Web-based Interactive Video Vignettes Create a Personalized Active Learning Classroom for Introducing Big Ideas in Introductory Biology

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Abstract: The typical "flipped classroom" delivers lecture material in video format to students outside of class in order to make space for active learning in class. But why give students passive material at all? We are developing a set of high-quality online educational materials that promote active, hands-on science learning to aid in teaching of core concepts for introductory biology at the college level. Interactive video vignettes (IVVs) incorporate evidence-based teaching strategies to address known areas of confusion for entering students. Each IVV includes a live-action scenario with undergraduates investigating a biological problem with a realistic experiment that users participate in. Through the course of each 10-20 minute video, users are required to make predictions, answer questions, collect data and draw conclusions. Branching and reflection of previous answers allows each user to have a personalized experience. Research into how students learn with these tools is being used to develop entire modules that will incorporate the IVV as a priming activity to be done as homework, along with suggested activities to be done in class that take the introduced concepts deeper and/or broader.

Keywords: Online learning, flipped classroom, student engagement, prediction

INTRODUCTION

Most members of the post-secondary biology education community are aware of the national calls for college biology education reform (Alberts, 2008; Woodin et al., 2010; Singer et al., 2012). Undergraduates need to understand the "process of science, the interdisciplinary nature of the new biology, and how science is closely integrated within society. Students also should be competent in communication and collaboration, as well as have a certain level of quantitative competency, and a basic ability to understand and interpret data." (AAAS, 2011). Educators should encourage critical thinking, focus on unifying concepts, de-emphasize rote memorization, and allow students to practice experimental design and analysis of data and scientific models (DiCarlo, 2006). This shift in emphasis necessitates the use of student-centered, interactive instructive "active-engagement" practices, which have been shown to be directly related to increased student learning gains (Knight & Wood, 2005; Armbruster et al., 2009; Smith et al., 2009; Freeman et al., 2014). Some instructors may choose to convert their whole course into a "flipped classroom" or may choose a combination of different student-centered activities.

Unfortunately, despite best intentions, it is often difficult for an instructor to redesign an entire course to incorporate evidence-based pedagogies centered on student-centered activities. Plus, in an effort to increase depth of coverage, instructors may struggle to decide which of the plethora of topics and concepts to focus on, particularly in broad, foundational courses such as Introductory Biology. Without easy-to-incorporate research-based pedagogical tools, many instructors may abandon the idea of trying to create a more student-centered, active engagement classroom. In order to help instructors, we are developing a set of high-quality educational materials that promote active, hands-on science learning to aid in teaching of core concepts for introductory college-level biology. The materials will be packaged as Modules for Interactive Teaching or MINTs. Each

MINT will be grounded in an Interactive Video Vignette (IVV) that is completed online by students prior to class. Each vignette combines narration, dialogue, real world video segments, question-based branching and video analysis tools to enable students to master concepts or participate in data collection and/or analysis techniques in a hands-on manner. The video analysis methods can range from measuring positions or dimensions by clicking on a video frame, to data collection and analysis. Question-based branching enables a vignette to address a user's specific needs by sending the user to different pages based on the user's answer. The high quality nature of the IVV and the attention to dialogue and scenarios make the IVVs engaging and enjoyable for the typical undergraduate student.

While IVVs as learning tools for physics students have been described (Laws et al., 2015) , there are no IVV or IVV-like resources for post-secondary biology education. The purpose of this manuscript is to describe the development of ten biology IVVs that are centered on the core concepts of *Evolution, Information Flow, Energy Transformation, Structure/Function relationships* and *Systems* as well as the process of science and interdisciplinary nature of biology as outlined in the AAAS/NSF Vision and Change Report (Woodin et al., 2010; AAAS, 2011). In order to create high quality IVVs a multidisciplinary group of individuals was recruited, with expertise in Biology Education Research (BER), curriculum/instructional design, IVV-based teaching tools, video production, software development, and assessment.

