Evaluating a Technology Supported Interactive Response System During the Laboratory Section of a Histology Course

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Monitoring of student learning through systematic formative assessment is important for adjusting pedagogical strategies. However, traditional formative assessments, such as quizzes and written assignments, may not be sufficiently timely for making adjustments to a learning process. Technology supported formative assessment tools assess student knowledge, allow for immediate feedback, facilitate classroom dialogues, and have the potential to modify student learning strategies. As an attempt to integrate technology supported formative assessment in the laboratory section of an upper-level histology course, the interactive application Learning Catalytics™, a cloud-based assessment system, was used. This study conducted during the 2015 Histology courses at Cornell University concluded that this application is helpful for identifying student misconceptions “on-the-go,” engaging otherwise marginalized students, and forming a new communication venue between students and instructors. There was no overall difference between grades from topics that used the application and grades from those that did not, and students reported that it only slightly helped improve their understanding of the topic (3.8 ± 0.99 on a five-point Likert scale). However, they highly recommended using it (4.2 ± 0.71). The major limitation was regarding the image display and graphical resolution of this application. Even though students embrace the use of technology, 39% reported benefits of having the traditional light microscope available. This cohort of students led instructors to conclude that the newest tools are not always better, but rather can complement traditional instruction methods. Anat Sci Educ 00:000–000. © 2016 American Association of Anatomists.

Key words: undergraduate medical education; microscopic anatomy; histology; virtual microscopy; digital morphology; e-learning; interactive computer graphics; formative assessment; instant feedback assessment technique

INTRODUCTION

Most instructors strive to prevent students from making faulty interpretations of topics; but if these misinterpretations are inevitable, then identifying them early is key (Dihoff et al., 2003; Watkins and Mazur, 2013). The use of any teaching tool that generates information about students’ achievements and can be used by teachers and students to improve learning is a formative assessment tool (Black and Wiliam, 2009; Balevi, 2015). The use of formative assessment to obtain and provide continuous feedback on student’s state of knowledge has been implemented in the biomedical sciences in many forms (Clynes and Raftery, 2008; Alexander et al., 2009; Trumbull and Lash, 2013; Antoniou and James, 2014). The repertoire of formative assessment tools in use in the histology course at Cornell University (BioAP4130/BioMS4130) encompass quizzes, laboratory reports, case study reports, and laboratory activities using both light microscopy and virtual microscopy as tools. Instructors utilize these to provide constructive feedback to students and gain insight into the misinterpretations and gaps in students understanding allowing modifications in teaching strategies. These assessments also contribute to the student’s final grade,
which summarizes the students’ achievements for the course, that is, the summative assessment (Nicola and Macfarlane-Dick, 2006). Whereas formative assessments “monitors to improve” student learning, summative is an evaluation of learning. Therefore, even though all graded portions of the final examination is not formative.

Students can benefit from formative assessments only when provided with feedback that allows them to act upon their learning (Perera et al., 2008; Trumbull and Lash, 2013). Feedback is an interactive process that provides information about a person’s performance of a task, which can be used as basis for improvement (Nicola and Macfarlane-Dick, 2006; Clynes and Raftery, 2008; Perera et al., 2008). Feedback provided through the analysis of formative assessments helps improve student’s learning strategies (Nicola and Macfarlane-Dick, 2006; Perera et al., 2008). Usually formal feedback, as those provided when students receive their graded written assignments, takes longer to reach the student and require student’s motivation in order to be effective (Mullet et al., 2014). Informal feedback is mostly delivered immediately by direct interaction between students and teacher during a laboratory session (Clynes and Raftery, 2008). In laboratory settings that require instructor-student interactions, immediate informal feedback is not only important but also the most frequent. However, informal feedback may never reach shy students who are not comfortable asking questions or seeking clarification (Sinclair and Cleland, 2007) resulting in marginalization and failure to achieve full potential (Sinclair and Cleland, 2007).

The timing in which a student receives feedback is also important and has variable outcomes (Dihoff et al., 2003; Sinclair and Cleland, 2007; Clynes and Raftery, 2008; Miller et al., 2014; Mullet et al., 2014) that inevitably depend on how students react to it (Dihoff et al., 2003). When feedback is provided while interacting with students it is said to be an immediate feedback (Shute, 2007; Mullet et al., 2014). Feedback provided days or weeks after an assessment has taken place is labeled as “delayed” (Shute, 2007; Mullet et al., 2014). Most classroom environments foster both immediate and delayed feedback. It can be generalized that students receiving immediate feedback are less likely to form memory of wrong concepts (Crouch and Mazur, 2001). In courses that progressively build new concepts upon recently acquired knowledge (e.g., concepts developed earlier in the course), the memory of a wrong concept may irreversibly impair the student’s understanding of the newer topic. Therefore, learning outcomes are at stake if a misconception is not promptly identified and corrected (Crouch and Mazur, 2001; Dihoff et al., 2003). In contrast, Mullet et al. have compelling evidence of the benefits of delayed feedback that cannot be taken for granted (Mullet et al., 2014). Envisioning that no approach is singly the best, the ideal feedback should have both the immediate and the delayed component.

