to think about and link their content knowledge externally. The CD laboratory experience also allowed them the opportunity to work in a multidisciplinary team, either in a research or job setting, and that there could be benefits to working in such a team. For example, one student noted that CD collaboration was realistic because each person cannot be an expert in all topics but that experts from different disciplines can come together to solve a larger problem.

“I thought it was great. It just shows that you don’t need to be an expert at everything but that you need to know how to use other experts.”

**EPHE focus group participant**

That this realization and externalization is one of the major benefits of an ID or a CD approach to learning has been previously noted (4). Although CD student interaction was one of the aspects of this laboratory that students found most enjoyable and relevant, it was also one of the areas in which the students expressed a desire for improvement. It may also be possible to stimulate further interactions between students by having them collaborate together using different modalities throughout the experience. For example, if small groups of students from CHEM and EPHE had to work together during both laboratory sessions and then had to come together with their final results and put them in context (i.e., discuss the implications of the results and identify the problems/contaminants that might be affecting the results), the overall level of interaction between disciplines would be much greater. This form of student collaboration would also allow for more integration between the disciplines. Student interaction and integration of concepts are closely linked so it is difficult to discuss one without the other. Tied in with the student desire to have more interaction between disciplines was a desire to further integrate the two subjects into a more cohesive laboratory experience. Being CD in nature, this laboratory was far more integrated than laboratories in previous years. However, by increasing the focus on student collaboration and by further integrating the two experiences, it may be possible to better put the material into context. This would ensure that students understand the implications of the results of the sweat analysis on exercise performance, electrolyte balance, and fluid replacement strategies while also drawing attention to the challenges that are likely to be experienced by the collaborative chemist.

Settings in which students collaborate or engage in peer tutoring have the potential to create a more effective learning environment, and this seems very well established for students collaborating within a discipline (15). Less research has been conducted on CD settings, although students have previously found CD collaborations to be useful because the focus tended to be quite broad and it placed the information in context (16). There are suggestions that this also creates a positive learning environment, one in which students may be more likely to take a deep approach to learning (16). This is beneficial because, as previously mentioned, there is strong evidence to support the notion that a deep approach can improve student learning and understanding of course materials (11).

**Conclusions.** Allowing current research and applied practices to inform teaching methods, with some effort and limited resources, it was possible to take two previously existing independent laboratory sessions from distinct disciplines and blend them to form an effective, relevant, CD laboratory experience for all. As with many newly implemented strategies, there were some aspects of the experience that require modifications to improve the overall experience of the laboratory sessions. Even so, the CD experiences stimulated interest among the students, gave them insight into practical applications of the techniques, and provided them opportunities for interactions with students from another discipline. These factors have been related to the creation of a positive learning environment for students, increasing engagement and learning.
It would therefore appear that this CD thermoregulation and sweat analysis laboratory experience has the potential to be used as an effective tool to improve undergraduate student experiences of learning in a laboratory setting.

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

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