METHODS

Our IVVs are designed for first and second year college biology majors, but most are appropriate for non-majors biology courses and Advanced Placement high school classes. Each scenario incorporates undergraduate science students involved in projects that are realistic and feasible for undergraduates. Each IVV is also aligned with one or two major biology concepts (AAAS, 2011) and centers around a "Big Idea" — an important biological principle that many undergraduate students struggle with. Table 1 provides a synopsis of each of the ten IVVs that have been produced thus far.

IVVs: Grounded in Education Research

IVVs incorporate lessons learned from education and cognitive research on how people learn. High quality IVVs are designed to promote "learning while doing," engaging learners with real-world problems, providing "scaffolding" support, reflection on their own learning processes, and feedback and guidance as learners progress (Bransford, et al., 1999). IVVs use principles of cognitive learning theories such as elicit-confront-resolve and constructivism to support deep learning of core concepts in biology. Unlike many videos made for teaching biology, IVVs are live action, require active participation of users, and depict a real-life scenario that requires solving a biological problem. An important and unique feature of our vignettes is that they require students to make predictions and then compare their predictions to experimental results. This strategy may help create cognitive dissonance required to overcome incorrect knowledge, especially if experimental results disagree with the original prediction. Education research has shown that allowing students to predict results, invent models, or construct a formula before being given the "correct answer" is a powerful way to improve student learning. For example, students who created graphs to describe data sets from psychology experiments had increased learning when compared to peers who summarized a chapter on the same experiments (Schwartz & Bransford, 1998). Allowing students to invent a mathematical formula before instruction also resulted in learning gains compared with students who were simply told the formula beforehand

Table 1. A description of each IVV aligned with core biology concepts and big ideas. Full IVV synopses may be found at http://ivv.rit.edu/bio.

IVV Title	Vision and Change Core Concepts	Big idea
How do you find a needle in a haystack?	Evolution Information flow	Mutations exist prior to selection
Why is my Phenol Red Yellow?	Structure/Function Systems	Buffers regulate pH by absorbing and releasing protons
Why didn't you write that down?	Structure/Function	Osmosis is a specialized diffusion resulting from the presence of a semi-permeable membrane
Marfamily	Information Flow	Mechanism of genetic inheritance
To Ferment or Not to Ferment: That is the Question	Energy Transformation	Environmental conditions (O_2) influence metabolic pathways
Extra Credit Project	Energy Transformation	Biosynthesis and cell growth are dependent on photosynthesis
Whose graph is better?	Systems	Populations exhibit variability due to abiotic influences
Dead thing by a tree	Systems Energy Transformation	The carbon link between decomposition and plants happens via gaseous carbon dioxide.
*Do you want salt with your eggs?**	Systems	Populations exhibit variability due to genetic influences.
*Going green**	Information Flow	Nonsense mutations affect protein expression but not transcription or replication.

* In production, available Spring 2017.

(Schwartz & Martin, 2004). Our own work demonstrated that having students participate in a constructivist model-building activity primed them for future learning of biology concepts related to information flow (Wright & Newman, 2011).

IVVs are designed for web delivery as out-of-class priming activities to prepare students for in-class discussion and problem solving. IVVs leverage practices that have been shown to be effective for online learning tools. For example, research comparing the utility of online learning pedagogies to traditional instruction found online tools that let users control their interactions, encourage reflection and increase interactivity enhance the online learning experience (Zhang et al., 2006; Means et al., 2010).

IVVs: User interactivity is a key component

Despite being high quality, the vast majority of online educational material is passive videos (e.g. blood cells moving through vasculature), animations of cellular processes (e.g. DNA replication), structural animations (e.g. structure of a glucose molecule), or narrated tutorials (e.g. how X-ray crystallography works). These tools are helpful for demonstrating processes and reviewing essential concepts, but they typically do not involve the user in the process of science or resolving cognitive dissonance when confronted with actual data. While existing online tools have the potential to enhance learning, they are not interactive and none of them contain the combination of real-world problems, scaffolding, reflection, and feedback that IVVs do. For example, in *Whose Graph is Better*, the actor directly asks the user for feedback on a graph created from data collected during the IVV scenario (see Fig. 1). As in all IVVs, the page will not advance until the user has answered the posed question. Feedback from the user is requested numerous times during this IVV, and as the user progresses through the IVV the characters also progress in their understanding of how to construct valid representations of their data.