Histology is a detail-oriented biomedical course that requires identification and description of the cellular organization in healthy tissue (Mione et al., 2013). It is traditionally taught as a combination of descriptive lectures and practical laboratory sections (Bloodgood and Ogilvie, 2006; Bloodgood, 2012). The latter aims to develop the students’ abilities to identify subtle morphological differences in characteristics of a tissue and integrate their knowledge of the functional aspects of an organ with their observation of a two-dimensional microscopic image (Bloodgood and Ogilvie, 2006; Mione et al., 2013; Hortsch and Mangrulkar, 2015; Selvig et al., 2015). This is a complex and multistep process that is usually facilitated by interaction between learners and teachers. Therefore, an ideal formative assessment tool would nurture student teacher communication, be able to display high-resolution images that react to user interaction, provide formative assessment to instructors, and allow for formal immediate and delayed feedback to students.

With advances in technology, teachers of morphology-based courses have tools that together with virtual slides can be used to engage students and assess learning outcomes before graded examinations are performed. Such tools are often referred to as classroom response systems (CRS) (Paschal, 2002; Schell et al., 2013) or audience response systems (ARS) (Alexander et al., 2009). Examples of CRSs are “clickers” (Briggs and Keyek-Franssen, 2010), the Piazza Q&A platform (Piazza, 2014), internet-based voting applications (Mathiasen, 2015), and the web-based Learning Catalytics™ platform (Schell et al., 2013; Mullet et al., 2014). These teaching tools are currently used to engage students and provide immediate feedback about their state of knowledge. Even though these tools are widely used, there are few formal reports about their effectiveness and how they are perceived by students (Alexander et al., 2009; Karolcik et al., 2015; Selvig et al., 2015) when used during laboratory sections. Even though many excellent technology supported formative assessment tools that provide immediate feedback are available, this study was conducted using the Pearson Learning Catalytics™ platform (Pearson Education Corp., Upper Saddle River, NJ) to readily identify misconceptions and provide a more inclusive and formal feedback.

Currently, the histology course at Cornell University uses microscopy as tool for immediate formative assessment. The course is in the form of a traditional lecture followed by an interactive laboratory session in which instructors assist students in examining histological slides; thus providing students with immediate informal feedback. The lecture component uses PowerPoint slides coupled with an educational talk. The laboratory component relies on student engagement in learning activities that refers back to concepts presented during lecture. The activities prompt students to find and correlate histological structures with organ function. Students are allowed to work in groups, formed without instructor intervention. It is during the laboratory session that all formative and summative assessments for the course take place. In the laboratory setting, students have access to multiple glass slides, computers (used to visualize the virtual slides), and traditional two-headed microscopes. During the laboratory section instructors make available histology books and atlases. If solicited, students receive immediate informal feedback while using virtual microscopy (VM) or light microscopy (LM) with glass slides. Unsolicited feedback is offered when instructors deem students are having difficulties with the topic (Bloodgood, 2012; Collier et al., 2012). Quizzes, laboratory reports and two examinations in the middle of the semester are the formative assessments used to provide delayed formal feedback.

**OBJECTIVE**

The purpose of this study is to evaluate the use of an interactive cloud-based classroom response system (CRS) to identify misconceptions “on-the-go,” minimize erroneous interpretation due to contradictory or confusing informal feedback,
and obtain a more inclusive teaching atmosphere (Stoltzfus, 2014). The targeted audience is undergraduate and graduate students enrolled in the 2015 histology course at Cornell University. The course’s laboratory component requires student engagement through active learning and peer learning activities. As an effort to improve students’ learning outcomes, the learning activities constantly incorporate the use of new teaching tools, currently using the VM technology coupled with the LM and problem based learning activities. However, misconceptions about the topics still arise and are not detected by instructors until grading high stakes assessments (Feldman and Capobianco, 2008). The Pearson Learning Catalytics™ platform is the selected CRS (Schell et al., 2013; Mullet et al., 2014). Surveys from students and instructors provide information on their perception of this CRS. Impact on learning outcome is assessed through self-reported experiences and through the comparison of question scores obtained on topics that did or did not use the CRS.