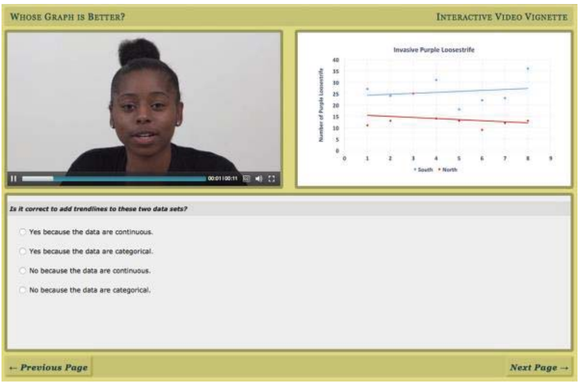

Fig. 1. A page from *Whose Graph is Better?* Here, the user is asked for feedback on a graph that was constructed by a character in the scenario.

Another feature of our IVVs is that all questions posed to the user are answered during the IVV. We did not want users puzzling about an answer choice or frustrated because a reasonable answer choice (in the eyes of a novice student) is marked as "incorrect". In some cases the question posed to the user is answered on the very next page of the IVV. Prediction questions, however, are purposely not answered on the following page because the prediction question often anchors the upcoming experiment in the IVV. In the IVV *Extra Credit Project,* the user is asked to predict the shape of the growth curve if an algal culture is placed in a vessel containing only water and trace elements while being exposed to air and light. After the user has observed the experiment and analyzed the data in the IVV, the original prediction is brought back and the user is asked if his/her original prediction is supported by the data (see Fig. 2). This strategy gives rise to cognitive dissonance, as the user must reconcile their original conception with actual data. The user is also supported in their new realization through the dialogue and wrap-up scenes that conclude each IVV.

At the end of each IVV, the user is asked to reflect on what they learned and questions they have about the topic. Reflection is an essential criterion of constructivist teaching, believed to support learning by reinforcing or transforming conceptual links in the student's mind (Baviskar et al., 2009; Harvey et al., 2016). The reflection may also be formative feedback for the instructor allowing the instructor to determine which concepts were mastered and which require further instruction with their class.

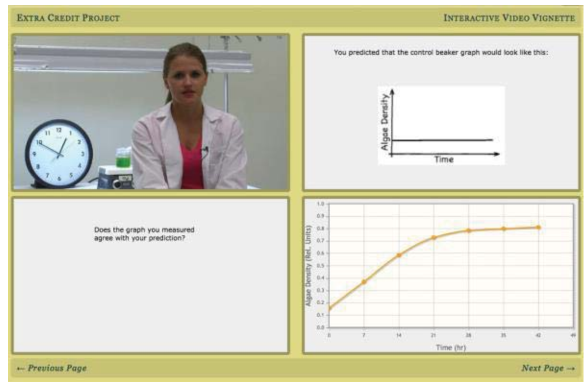

Fig. 2. A page from *Extra Credit Project*. Here, the user's original prediction is brought back to them in juxtaposition with the actual experimental data.

IVVs use principles of Universal Instructional Design

In order to accommodate a wide range of undergraduate students, IVVs are constructed with the principle of Universal Instructional Design in mind. This principle suggests that any strategy that helps one population of students is likely to positively impact the whole class (Pliner & Johnson, 2004). We argue that Interactive Video Vignettes may be an important tool to reach many groups of biology learners. For example, the IVV scenarios and dialogue are meant to be accessible to students with little biology background. While the team did focus on challenging biology concepts, we purposely did not incorporate unnecessary technical and/or overly complicated language. Each IVV is close-captioned so that students who are Deaf or Hard-of-Hearing or English Language Learners can fully participate in the IVV experience. Each page of an IVV also gives the user the option to go back so students may review or re-watch pages as many times as they need to feel comfortable with the material.