This research was done according to Cornell Institutional Review Board Policy # 2 and under paragraph 2 of the Department of Health and Human Services Code of Federal Regulations 45CFR46.101(b) and has protocol ID# 1503005435.

MATERIALS AND METHODS

Software

The Pearson Learning Catalytics™, version 2015 (Pearson Education Corp., Upper Saddle River, NJ) is the Internet based teaching tool selected to provide formative assessment. The following were the reasons for making this choice: (1) Learning Catalytics™ CRS is not restricted to multiple-choice questions. Instead, examples of question types that can be created include written short or long answers, word cloud, matching pairs, identifying regions, and sketching (see Figs. 2 and 4 for examples). (2) Students can use any web-enabled device (such as smart-phones, computer and tablets.) Thus, the existing laboratory setting did not require the purchase of any extra device. (3) It has an interactive component where students not only answer the questions in real time, but also are able to let instructors know if they understood the reasoning behind an answer. (4) Students could submit questions without the need to raise their hands, speak out loud, or wait for all students to submit their answer. (5) Students’ responses are immediately made available on instructor’s device (Schell et al., 2013; Mullet et al., 2014). (6) It is user friendly and the implementation only requires that students and instructors have access to the Internet, a web-enabled device, and a valid account. At the time of the study the student cost was US$12.00 for six months. (7) For the purpose of this study Pearson Education made available two instructor accounts and 50 student accounts for a period of four months free of charge.

To test the tool in a laboratory session, four small modules containing ten to fifteen questions each were generated using the software. The modules were delivered as 15–30 minute review sessions. The sessions were interactive in the sense that students and instructors actively discussed concepts. Furthermore, as each question was delivered, students articulate a response. This commitment to an answer has been shown to make students more likely to seek understanding and engage in discussion (Alexander et al., 2009; Ludvigsen et al., 2015). The notation “interactive review session” (IRS) was chosen as a descriptor since the activity was designed around previously learned topics and required meaningful learning (there was no passive delivery of information). Instructors also reminded students that the IRS was voluntary, had no impact on their grade, and used an interactive CRS platform. Placing the IRS at the end of the laboratory session was partially based on Favero’s description of review sessions, and partially as an attempt to minimize any negative impact to the course if students shunned the activity (Favero, 2011).

Study Participants

All of the students enrolled in the spring semester of the 2015 histology course at Cornell University were encouraged to participate in the study. Every intervention and survey request provided participants with information regarding the research goal and procedures of the study. Participation was not required, and students were allowed to withdraw at any time without any penalty. The Institutional Review Board (IRB) at Cornell approved the research methods used. The Pearson’s Learning Catalytics™ software was kindly made available by Pearson Education representatives, free of charge, for all students regardless of their choice to participate in the study.

The staff for this laboratory semester consisted of one faculty member, one postdoctoral teaching assistant (TA), one graduate TA and five undergraduate TAs. The faculty member and the graduate TA (authors of this article) envisioned and implemented the IRSs activities. The graduate TA did not participate in any survey. During the laboratory, all staff members (referred to as instructors throughout the manuscript) were encouraged to hover around the room waiting for students to call for help. Instructors had weekly meetings in which the slides and slide descriptions were thoroughly reviewed to ensure comparable and homogeneous knowledge of the topics.

Interactive Review Session

The IRS questions were designed around the topics: integument; gastrointestinal tract (GIT); oral cavity; and endocrine system (thyroid, liver and pancreas). There are six questions from the Oral Cavity module available as Supporting Information. Questions covering the material suggested for the week, were designed a day prior to the activity, and mirrored instructors’ previous experiences about student misconceptions. Studies by Freeman et al suggest that the students are more likely to engage in an interactive exercise if they are more familiar with one another and with their instructors (Freeman et al., 2014). Therefore, these IRSs were implemented during the second half of the semester as an attempt to obtain a better participation rate once students had time to build a relationship with instructors and with each other.

Measure of Impact in Learning Outcome

To test if the CRS mediated feedback impacted learning outcomes, surveys and final examination question scores were utilized. Question scores derived from topics either using or not using the CRS were compared. For topics that did not
use the CRS, formal delayed feedback had previously been provided through quizzes and laboratory reports. Examination scores was not linked to students’ identification and the quantitative analysis used question scores from all students, independent of their participation on the IRS. Final examination scores did not follow a Normal distribution (both score types with a \( P/W < 0.001 \) for the Shapiro–Wilk goodness-of-fit test). Therefore nonparametrical Wilcoxon comparison for each pair method was used to compare the difference between scores from IRS and non-IRS topics. A table containing the averaged scores, ± standard deviation (±SD), and median for the 23 questions can be found in the Supporting Information. There was a total of 11 non-IRS and 12 IRS related questions for the final examination. All statistical analyses were done using JMP Pro software, version 12.0.1 (SAS Institute Inc., Cary, NC). Students and instructors were asked to provide feedback about their experiences by answering voluntary and anonymous surveys. The impact on students’ grades was not a focus in this study instead, the study was designed to identify misconceptions “on-the-go,” minimize confusion due to informal feedback and obtain a more inclusive teaching environment.

**Surveys**

To assess how students experienced each module of the IRS, specific internet-based surveys were designed for each module (mini-surveys). These surveys were sent to students soon after IRS ended utilizing the Cornell Qualtrics platform (a web-based survey tool available to the Cornell community). The information provided in the different surveys was used to improve each subsequent IRS (Supporting Information). Two paper-based surveys were generated: [1] one delivered before the IRS activity began (Supporting Information); [2] and another delivered the last day of class; prior to final examination and after all IRSs (Supporting Information). All surveys had questions that used the five-point Likert type scale: 1 = Strongly disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly agree; 1 = poor rating and 5 = excellent rating) and open-ended questions. Kendall’s tau B and Cronbach’s alpha statistical tests were performed to assess correlation and reliability using JMP® Pro 12 software, (SAS Institute Inc., Cary, NC). Responses with correlation coefficient \( r \) above \( r > 0.6 \), Kendall’s tau \( P \) value \( P(t) < 0.05 \) and Cronbach’s alpha \( x > 0.7 \) were combined to represent a measure of positive or negative students’ perception. This combined Likert is therefore a 10 points scale. All mean values provided are accompanied by respective standard deviation (±SD). Survey [1], adapted from Harris et al. (2001), was designed to obtain information about the students’ perception of LM and VM, which are the two teaching tools used for immediate formative assessment and informal feedback during this histology course. Students had access to both tools in the laboratory setting (open from 8:00 am to 5:00 pm on weekdays) and VM at all times in their personal computers. The survey assessed student’s preference for the tools, difficulty in use and usefulness understanding the material (Supporting Information). Survey [2] was designed to provide information about how students perceived the IRS and the CRS software, and if the activity helped them understand the material. This survey was designed by the authors and tested by six fellow graduate students to assess clarity. Answers from paper-based surveys were typed into excel spreadsheet for analysis, exactly as written by surveyed individual (Supporting Information). Sample answers found in this manuscript were transcribed exactly as originals. Authors’ observations coupled with instructors’ surveys (delivered using Qualtrics platform) to assess software usefulness, and effect on student performance, were used to evaluate the activity from a non-student perspective. Excel spreadsheets for all surveys are provided as Supporting Information.

**Course Context**

The study was performed during the laboratory session of the Histology course BioAP4130/BioMS4130 taught in the spring semester of 2015 at Cornell University in Ithaca, NY. This is an upper-level undergraduate course offered by the Department of Biomedical Sciences at the College of veterinary medicine. It is a four-credit course, offered only during spring semesters; the class meets twice a week (Monday and Wednesday) for 14 weeks and the contact hours add up to 24 hours of lecture and 56 hours of laboratory. The course consists of 28 lectures during 55 minutes, followed by 28 two-hour laboratory sections. There are two laboratory sections that are used for preliminary examinations without any laboratory activity.

The classroom size for the spring 2015 semester was 39 enrolled students plus two auditing graduate students (not included in the study). The course’s prerequisite is a three-credit introductory biology course (BIOMG 1350 Introductory Biology: Cell and Developmental Biology) and students are also recommended to have taken principles of biochemistry (BIOMG 3300 or BIOMG 3310) or equivalent.

The course content covered all major organ systems. Both glass and virtual histology slides from a variety of vertebrate species were available, even after course hours. Virtual slides were obtained from glass slides scanned using the Aperio CS2 Digital Pathology Scanner system (Leica Biosystems, Buffalo Grove, IL). Students had access to scanned slides through Aperio eSlide Manager, version 12.1.0.5029 (Leica Biosystems Inc.), and laboratory computers have the Aperio ImageScope, version 12.3.0.5056 (Leica Biosystems), viewing software to perform image analysis. Weekly packets intended to guide students through the laboratory activities contained factsheets (with brief overview of most basic concepts, together with detailed description of suggested slides) and an assignment guiding students in their learning of histology. The students used the assignments to generate laboratory reports, with five out of nine being graded. Students were recommended to hand-in the nongraded reports in order to receive formal feedback. Laboratory reports and quizzes were low stakes assessments (Gilboy et al., 2015). Grades obtained during the course length were used to assess and provide feedback on student’s strength and weakness (formative assessment and formal feedback, respectively) (Krasne et al., 2006; Pulfrey et al., 2013) and numerical values were used to determine the student’s final grade. Even though students had access to most specimens through virtual slides, some samples were provided only as glass slides with the goal of encouraging students to develop their light microscopy skills. During the laboratory sessions, students were encouraged to work in pairs or small groups, but a few elected to work independently (Braun and Kearns, 2008).
Assessments and Assignments