Students, if they choose, may redo the entire IVV; there is no limit on the number of times an individual user can participate in an IVV.

Another consideration is the growing number of college students with learning disabilities, Autism Spectrum Disorder (ASD), Social Anxiety disorders or other diagnoses that may impact success in the college classroom. A recent report from the US Department of Education looking at enrollment at 2 and 4 year colleges found that 73% of all post-secondary institutions enroll students with hearing difficulties, 86% enroll students with specific learning disabilities, and 35% enroll students with speaking and/or language impairments (Raue & Lewis, 2011). Taking into account the increase in the past decade of persons diagnosed with ASD (Baio, 2014), colleges will most likely experience, if not already experiencing, an increase in the number of undergraduates with ASD. Students with ASD in post-secondary settings face a host of challenges, such as the struggle of how to be engaged and interact with others in the classroom. IVVs as learning tools allow users to privately experience interactivity and "active engagement" in the comfort of personal space, which may be beneficial for students with ASD, social anxiety, or extreme shyness. In addition to creating IVVs that are accessible to users of varying backgrounds, the team has made an effort to incorporate visually diverse actors to try and overcome issues related to exclusiveness and bias that are part of our current science culture (Xu, 2008; Strayhorn, 2010; Reyes, 2011).

Creation of the IVVs

Each IVV is more than just a story about biology. Because our IVVs incorporate prediction questions, experiments, data analyses activities, and real-world scenario/dialogue, we relied on a number of resources to inform construction of each IVV. We began with the five core Vision and Change concepts for undergraduate biology education (AAAS, 2011). We reviewed the literature on the construction of biology concept inventories and reviewed the items in tools such as the Osmosis and Diffusion Conceptual Assessment (Fisher et al., 2011), the Introductory Molecular and Cell Biology Assessment (Shi et al., 2010), the Photosynthesis and Respiration Concept Assessment (Haslam & Treagust, 1987), the Genetics Concept Assessment (Smith et al., 2008), the Dominance Concept Inventory (Abraham et al., 2014), and the Conceptual Inventory of Natural Selection (Anderson et al., 2002). Many of these publications about biology concept inventory tools also illustrate common misconceptions or alternative conceptions held by biology students, which was useful during our process. Finally, three project leaders have extensive experience teaching a variety of college biology courses and laboratories (Introduction to Biology, Cell Biology, Molecular Biology, Microbiology, and Genetics), and were able to use these classroom experiences to help focus the IVVs on problematic concepts and incorrect ideas commonly held by students.

Once a central scenario is agreed upon, the IVV team designs, tests, and revises the central experiment that is featured in the IVV. The central scenario must be applicable to the "real world", align with one of the Vision and Change core concepts, make sense with the central experiment in the IVV, and be accessible to potential student users from a variety of backgrounds. Because IVVs use live action, the team does not depend on computer animations or simulations for the central experiment. The experiment must be justified by the scenario and feasible for undergraduates to accomplish. For example, the scenario in the IVV *Why didn't you write that down?* begins when undergraduate lab partners realized no one in their group wrote down the glucose concentrations on their two bottles of growth media. Unable to make more, the students figure out a way to test the media using common laboratory equipment and determine which bottle

Fig. 3. Selected pages from *How Do You Find a Needle in a Haystack?* A) An undergraduate student, working on a research project, is excited to see that her bacterial transformation finally resulted in growth of a few clones on an antibiotic selection plate. Unfortunately her clones do not contain any plasmid DNA nor the gene of interest (they were just false positives, although she does not realize it yet). B) During a lab meeting the student explains her results and frustrations to her lab group. The post-doctoral fellow asks her about negative controls and the undergraduate student becomes confused. Here, the user is asked which negative control should have been used in the cloning and transformation experiment. C) The student does some research and learns about endogenous antibiotic resistance genes and mutations. During another lab meeting the two undergraduate students come to the incorrect conclusion, shared by many novice biology students, that the antibiotic in the media caused mutations in the bacterial DNA. Here, the user is asked whether they agree. D) The students set up a new experiment using replica plating and DNA sequencing of bacterial clones that have or have not been exposed to the antibiotic. The user is asked to analyze DNA sequence data and then is asked if the data supports or refutes the statement that antibiotic causes mutations. After further discussion with the lab group, the students come to the correct conclusions about random mutations that exist in a population and how antibiotic resistant populations become problematic due to overuse of antibiotics.