Assessments of three types were used: quizzes, written laboratory reports, and examinations. There were four quizzes, which together were worth 15% of the total grade; five graded written laboratory reports (and four non-graded and voluntary), which together were worth 15% of the total grade; three examinations (two preliminary and one final examination), which together represented the remaining 70% of the final grade. Grades are not curved. The low-risk written assignments and quizzes were designed to engage students with the subject matter and to prepare them for the examinations. The majority of the written assignments required the student to use glass slides to be fully answered. The impact of the use of the CRS during the IRS on learning outcome was restricted to questions derived from the final examination.

RESULTS

Classroom Demographics

There were 39 students enrolled in the 2015 histology course, 19 females, and 20 males (Table 1). From these, 28 volunteered (12 males and 16 females) to answer the first paper-based survey [1] (Supporting Information) and 25 students (9 males and 16 females) answered the second paper-based survey [2] (Supporting Information). These surveys provided us with information about the students’ career goals, the usefulness of the teaching tools (e.g., VM, LM, and CRS) and if they recommended the tool (these are summarized in Fig. 1). There were always more females that answered the surveys than males, including the mini-surveys (Table 1). These students are high achievers with 72% seeking to pursue a professional medical (MD) or a veterinary degree (DVM) (mean Likert scale of 4.2 ± 1.5).

Interactive Review Sessions

The IRS preferentially exposed students to images derived from unfamiliar histological samples in order to obtain information about the students’ understanding. The goal of this approach was twofold: avoid responses based on memorization of particular aspects of the slide (e.g., histological artifacts) and help identify misconceptions on foundational concepts (e.g., differentiation between organ structure and cell morphology) (Fig. 2). In this regard, Pearson’s Learning Catalytics software was a good tool to identify topics in which students needed more clarification. Figure 2c is an

Table 1.

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IRS, interactive review session.

Figure 1.

Summary of surveys’ responses. First two bars summarize career aspirations. Following bars summarize student’s perception of interactive review sessions activity, classroom response system used, and microscopic methods. CRS, classroom response system; DVM, doctor of veterinary medicine program; IRS, interactive review sessions; LM, light microscopy; MD, doctor of medicine program, PhD, doctorate of philosophy program; VM, virtual microscopy; Error bars represent ± standard deviation. Five-point Likert scale used: 1, strongly disagree; 2, disagree; 3, neutral; 4, agree; 5, strongly agree.
example of a composite sketch type question. This question asked students to draw a line on the interface between the dermis and the epidermis. After delivering the question it was noticeable that some students had a misconception, with seven out of 22 (32%) responses being wrong. Once students saw the composite sketch of their answers, they were asked to share the reasoning for their answer with their peers. When the question was delivered again, 96% of answers
were correct. The student that still marked the wrong answer was identified (instructors have access to individual answers) and later received an email from the instructor via the software addressing the misconception. Another example of the subtlety of misconceptions that can be identified is presented in Figure 2a, a composite sketch type question. The data from students’ responses allows instructors to determine that, although students could indicate the transition point, many had trouble differentiating stomach from duodenum. Figure 2a is another example taken from the endocrine IRS.

Despite the clear benefit of the application toward identifying misconceptions and promoting formal immediate feedback, for this small cohort of students, the platform did not improve final examination scores above that of the currently employed feedback methods (Fig. 3). The averages and median scores for individual questions can be found in the Supporting Information. The Wilcoxon comparison for each pair method had P value = 0.11, thus there was not strong evidence to support difference in students’ performance when answering questions from topics derived or not derived from the IRS. The average score for questions derived from IRS topics was 7.4 ± 0.96, whereas the average from non-IRS topics was 7.6 ± 1.07. However, these are absolute values that include all students regardless of their attendance for the IRS.

Survey [1]: Microscopes

Both LM and VM, the traditional tools used for immediate formative assessment and immediate informal feedback, were familiar to this cohort of students. There was an overall positive perception for both LM (7.1 ± 1.72) and VM (9.2 ± 1.07), as determined by combined Likert scale obtained from questions pertaining to usefulness of tool and recommendation of tool (Fig. 1 and Supporting Information—Table 2 columns Q1-1, Q6-1, and Q1-2, Q6-2). When asked about benefits of using both VM and LM in open-ended questions, students’ responses reflected appreciation for both. However some students would rather have only the VM (Aperio refers to VM): “no, I liked Aperio and felt it was sufficient alone and convenient for me to study at home”.