contained 5% vs 20% glucose. In another IVV, *Why is my Phenol Red Yellow?*, the student actors puzzle over the visible red-to-yellow color change that tissue culture media turns as mammalian tissue culture cells grow and age, which provides a logical transition for a discussion about pH indicators and chemical buffers**.** Later in the IVV the students design an experiment to test buffering capacities of each ingredient found in the growth media.

Once the team is satisfied with the scenario, the experiment, and the experimental results, the team creates the prediction questions and determines how the future user will be involved in the IVV. For example, in *How do you find a Needle in a Haystack?* the user must use the genetic code to determine outcomes of various mutations documented by DNA sequencing. In *Whose Graph is Better?* the user helps the IVV actors go through a series of steps to figure out the best way to display analyzed data. At this point, the remainder of the dialogue is written and revised as necessary. Finally, the team creates a storyboard, recruits actors, and works with a motion picture science team to determine a location and schedule for the video shoot. Video shoots for all scenes for a single IVV takes an average of 2 working days.

Figures 3 and 4 illustrate selected pages and descriptions of two of the IVVs we have produced. Each IVV, on average, takes 10-20 minutes for the user to complete. Each IVV incorporates prediction questions that

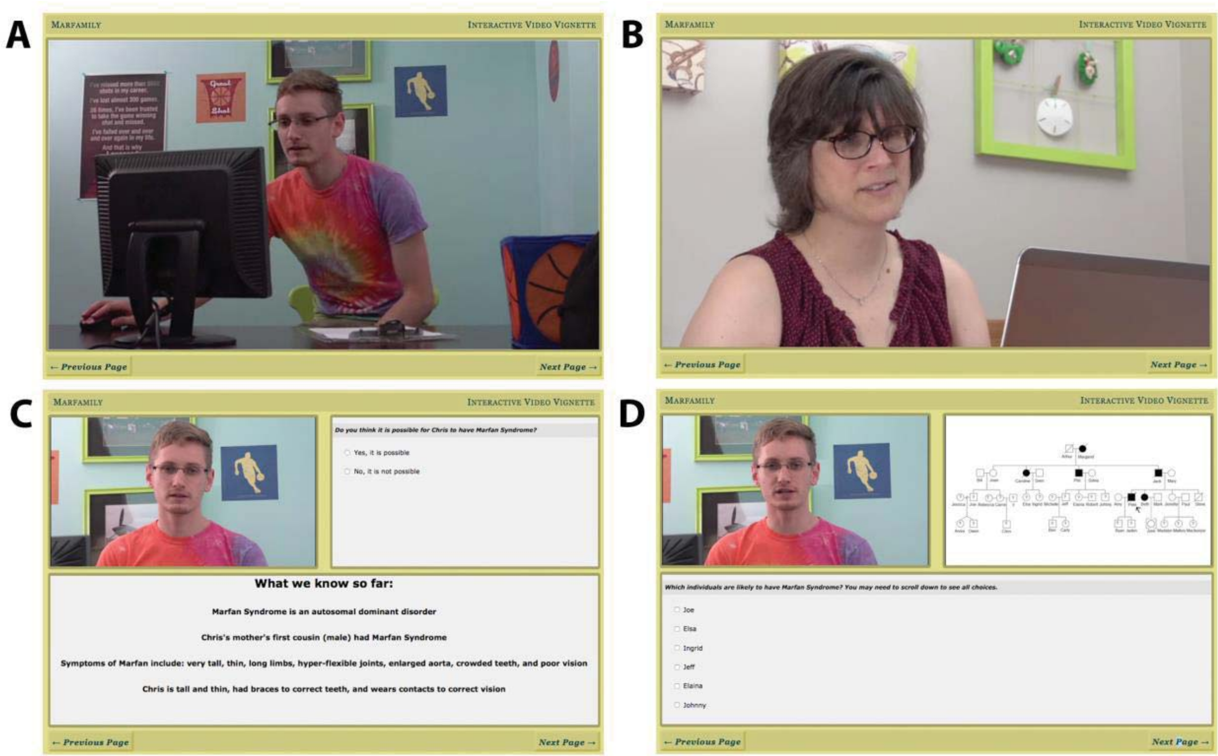

Fig. 4. Selected pages from *Marfamily*. A) While video-chatting with his Mother, a college student (Chris) learns that his Mom's cousin has died, very unexpectedly. Tests revealed the cousin had Marfan Syndrome, which was surprising news to the family. B) During the video call, Chris and his mother learn about the basic genetics and clinical symptoms of Marfan Syndrome. The Mother has many questions such as "What is a gene?" and "What does dominance mean?" The user is invited to answer the questions to help learn about important genetics concepts. A branching feature is part of this IVV. The next page of the IVV is dependent on how the user answers the questions. C) The user learns that Marfan Syndrome is an autosomal dominant disorder and that individuals with Marfan syndrome are generally very tall with long flexible limbs, poor eyesight and crowded teeth. Unfortunately these symptoms describe many people in the family! Based on the available data, the user is asked to predict whether Chris (who is a tall basketball player) could have Marfan Syndrome. D) Through back and forth dialogue Chris and his Mom build a family tree and the user learns about proper pedigree construction. Physical and health characteristics are provided for each individual of the family, and the user is asked to determine which members of the family most likely have Marfan Syndrome. In the end, Chris, his Mom, and the user are relieved to learn that Chris could not have inherited Marfan Syndrome after all.