There were 11 students (39%) that answered “yes” they benefit from having access to both methods VM and LM together and 6 (21%) answered “no” (Supporting Information—Table 2 Q2). One student reported the LM as the favorite method of learning. The following quote best represented this cohort of students: “to an extent yes [only one method is sufficient], but both are better in tandem. The virtual is convenient, but the optical is useful on developing microscopic techniques/understanding. Both correct for each ones shortcomings”.

Survey [2]: Interactive Review Session

On average students thought the review sessions were helpful (five point Likert of 4.2 ± 0.91) but software only slightly improved guiding the session towards problematic topics (five point Likert of 3.8 ± 0.99). However, there was significant correlation between student’s response when asked if “the use of an interactive software was helpful to tailor the review session to topics [they] had trouble understanding” (Fig. 1 and Supporting Information—Table 3-Q4) and if “[they] recommend having review sessions” (Fig. 1 and Supporting Information—Table 3-Q5). Even though the correlation was weak between the other questions, the average Likert score for all leaned towards 4, thus a good rating (Fig. 1 and Supporting Information—Table 3). The combined Likert score of 8.0 ± 1.77 (Supporting Information—Table 3—association of Q4 and Q5) suggests that students’ perception of the interactive review session using the Learning Catalytics platform (IRS using CRS) was over-all positive. Furthermore, students would recommend the use of interactive software during review sessions (five point Likert of 4.2 ± 0.71) (Supporting Information—Table 3- Q6). Student’s self-reported experiences show that although rated as helpful, some students felt that the review modules were not well structured: “I like how the material is presented but it’s quite time consuming. With better organization and communication, it’d be more time efficient,” or “Learning catalytics can be more useful if the questions are improved.”

The theme about the images size and quality was common throughout the activity and is evident in the surveys: “Learning catalytics is great. But I wish pictures could be bigger,” or “Bigger pictures, pictures that showed the right answer at the end CLEARLY.”

The ability to communicate with instructors using the CRS was recurrent: “I was able to provide anonymous question that whole class could benefit from;” and “they [IRS using CRS] are great to reinforce material and learn new things! I also like how you can message the instructor privately to identify material you struggle with.”

Mini-Surveys

The mini-surveys were helpful in designing and structuring the IRs. For instance the first mini-survey (Supporting Information—Table 1—mini-survey 1—Integument) clarified that waiting for 90% of the students to answer was not an ideal threshold for setting up the review’s pace. After this feedback
a time limit of 30 seconds to 1 minute was set for inputting the answers. Another request that aided delivery was to use a projector to go over the questions as suggested by other students: “[have] a set time to answer each question and then move on. If most of the class gets it wrong then explain in depth the answer but If a vast majority of the class gets it correct then move on;” or “Maybe use the projector in the lab to put the questions up…”

With regards to the second mini-survey (Supporting Information—Table 1—mini-survey 2—Oral Cavity) issues with the quality and size of images were raised. Also it was noted that the IRS material was not available to students once the section ended. “[Suggestion for the next IRS] Bigger pictures;” “Yes, it was helpful, but I did not find it afterwards to aid in my study, was it posted?”

At the third mini-survey (Supporting Information Table 1—mini-survey 3—gastrointestinal tract) students’ statements revealed familiarity with the different question types. When asked for suggestions for the next IRS students’ responses reflected the types of questions they deemed helpful: “The what is this, and what is its function—questions;” “having the images and having to sketch or circle things is very helpful!” Only four students answered the fourth mini-survey (Supporting Information Table 1—mini-survey 4—endocrine), and their response suggests that the activity was helpful: “It helps clarify what we are looking at in the slides.”

Instructor Survey

A total of four out of six TAs answered the survey. From the instructors’ survey, the theme about the image quality became evident one more time. When asked for their opinion about if the software was an effective method to deliver the IRS (Supporting Information—Table 4—question 7) three out of the four answers reflected the CRS’s limitation: “I just wish that the images could be bigger. I thought the software was great because they could draw on images and I liked the way we could see which answers were the most common. The software seemed pretty good to me.”

Observations from the Authors

During the review modules the students appeared interested and engaged. Students did not limit participation in the IRS to being physically present, and three students used cell phones to access the interface while leaving the classroom. During the later sessions students were more likely to ask questions especially by sending messages using the software rather than by voicing them. For instance, two students that never requested help during the regular laboratory activity were noticeably more active and seemed comfortable texting their questions to the instructors rather than voicing them. Therefore, the Learning Catalytics was able to engage a different cohort of students that might have otherwise been marginalized (DiLullo et al., 2011) yielding in a more inclusive classroom environment.

Although the process of creating the review modules perse required a lot of up-front work, the positive response of the students made the effort worthwhile. Besides the student’s engagement in the activity, the CRS allowed for visualization of students’ misconceptions. For instance, the example in Figure 2c allowed instructors to visualize that 32% of students believed that the layers of the epidermis had a maximum depth of a couple of cell layers. While most students were able to list the layers that formed the epidermis in a short-answer type question, seven out of 22 students failed to correctly draw a line in the interface between dermis and epidermis on an unfamiliar sample (Fig. 2c). This interactive exercise revealed that several students resorted to the color differences, instead of conceptual knowledge, to differentiate the layers in the image. The image was from thick epidermis that had a much wider layer than the histological slide suggested by the laboratory activity handout. The example in Figure 2a shows student’s ability to identify the transition point between duodenum and stomach, but not differentiate which side is the duodenum. The CRS provided the ability to identify and address subtle issues like these. It also allows instructors to provide immediate feedback to all (if a prevalent misconception is identified) or individualized (if it is an isolated case). Students can benefit from the feedback immediately or delayed by revisiting previously given modules. Therefore, the CRS is an efficient immediate formative assessment tool that can be used to provide formal immediate and delayed feedback.

Every review module provided authors with different observations. For instance, during the first review module, it was noticed that students were not expecting to actively answer questions. Even though they were informed about the need to actively participate, they seemed to be expecting a passive review in which instructors lectured about the important topics. This probably reflects previous experiences in which instructors provided a list of important concepts without the need to actively participate. However there was a shift in students’ behavior for the next modules, with the majority studying the material, and preparing for the review. The students clearly did not like to answer questions incorrectly even when their identity was not disclosed. Because 75% of students were either on the preparatory track for veterinary (pre-vet) or human (pre-med) medicine our interpretation is that there was an intrinsic desire for students to excel and demonstrate their understanding of the material. Another general observation that supported this interpretation was that when questions were easy, students stopped participating, whereas if the questions were challenging, they would engage more in the activity. Therefore current observations might not represent how students would react in a less competitive environment.

DISCUSSION

Classroom Response Systems in the Laboratory Setting

Student’s response to survey [2] suggests that this cohort of students value the IRS, independent of the use of a CRS, but would recommend implementing it if available. To be better suited for a laboratory setting, the CRS would need to be coupled with a microscopy method. Whereas the VM facilitates group learning (Harris et al., 2001; Braun and Kearns, 2008; Husmann et al., 2009), the LM is still the most used method outside of the classroom. For instance clinical and academic settings still require the use of the traditional microscope to expedite sample analysis or diagnosis of diseases, such as the evaluation of fine-needle aspirates and skin surface cytology (Pratt, 2009). It was unexpected to find that only 42% of the responders envision using the LM throughout their professional career (Supporting Information—Table
Q2-1) since 72% seek a medical (MD) or a veterinary degree (DVM). Although a CRS does not replace the VM or the LM as teaching tool it can be used to motivate and engage students on learning activities.

A major limitation of the CRS was image size and quality. Morphology-based biomedical courses rely on student's interpretation of images. In the same way recognition and perception of visual stimuli shifts between individuals (Partos et al., 2016), students' perceptions of histological images are variable and unpredictable (Fig. 4) (Fouché, 2015). It is important for teachers to anticipate topics in which students will have difficulties and possible misinterpretations, in order to remove such obstacles as quickly and efficiently as possible.

A teaching tool that allows the incorporation of an interactive live digital imaging technology would be better suited for a laboratory setting (Higazi, 2011). The results from survey [2] illustrate the importance of image size and quality in morphology-based biomedical courses. Hopefully, this result will encourage instructors and software developers to invest in integrating interactive teaching software to microscopy, in order to devise better technology-supported formative assessment tools.

**Classroom Response Systems to Identify Misconception**

As exemplified in Figure 2 the CRS has greatly aided in the identification of subtle misconceptions. The software allows multiple types of questions (Lukoff, 2013; Schell et al., 2013; Mullet et al., 2014) (Figs. 2 and 4) and instructors were able to monitor responses in real-time. As soon as misconceptions were identified instructors were able to immediately guide students to correct the problem in class discussion.

Although the CRS can be used to identify students’ misconceptions as they occur (e.g., “on-the-go”), there are limitations for instructors to use this technology in a laboratory setting. For instance, the inability to integrate VM with the teaching software limits possible interactions to planned discussion, since the activity has to be prepared in advance to use images. Morphology-based biomedical courses often rely on high-resolution images and benefits from students’ interaction with virtual slides. Therefore, being unable to integrate VM with the CRS is a limiting factor, especially impairing the creation of questions in real-time (Antoniou and James, 2014).