are often rooted in areas of documented confusion for biology students. For example, the IVV *How do you find a Needle in a Haystack?* is based on the prevalent misconception that organisms mutate/change/evolve in response to an environmental condition (Andrews et al., 2012). Students often do not realize or cannot articulate that random mutations are already present in a population. In *Marfamily* the user is asked to answer genetics questions that are known to be problematic for biology students such as, "What is meant by dominance?" The incorrect "distractor" choices are based on student misunderstandings that have been documented in the literature and/or observed in actual college classrooms. For example, many students incorrectly think that "dominant" means "stronger" or "more common." Knowledge of common misunderstandings or misconceptions allows the research team to incorporate believable distractors into each item (Towns, 2014). Prior to the development of the IVV *Whose Graph is Better?,* several college-level biology instructors were questioned about the types of mistakes that novice students often make when constructing graphical representations of data. The common mistakes were then incorporated into the IVV as a way to let the user think about and receive feedback on how to display quantitative data.

Table 2. Alignment of learning goals with novice ideas and IVV embedded-ideas from the IVV *Why is my Phenol Red Yellow?*

Novice Ideas	Ideas addressed in the IVV	Learning Goals of IVV: By the end of the IVV users should be able to…
Acids are defined by a pH < 7 Acids are compounds that "burn through" metal or other things	An acid is a proton (H+) donor	Identify the correct definition of an acid
Water and carbon dioxide do not react Water and carbon dioxide react to make glucose	When carbon dioxide (CO2) reacts with water (H2O), carbonic acid (H2CO3) is produced. The production of carbonic acid can lower the pH of a solution	Describe why release of carbon dioxide in an aqueous solution lowers the pH of that solution
Buffers are "magic boxes" that interact with acids and bases	Buffers protect against a decrease in pH of a solution by binding to free protons (H+) in the solution	Analyze experimental data to determine which chemical compound has buffering capabilities
Buffers exist to maintain homeostasis	Molecules such as amino acids have chemical structures that allow them to act as buffers	Correlate amino acid structure to function of buffer
Buffers "balance" pH	There is a limit to the quantity of protons that a buffer can bind to	Define how buffers act to regulate pH change

An important part of the IVV construction process was articulating the learning gains that are the desired outcome of each IVV. Along with learning gains, the IVV research team used the literature and classroom experience to identify novice ideas that students often hold about the subject. Table 2 illustrates the alignment of novice ideas and learning goals in the IVV entitled *Why is My Phenol Red Yellow?* In this case, the novice ideas are incorrect or incomplete ideas that beginning biology students often hold about acids, bases, chemical buffers, and interactions between carbon dioxide and water. Novice ideas were taken from the literature (Ross & Munby, 1991; Orgill & Sutherland, 2008) as well as our own experience working with undergraduate students. More advanced ideas discussed in the IVV and intended learning goals are also included in the table.

IVV Software and Video Production

Interactive Video Vignettes are web applications that are written in HTML5 and JavaScript. These technologies are compatible with a variety of devices such as laptops, desktops, and tablets. While the IVVs will play on smart phones, we do not recommend using them due to limited screen size. The software team is currently developing a Java application called Vignette Studio so that, in the future, other instructors or developers may create their own IVVs (Laws et al., 2015). The application package will incorporate a drop-and-drag interface for users to easily add images, videos, and multiple-choice questions to particular pages of the vignette. The software will also allow developers to add branching multiple choice questions so that a user experiences a different page depending on which of the multiple-choice options are chosen.

After the videos for an IVV are shot, they go through several weeks of post-production. This includes video editing and creating the final web application. As described earlier, all IVVs are close-captioned so they are accessible and usable for hearing impaired users. Each IVV starts with an instruction page that includes a space for users to enter their name, and ends with a summary page that displays the user's name, date, amount of time taken to complete the IVV, and their final reflection answers. The final page can be printed or captured as a screenshot as proof to instructors that their students completed the assignment. During the research phase of the project, IVVs are being hosted on an internal server at RIT for student use. A public website (http://ivv.rit.edu/bio) containing full MINTs (links to IVVs and activities, full descriptions of the IVVs, learning goals, assessment resources, advice for instructors, etc.) is under development. A preliminary version of Vignette Studio software is available for download on Compadre (http://www.compadre.org/IVV/studio.cfm). The Compadre website has more details about the creation and use of IVVs.

FUTURE WORK

In order to determine IVV effectiveness, the team has created multiple-select assessment questions to address the intended learning objectives for each IVV. The multiple-select format assessment has the potential to more accurately characterize student mental models than forced choice or short answer questions (Couch et al., 2015; Newman et al., 2016). Deep analysis of the choices students make will help the team understand which parts of the IVVs are most effective and where incorrect student ideas still persist. Detailed analyses of these results allows us to refine the materials, to create appropriate assessments of learning, and to inform instructors of common areas of confusion that can be followed up through additional activities and discussions. These will be disseminated as MINTs: modules that not only include IVVs but also contain activities and ideas for instructors on how to implement the IVVs as integrated lessons from pre-homework through assessment. Our eventual goal is to have a set of materials that could be used to teach an entire introductory biology course, but which is also customizable for each instructor to pick and choose topics and materials.

The materials developed in this project will impact biology students across the country, both directly (by providing them with tools to promote deep learning) and indirectly (by providing biology education researchers with new sources of data that will be used to improve education). Using research-based methods of development ensures the quality of the materials and maximizes their effectiveness. The investigation into student thinking is opening new avenues of research for future work, such as how students think about the relationship between genes and traits, or how students think about systems.

CONCLUSION

IVVs are a fun and informative way to introduce students to important biology concepts. To date we have piloted the use of the completed IVVs in several first-year biology courses at two institutions. Anywhere from one to seven IVVs have been assigned in one-semester courses, and students had positive reactions to them. We aim to have production of remaining IVVs complete in spring 2017, followed by publication of entire learning modules (MINTs). The MINTs will include not just IVVs but complete lesson plans for major concepts covered in an introductory biology course. MINTs will provide instructor-focused notes, best practices for incorporation of the IVV with in-class materials, and evidence for their effectiveness. The combination of IVVs and MINTs will provide introductory biology instructors high quality, ready to use, student-centered learning tools to aid in teaching of core biological concepts.

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