**Formal Immediate Feedback**

The BioAP4130/BioMS4130 laboratory setting relies on informal immediate feedback, where students have to interact with professors and TAs to clarify doubts that they may have from observing a histological sample (Bloodgood, 2012; Collier et al., 2012). Besides student’s personality (Sinclair and Cleland, 2007; Khalil et al., 2013), other factors that interfere with students seeking feedback and student satisfaction with feedback are inconsistencies among instructors (Warman et al., 2016) (Supporting Information—Tables 2 and 3). Furthermore, instructors have to adapt to the students’ diverse learning styles and interpretations in order to provide effective feedback during every activity (Twenge, 2009; DiLullo et al., 2011). In this regard, the CRS not only provided a platform for formal immediate feedback, but also allowed for a consistent yet individualized feedback. The latter can be done using the software’s ability to provide written feedback that stays associated to that particular student’s account (Baleni, 2015).

**Inclusive Environment**

The result that the CRS provided a new venue of communication with the instructors was an unpredicted positive outcome of using the CRS. Students who are shy or uncomfortable asking questions are often marginalized and may fail to achieve their full potential (Sinclair and Cleland, 2007; Khalil et al., 2013). In this regard the CRS allowed for a more inclusive environment where shy students obtained immediate feedback without the need to vocalize their questions (Chen, 2015). Both students and instructors appreciated this aspect of the CRS. The tool also minimizes erroneous interpretation due to contradictory or confusing informal feedback (Warman et al., 2016), since the immediate feedback can be formal and homogeneous (minimizing differences in instructors’ ability to guide students through the material, diversity in visual perception. Students’ diverse interpretation of how a melanocyte looks like. Students were asked to draw a melanocyte.
background knowledge and teaching experience) (Stoltzfus, 2014). Furthermore, the fact that 39% of students’ report they benefit from having access to both VM and LM, one student prefers the LM (Supporting Information—Table 2), and 37% strongly recommend the use of the CRS, supports that having a variety of stimuli helps provide a more inclusive environment. Therefore, in training students for their professional careers, the use of different teaching tools, both old and new, results in better learning experiences.

Limitations of This Study

The findings detailed in this manuscript are dependent on self-reported experiences and student scores obtained from a small number of questions that were drawn from the course’s final examination. Beyond the intrinsic difficulties in comparing student performances, the quantitative analysis included all students, regardless of their presence in the IRS, and was limited to questions from one single examination. The questions present at the final examination had different degrees of complexity that confound the analysis between IRS and non-IRS topics. Therefore, the quantitative analysis (Fig. 3) is limited, and cannot be taken as predictive of the impact on learning outcome when CRS-mediated feedback is compared to traditional delayed feedback. Furthermore, multiple other studies report that CRS not only engages students, but also improves learning outcomes (Alexander et al., 2009; Briggs and Keyek-Franssen, 2010; Mostyn et al., 2012; Talbert 2013).

Responses for the survey [2] had weak correlation, which may indicate variability in students’ interpretation of the questions or willingness to provide feedback. There were also unexpected technical difficulties reported by students during the surveys. The most common complaints were: trouble with visualization eSlide Manager platform (Leica Biosystems, Buffalo Grove, IL) from students using Macintosh Computers (Apple Corp, Cupertino CA); that instructors were inexperienced using the CRS software; and that there were significant time constraints of the IRSs activity. Although there was interaction between the participants, it relied on a planned activity. An exclusive interactive experience, without previous planning and where the teacher is responsive to events as they arise (Antoniou and James, 2014), would require a CRS capable of incorporating the virtual microscopy.

In this study, the Learning Catalytics™ software did not improve learning outcome as measured through question scores, but helped instructors gain insight about students’ interpretation of fundamental concepts.

CONCLUSIONS

The use of the CRS facilitates prompt identification of misconceptions and allow for a more inclusive classroom environment. However, the fact that the questions have to be planned in advance limits its abilities as an interactive teaching tool (Antoniou and James, 2014; Warman et al., 2016). Nevertheless, both students and instructors agreed that the use of the interactive software was beneficial. Overall the CRS improved the instructors’ ability to (1) engage students in learning activities, (2) identify misconceptions that would otherwise be unnoticed, (3) provide formal immediate feedback (4) exchange information by opening a new venue of communication between students and teachers. Furthermore, this cohort of students value the availability of multiple teaching tools instead of replacement of older ones, especially when such a tool is still prevalent in the work environment. Therefore, although the CRS is not essential it is an effective teaching tool to identify misconceptions and provide feedback.

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